APPENDIX N: AQUATIC RESOURCES INCLUDING ESSENTIAL FISH HABITAT

N1: Supporting Aquatic Resources Information for EIS

N2: Essential Fish Habitat Assessment

N3: Essential Fish Habitat Correspondence

(to be provided in the FEIS)

N1: Supporting Aquatic Resources Information for EIS

Habitat Suitability Index Models for Determining Impacts of the Mid-Barataria Sediment Diversion Project

FINAL

APPENDIX N1 – AQUATIC RESOURCES

HABITAT SUITABILITY INDEX MODELS FOR DETERMINING IMPACTS OF THE MID-BARATARIA SEDIMENT DIVERSION PROJECT

INTRODUCTION

Habitat Suitability Indices (HSI) are widely used for evaluating impacts of climate change, water resource projects, and restoration projects on fish and wildlife species habitat suitability (for example, USFWS 1980, CPRA 2017). The overall HSI for a species can be based on multiple interacting environmental or physical habitat conditions. The suitability score is standardized between 0 and 1 for each habitat or environmental variable and is usually based on species life history information and observed habitat preferences, or else fitted to presence-absence or relative abundance data from field studies. A habitat suitability of 0.0 means the habitat is unsuitable. A habitat suitability score of 1.0 means the habitat is optimal or most suitable for supporting the species.

Coastal restoration and water resource projects in Louisiana have used versions of HSIs for key species (Foret et al. 2003, Nyman et al. 2013). The 2017 Louisiana Coastal Master Plan (LACMP) invested in HSI model improvement that incorporated updated species information and a statistical-based analysis to fit environmental variables to available fisheries-independent monitoring data collected coast-wide by the Louisiana Department of Wildlife and Fisheries (LDWF; Hijuelos et al. 2016a).

Ten species and life-stage specific HSI models were selected for use in evaluation of the Mid-Barataria Sediment Diversion (MBSD) Project alternatives, and for communicating potential impacts on species habitat suitability over time and space based on MBSD operational scenarios over the 50-year analysis period (see Table N1-1). All but two of the ten HSIs are versions of the 2017 LACMP HSIs (LACMP 2017, Appendix C). The Louisiana Trustee Implementation Group (LA TIG) additionally requested to include HSIs for southern flounder, Atlantic croaker, and red drum because of their economic and ecological importance; the red drum HSI was later dropped from the analysis. The southern flounder and Atlantic croaker HSIs used parts of the original HSIs developed for the estuarine-dependent life stages (see Carruthers et al. 2019 and references therein) where generated Delft3D outputs were available to drive the species' models (see Table N1-1).

Table N1-1
Ten species HSI equations, the mean environmental drivers over the indicated time period with the annual percent marsh estimated annually per cell, and source for the HSI equation. All environmental drivers are mean monthly values unless otherwise noted.

Key Species Life Stage	HSI Equation	Environmental Drivers	Source
Blue crab early juvenile	$HSI = (SI_1 * SI_2)^{0.5}$	SI_1 - January to March, August to December salinity and temperature SI_2 – Percent of cell that is marsh vegetation	O'Connell et al. 2016a
Brown shrimp early juvenile	$HSI = (SI_1 * SI_2)^{0.5}$	SI_1 – April to June salinity and temperature SI_2 – Percent of cell that is marsh vegetation	O'Connell et al. 2016b
White shrimp early juvenile	$HSI = (SI_1 * SI_2)^{0.5}$	SI_1 – June to November salinity and temperature SI_2 – Percent of cell that is marsh vegetation	O'Connell et al. 2016c
Bay anchovy juvenile	$HSI = (SI_1 * SI_2 * SI_3)^{0.33}$	SI_1 – Annual salinity and temperature SI_2 – Percent of cell that is marsh vegetation SI_3 – Annual chlorophyll A concentration	Sable et al. 2016a
Gulf menhaden early juvenile	$HSI = (SI_1 * SI_2 * SI_3)^{0.33}$	SI_1 – January to July salinity and temperature SI_2 – Percent of cell that is marsh vegetation SI_3 – January to July chlorophyll A concentration	Sable et al. 2017
Spotted seatrout early juvenile	$HSI = (SI_1 * SI_2)^{0.5}$	SI_1 – September to November salinity and temperature SI_2 – Percent of cell that is marsh vegetation	Sable et al. 2016b
Largemouth bass juvenile and adult	$HSI = (SI_1 * SI_2 * SI_3)^{0.33}$	SI_1 – March to November salinity and temperature SI_2 – Percent of cell that is marsh vegetation SI_3 – March to November chlorophyll A concentration	Hijuelos et al. 2016b
Atlantic croaker juvenile	HSI = minimum of SI_1 or SI_2	SI_1 – March to May salinity SI_2 – March to May water depth	Carruthers et al. 2019
Southern flounder juvenile	$HSI = (SI_1^2 * SI_2)^{0.33}$	SI_1 - Annual salinity SI_2 – May to August temperature	Carruthers et al. 2019

Table N1-1 **Ten species HSI equations, the mean environmental drivers over the indicated time period with the annual percent marsh estimated annually per cell, and source for the HSI equation.** All environmental drivers are mean monthly values unless otherwise noted.			
Key Species Life Stage	**HSI Equation**	**Environmental Drivers**	**Source**
Eastern oyster	HSI = $(SI_1 * SI_2 * SI_3 * SI_4 * SI_5)^{0.20}$	SI_1 – Percent of cell that is cultch set to 1.0 SI_2 – May to September salinity for spawning SI_3 – Minimum monthly salinity SI_4 – Annual salinity SI_5 – Percent of the cell that is land	Hijuelos et al. 2016c

The ten HSIs differentially used monthly and spatially-averaged salinity, temperature, water depth, and chlorophyll A concentration, as well as the estimated annual areal proportion (or percent) of marsh to open water habitat, and water depth (see Table N1-1). The HSI inputs were generated by the Delft3D hydrodynamic and water quality (DWAQ) model, and averaged by month (minimum, maximum values also were estimated) for the 20 spatial polygons (see EIS Figure 4.10-10). The monthly averaged environmental inputs from Delft3D were provided for years 2020, 2030, 2040, 2050, 2060, and 2070. The Eastern oyster HSI results by the Comprehensive Aquatic Systems Model (CASM) polygons were too coarse, and missed finer-scale delineations of suitable oyster habitat in the lower bay and at the barrier islands, so the Eastern oyster HSI was re-run on the Delft3D grid cells (TWIG 2019).

The species-specific HSI results are presented in the EIS Chapter 4, Section 4.10 Aquatic Resources section for the No Action Alternative, the Applicant's Preferred Alternative (75,000 cfs), and then for a subset of key species for the Other Alternatives. Maps of HSI scores for each simulated decadal year are presented for the 10 species under the No Action Alternative (see EIS Figures 4.10-12 through 4.10-14). The difference in HSI values between the Applicant's Preferred Alternative and the No Action Alternative are presented in the EIS document (see EIS Figures 4.10-16, 4.10-18 through 4.10-19). For demonstration of the HSI results for Other Alternatives, Table 4.10-7 in the EIS document lists the difference in the HSI values between the 50,000 cfs Alternative, the Applicant's Preferred Alternative (75,000 cfs), and the 150,000 cfs Alternatives for brown shrimp, blue crab, and largemouth bass. All HSI results presented in Chapter 4, Section 4.10 Aquatic Resources of the EIS document and in this appendix use the input data and suitability results provided in Appendix B of Carruthers et al. 2019.

To assess the No Action Alternative scenario and to provide readers with a clear demonstration of the modeled HSI results, HSI values by polygon and decadal year are tabularized in this appendix. Although the maps included in the EIS document often provide a clear indication of the spatial differences among polygons, and changes in habitat scores over decadal years, the tables are useful for identifying smaller changes in the HSI results by polygon and over time. In addition, some of the HSI results by polygon were plotted against mean predictor variables (for example, seasonal salinity, temperature, chlorophyll A concentration, and annual percent marsh vegetation) to show which environmental inputs more greatly influenced the overall species HSI results over space and time. The HSI polygon map, tabularized data, and scatter plots for brown shrimp are provided in the EIS as an example of how the HSIs were assessed (see EIS Figure 4.10-11). Tabular results and any additional plots that support the HSI results summarized for the remaining species are included in this appendix with references to the maps in the EIS document.

The Applicant's Preferred Alternative, and the other alternatives, are described as differences in the species HSIs over time and space compared to the No Action Alternative. In this way, the absolute value of the calculated HSIs for the No Action Alternative (see Tables N1-2 through N1-10) can be used with the changes in the HSI values for the operational alternatives to not only determine whether the habitat suitability is better or worse, but if the increase or decrease in the HSI translates to a relatively impactful change. For example, if a species' HSI increases by 0.3, that could mean the HSI changed from 0.6 to 0.9. In this case, the habitat suitability for that species has increased to be near optimum. However, a 0.3 increase could also mean the HSI changed from 0.1 to 0.4. In this case, although the habitat has become more suitable for a species, it is still far from being considered optimal habitat. The determinations in the changes to HSI values are briefly described in this appendix for documentation, and are the same as those written for the key species in the Applicant's Preferred Alternative of Chapter 4, Section 4.10 Aquatic Resources in the EIS document.

NO ACTION ALTERNATIVE

The HSI results under the No Action Alternative for the key species discussed in Section 4.10 Aquatic Resources are summarized in the EIS with other relevant information regarding habitat changes impacting these key species and the detailed species HSI results are presented in this appendix.

Brown Shrimp

For brown shrimp, the modeled HSI for early juvenile habitat suitability under the No Action Alternative ranges from about 0.44 to 0.85 (out of a score from 0 to 1) in year 2020, with highest suitability scores concentrated in the mid and lower western polygons of the Barataria Basin (see EIS Figure 4.10-12a). Habitat suitability in the model is primarily driven by salinity, with interacting and increasing temperature in the polygons (see Figure N1-1). Over time, the brown shrimp HSI values are projected to decrease slightly, generally on the order of about –0.10 by 2070 (see Table N1-2). The largest reductions in the HSI scores are anticipated to occur over time in the polygons that had the highest starting suitability scores in 2020 (see polygons 9 through 17 in Table N1-2). By the end of the No Action Alternative simulation in 2070, the juvenile brown shrimp habitat suitability is projected to be reduced across most polygons (see EIS Figure 4.10-12a), primarily because the proportion of vegetation to open water is reduced to below 0.20 (or 20 percent) (see Figure N1-1). The continued marsh loss over time appears to allow the high spring Mississippi River discharge to flow more freely into portions of the Barataria Basin because salinities are also reduced in these polygons (see Figure N1-1). The intuitive response is an increase in salinity throughout the basin without the planned diversion, however the reduced salinity in the spring demonstrates the opposite effect and likely indicates the baseline driving force of the high Mississippi River flow with the Barataria Basin. The reduced juvenile brown shrimp habitat suitability with decreasing spring salinities (below 10 ppt) is also evident when examined over time within the scatter plots (Figure N1-1), indicating the significant effect that low salinities can exert on the HSI modeled early juvenile shrimp habitat suitability.

Table N1-2
Brown shrimp juvenile HSI results by polygon and decadal year under the No Action Alternative

	Simulated Year					
Polygons	2020	2030	2040	2050	2060	2070
1	0.4597	0.4692	0.4749	0.4938	0.5143	0.4504
2	0.4788	0.4918	0.5024	0.5227	0.5341	0.5534
3	0.4866	0.5071	0.5204	0.5432	0.3760	0.3448
4	0.5157	0.5329	0.5502	0.5792	0.5185	0.3620
5	0.4922	0.5102	0.5267	0.4838	0.3768	0.3359
6	0.5975	0.5948	0.6190	0.6401	0.4981	0.4150
7	0.5579	0.5719	0.5554	0.5283	0.4621	0.4220
8	0.5831	0.5735	0.5513	0.4986	0.4165	0.4025
9	0.7713	0.6946	0.6605	0.5903	0.4616	0.4186
10	0.7236	0.6973	0.6790	0.5896	0.4158	0.3750
11	0.6812	0.5698	0.4809	0.3815	0.3190	0.3218
12	0.6568	0.5572	0.4652	0.3714	0.2999	0.2967
13	0.7213	0.6524	0.6294	0.5618	0.4112	0.3867
14	0.4641	0.3978	0.3945	0.3704	0.3285	0.3279
15	0.6676	0.5684	0.5331	0.3787	0.3009	0.2869
16	0.8536	0.7597	0.6992	0.5777	0.4592	0.4477
17	0.7010	0.6366	0.6267	0.5544	0.4864	0.4668
18	0.5906	0.4655	0.4562	0.3747	0.3318	0.3262
19	0.4430	0.3898	0.3586	0.3156	0.2967	0.2911
20	0.6168	0.5812	0.5685	0.5523	0.5373	0.5379

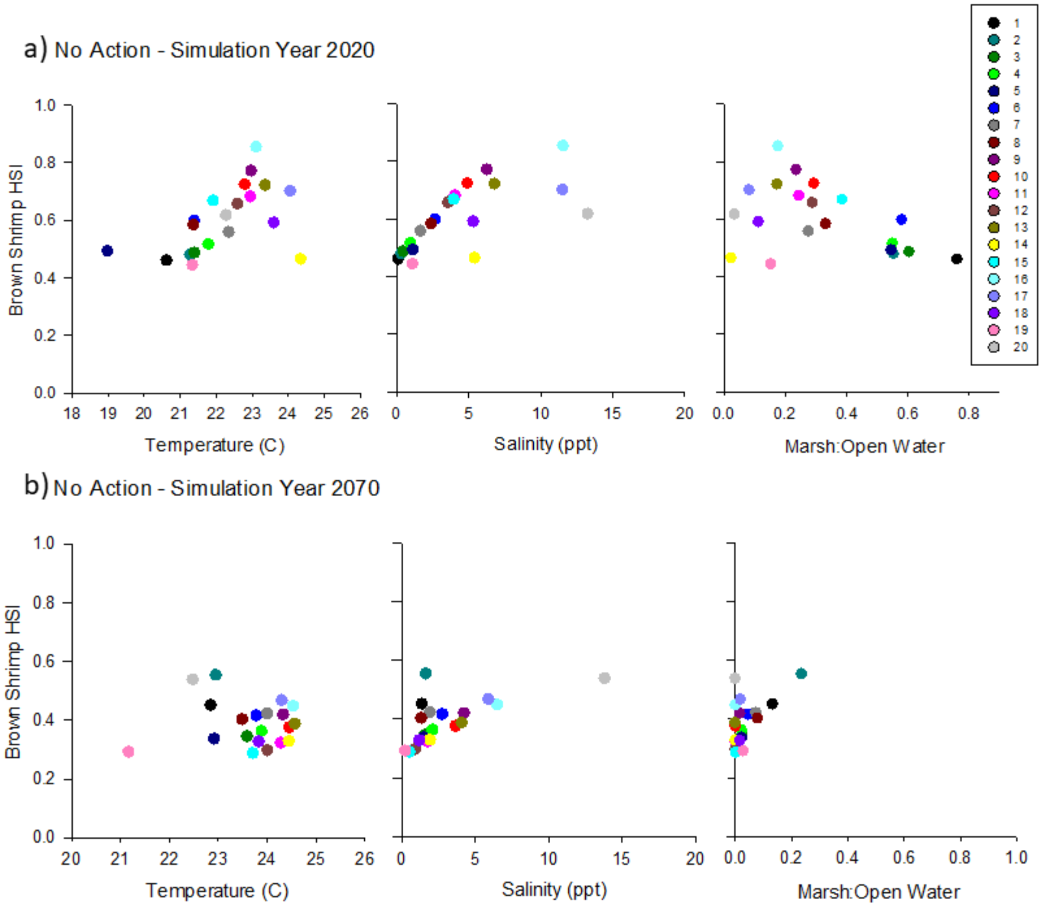


Figure N1-1. **Brown shrimp early juvenile HSI in relation to seasonal temperature and salinity, and the proportion of marsh in the polygons for 2020 (a) and for 2070 (b) under the No Action Alternative.**

White Shrimp

The modeled juvenile white shrimp habitat suitability across the Barataria Basin shows a small range across polygons of about 0.48 to 0.67 under the No Action Alternative at the beginning of the simulation in year 2020 (see Table N1-3). The higher suitability scores greater than or equal to 0.6 are concentrated in the polygons at the lower-mid and eastern region of the estuary and then at the lower westernmost polygon 16 (see EIS Figure 4.10-12b, Table N1-3). Over time, the shrimp HSI values decrease by about -0.10 to -0.25 throughout the polygons by the end of the No Action Alternative simulation in 2070, with exception of polygon 2 in the western upper basin that does not change and is the only one to remain above 0.5 suitability (see EIS Figure 4.10-12b and Table N1-3). The polygons that originally had the higher suitability scores above 0.6 are reduced to almost half of their original scores by 2070 (see Table N1-3). Therefore, after the 50-year analysis period under the No Action Alternative, the polygons are projected to provide relatively less and lower suitability habitat for white shrimp early juveniles (polygon scores mostly in low to mid-0.30s).

Table N1-3
White shrimp juvenile HSI results by polygon and decadal year under the No Action Alternative

	Simulated Year					
Polygons	2020	2030	2040	2050	2060	2070
1	0.5280	0.5310	0.5465	0.5231	0.5206	0.4249
2	0.5238	0.5275	0.5303	0.5327	0.5289	0.5203
3	0.5212	0.5220	0.5214	0.5155	0.3531	0.3124
4	0.5332	0.5320	0.5319	0.5234	0.4655	0.3165
5	0.5422	0.5451	0.5415	0.4666	0.3749	0.3292
6	0.5757	0.5641	0.5618	0.5426	0.4291	0.3565
7	0.5274	0.5280	0.5002	0.4651	0.4218	0.3860
8	0.5616	0.5599	0.5275	0.4731	0.4179	0.4085
9	0.5950	0.5440	0.5010	0.4333	0.2851	0.3384
10	0.5933	0.5822	0.5559	0.4783	0.3591	0.3312
11	0.6024	0.5409	0.4567	0.3720	0.3232	0.3341
12	0.6054	0.5536	0.4626	0.3826	0.3163	0.3195
13	0.5765	0.5474	0.5229	0.4782	0.3722	0.3595
14	0.4029	0.3833	0.3814	0.3804	0.3484	0.3587
15	0.6734	0.6472	0.5977	0.4504	0.3460	0.3338
16	0.6727	0.6123	0.5547	0.4535	0.3743	0.3707
17	0.5544	0.5382	0.5142	0.4860	0.4565	0.4363
18	0.5676	0.5079	0.4712	0.4324	0.3783	0.3790
19	0.4840	0.4406	0.4191	0.4000	0.3621	0.3631
20	0.4834	0.4572	0.4218	0.4017	0.3997	0.3906

The white shrimp early juvenile HSI results are plotted against mean salinity and temperature inputs from June through November, and against the annual percent of the polygon that is vegetated marsh for 2020 (see Figure N1-2a) and for 2070 (see Figure N1-2b). The seasonal salinity and temperature within the polygons shift very little between the start and the end of the No Action Alternative simulation (see Figure N1-2a). By the end of the No Action Alternative simulation in 2070, the juvenile white shrimp habit Table N1-3) because the proportion of vegetation to open water is reduced to below 0.20 (or 20 percent, Figure N1-2b). The suitability in polygon 2 remains at its original value because the proportion of marsh vegetation has remained above 0.20 (see Figure N1-2b).

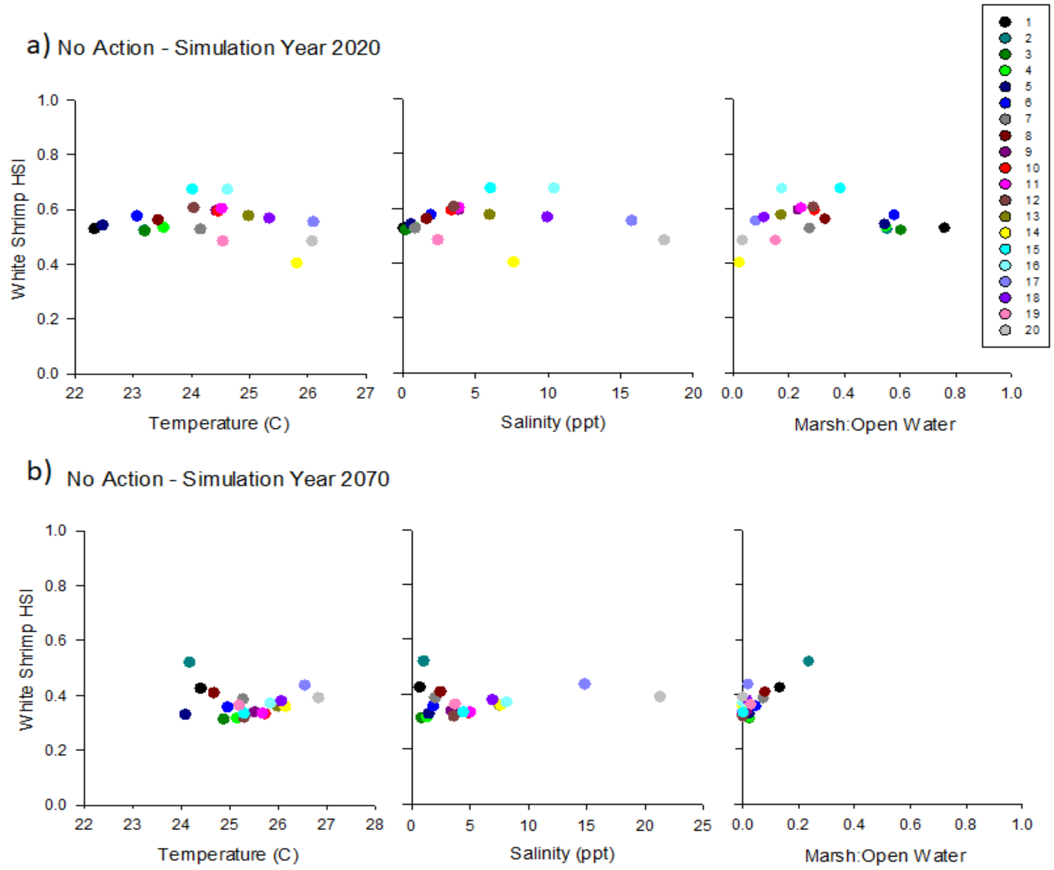


Figure N1-2. **White shrimp early juvenile HSI in relation to seasonal temperature and salinity, and the proportion of marsh in the polygons for 2020 (a) and for 2070 (b) under the No Action Alternative.**

Blue Crab

The modeled blue crab early juvenile habitat suitability is highest in the upper and middle estuary polygons at the start of the simulation in 2020 (see Table N1-4, and EIS Figure 4.10-12c), with HSI values well above 0.9 and near optimum. The blue crab HSI values generally decrease moving towards the lower basin, with the lowest habitat suitability of about 0.39 in polygon 20 at the delta (see Table N1-4). This general spatial trend with highest habitat suitability in the upper estuary and decreasing suitability moving towards the low estuary is generally consistent over the simulated 50-year analysis period (see EIS Figure 4.10-12c).

Juvenile blue crab HSI values decrease over the 50-year analysis period simulation in all polygons when the 2070 values are compared with the 2020 values (see Table N1-4). However, the reductions in habitat suitability over time vary among the polygons (see EIS Figure 4.10-12c). The reduction in blue crab suitability is slight (approximately 0.10 or less) for polygons 2, 14, 17, 18, and 20 (see Table N1-4). The reduction in habitat suitability is around 0.2 for polygons 1, 16, and 19 (see Table N1-4). These polygons with the smallest reductions in habitat suitability (about 0.2 or less) are at either the upper extreme in the Barataria Basin or the lower extreme of the basin around the barrier islands and delta (see EIS Figure 4.10-12c). The rest of the polygons show larger reductions in the blue crab HSI scores between 0.3 and 0.45 by 2070 (see Table N1-4 and EIS Figure 4.10-12c). Overall under the No Action Alternative, the area of optimum suitability for the early juvenile blue crab contracts over time to the upper estuary (see EIS Figure 4.10-12c). Suitability for blue crab is generally reduced from relatively high habitat (0.7 to 0.9) to mid-level (0.5 and 0.6) and lower suitability habitat (0.3 and 0.4).

Table N1-4
Blue crab juvenile HSI results by polygon and decadal year for the No Action Alternative

	Simulated Year					
Polygons	2020	2030	2040	2050	2060	2070
1	0.9894	0.9929	0.9873	0.9955	0.9949	0.8127
2	0.9920	0.9915	0.9918	0.9907	0.9886	0.9606
3	0.9949	0.9947	0.9951	0.9943	0.6837	0.5934
4	0.9902	0.9900	0.9897	0.9878	0.8813	0.5783
5	0.9826	0.9776	0.9757	0.8395	0.6706	0.5672
6	0.9766	0.9787	0.9782	0.9759	0.7759	0.6132
7	0.9776	0.9719	0.9158	0.8329	0.7516	0.6497
8	0.9508	0.9449	0.8853	0.7691	0.6949	0.6448
9	0.9162	0.8723	0.7978	0.6973	0.5645	0.5189
10	0.9172	0.9149	0.8570	0.7012	0.5284	0.4455
11	0.8679	0.7851	0.6426	0.4847	0.4504	0.4367
12	0.8862	0.8259	0.6732	0.5254	0.4774	0.4617
13	0.7563	0.7355	0.6721	0.5724	0.4603	0.4078
14	0.4655	0.4628	0.4362	0.4034	0.4134	0.4031
15	0.7992	0.8251	0.7404	0.5402	0.4822	0.4554
16	0.6885	0.6778	0.5953	0.4960	0.4434	0.4201
17	0.4587	0.4743	0.4443	0.3988	0.3972	0.3662
18	0.5617	0.5697	0.5213	0.4717	0.4692	0.4585
19	0.7997	0.7720	0.6831	0.6119	0.5847	0.5525
20	0.3980	0.3869	0.3542	0.3216	0.3138	0.3033

The blue crab HSI results are plotted against the mean salinity and temperature from August through March, and against the percent of polygon that is marsh vegetation for 2020 (see Figure N1-3a) and 2070 (see Figure N1-3b). The general reduction in the modeled juvenile blue crab habitat suitability from the upper estuary polygons to the lower estuary polygons is due to reduced percent marsh vegetation and increasing salinity (see Figure N1-3b). The polygons in the lower estuary are primarily composed of open water bay habitat (percent marsh is less than or equal to 20 percent) whereas the upper and mid-estuary polygons are comprised of greater than or equal to 30 percent marsh vegetation (see Figure N1-3b) which is within the modeled suitability optimum range of 25 to 80 percent (see Figure 9 in O'Connell et al. 2016a).

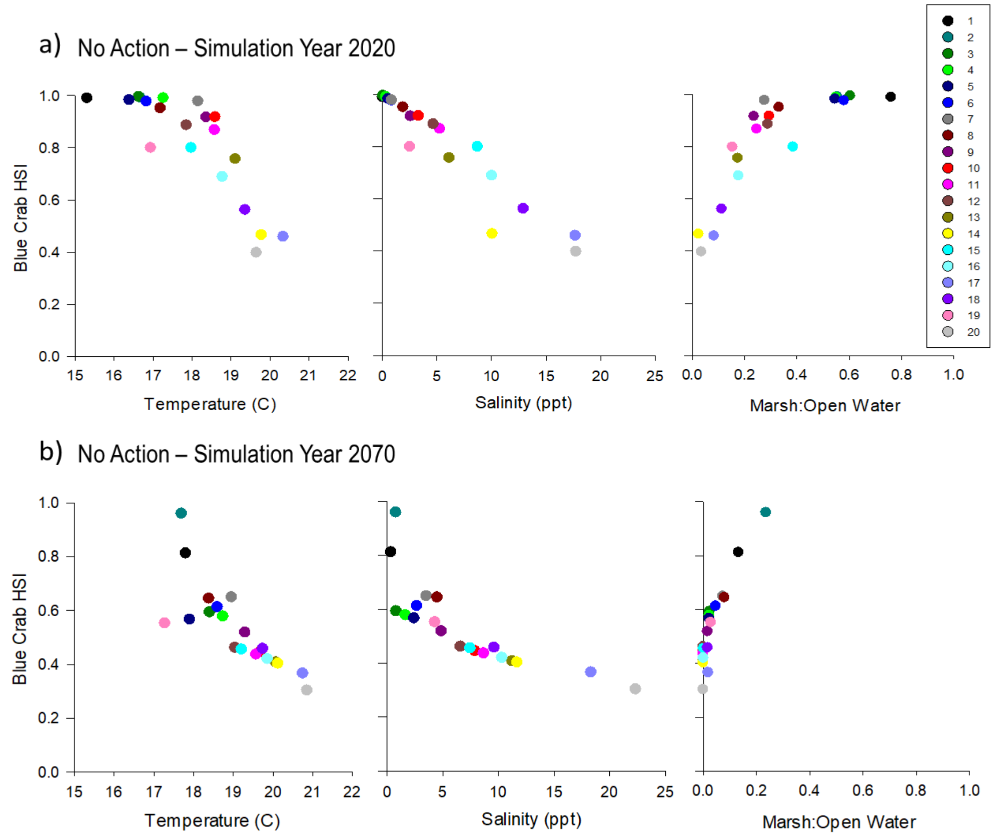


Figure N1-3. **Juvenile blue crab HSI in relation to seasonal temperature and salinity, and the proportion of vegetated land to open water for 2020 (a) and for 2070 (b) under the No Action Alternative.**

Both 2020 and 2070 show the general reduction in HSI scores for the Barataria Basin polygons moving towards the gulf primarily due to the lower percent marsh. Comparing the 2020 plots (see Figure N1-3a) to the 2070 plots (see Figure N1-3b) also shows the large reduction in marsh habitat over the 50-year analysis period for most polygons (as well as some increasing salinity and temperature). By 2070, all polygons in the Barataria Basin are projected to have less than 25 percent marsh vegetation left under the No Action Alternative. Only the upper most polygons in the Barataria Basin (1 and 2) have habitat suitability scores above 0.8 by 2070 (see Table N1-4), due to the highest percent marsh coupled with the lowest salinities (see Figure N1-3b).

Bay Anchovy

The modeled bay anchovy juvenile habitat suitability across polygons and decadal years show a small range of relatively low scores under 0.4, with most scores between 0.2 to 0.3 for the No Action Alternative (see EIS Figure 4.10-13a and Table N1-5). Polygon 17 at Grand Isle, and polygon 20 at the birdfoot delta, have the lowest suitability scores at the beginning of the simulation in 2020 (see Table N1-5). The bay anchovy HSI values by polygon change very little over the decadal years, with some suitability scores slightly increasing and others slightly decreasing (see Table N1-5). Only polygon 19 shows a change greater than +/- 0.10 over time for the No Action

Alternative, with an approximate reduction of -0.13 in the 2070 HSI compared to 2020 (see Table N1-5). The modeled bay anchovy suitability is therefore never good (scores typically between 0.2 and 0.4) for the No Action Alternative simulation (see Table N1-5 and EIS Figure 4.10-13a). Some spatial shifts in the habitat suitability across the Barataria Basin is evident over time (see EIS Figure 4.10-13a) but overall suitability remains poor for the bay anchovy juveniles under the No Action Alternative.

Table N1-5
Bay anchovy juvenile HSI results by polygon and decadal year for the No Action Alternative.

	Simulated Year					
Polygons	2020	2030	2040	2050	2060	2070
1	0.3136	0.2713	0.2894	0.3350	0.3582	0.3430
2	0.2487	0.2428	0.2501	0.2549	0.2741	0.3049
3	0.3220	0.2949	0.3331	0.3649	0.3178	0.3004
4	0.2750	0.2648	0.2839	0.2938	0.3163	0.2636
5	0.2945	0.2939	0.3374	0.3713	0.3754	0.3294
6	0.2871	0.2755	0.2961	0.3152	0.3350	0.3045
7	0.3184	0.3016	0.3224	0.3206	0.3454	0.3267
8	0.3157	0.3316	0.3529	0.3762	0.4071	0.3893
9	0.3270	0.3135	0.3122	0.3112	0.3160	0.2882
10	0.3433	0.3438	0.3455	0.3257	0.3007	0.2613
11	0.3430	0.3456	0.3174	0.2792	0.2917	0.2758
12	0.3526	0.3728	0.3459	0.3225	0.3370	0.3177
13	0.3339	0.3463	0.3220	0.3043	0.2847	0.2440
14	0.2339	0.2550	0.2358	0.2258	0.2349	0.2126
15	0.3922	0.4497	0.4165	0.3659	0.3492	0.3007
16	0.3044	0.3445	0.3028	0.2825	0.2831	0.2616
17	0.2032	0.2255	0.2060	0.1893	0.1887	0.1721
18	0.3341	0.3783	0.3128	0.2731	0.2649	0.2276
19	0.2973	0.2574	0.2273	0.2005	0.1721	0.1643
20	0.1406	0.1341	0.1262	0.1213	0.1207	0.1185

The juvenile bay anchovy HSI results by polygon are plotted against the mean annual temperature, salinity, the percent marsh vegetation, and chlorophyll A concentration for 2020 (see Figure N1-3a) and 2070 (see Figure N1-4b). The anchovy HSI results are primarily driven by chlorophyll A concentrations spatially (see Figure N1-4). All HSI values are less than or equal to 0.5 due to the Delft3D-generated chlorophyll A outputs being considerably lower than the concentration data used to fit the suitability function for the HSI (see Figure 12 in Sable et al. 2016a). In retrospect, the chlorophyll suitability index should have been held constant after the first review of the Delft3D generated outputs showed concentrations being lower than the concentrations originally used to describe the relationship. Although the chlorophyll suitability index caused depressed suitability scores for bay anchovy and Gulf menhaden, the relative changes in suitability were ultimately driven by other variables. The chlorophyll suitability scores therefore do not impact the discussion of relative changes in the HSIs, and in reality the suitability for bay anchovy and Gulf menhaden are likely much greater than indicated for the Barataria Basin as the LDWF field monitoring data indicate. Over time, changes in the HSI scores are due to decreases in the percent marsh under the No Action Alternative (see Figure N1-4b); note that chlorophyll A concentration also increases in several of the polygons over time.

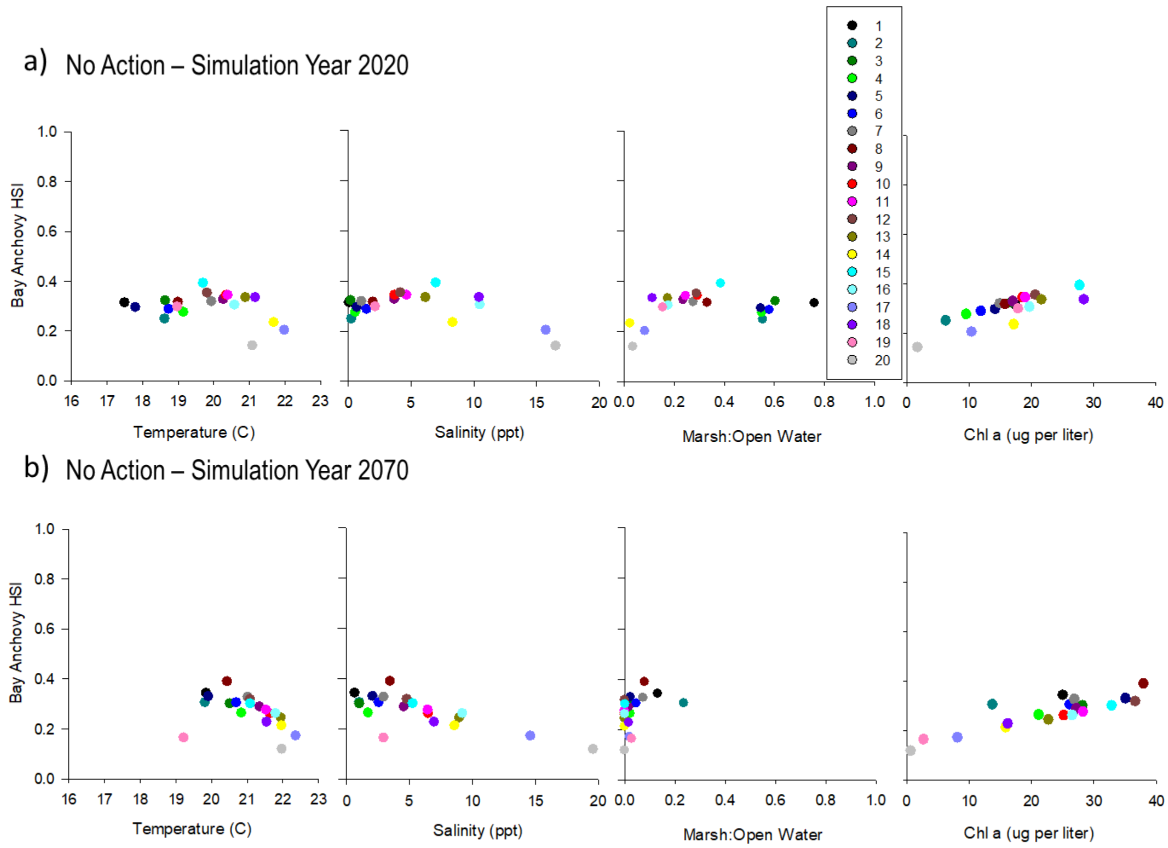


Figure N1-4. **Bay anchovy juvenile HSI in relation to the mean annual temperature, salinity, percent vegetation (Marsh:Open Water), and chlorophyll A concentration in the polygons for 2020 (a) and for 2070 (b) under the No Action Alternative.**

Gulf Menhaden

The modeled Gulf menhaden early juvenile HSIs across the Barataria Basin (see EIS Figure 4.10-13b) are generally similar in magnitude and spatial patterns to bay anchovy (see EIS Figure 4.10-13a) for the No Action Alternative. However, the menhaden HSI scores are often even lower than the bay anchovy scores (see Table A1-6), with the menhaden HSI results usually at or below 0.3. The higher habitat suitability is, like the anchovy, most often along the middle and eastern region of the estuary from 2020 through 2060 (see EIS Figure 4.10-13b). By 2070, Gulf menhaden juveniles are left with poor suitability habitat throughout the basin other than in polygon 8, the only polygon with a suitability score above 0.30 (see Table N1-6) and with the highest chlorophyll concentration.

Table N1-6
Gulf menhaden early juvenile HSI results by polygon and decadal year for the No Action Alternative.

	Simulated Year					
Polygons	2020	2030	2040	2050	2060	2070
1	0.2944	0.2317	0.2695	0.2881	0.3078	0.2808
2	0.2450	0.2341	0.2373	0.2443	0.2578	0.2745
3	0.3011	0.2543	0.2783	0.2977	0.2598	0.2486
4	0.2681	0.2491	0.2596	0.2732	0.2892	0.2361
5	0.2731	0.2736	0.3096	0.3287	0.3248	0.2899
6	0.2645	0.2495	0.2631	0.2839	0.3001	0.2698
7	0.2997	0.2753	0.2843	0.2875	0.3049	0.2864
8	0.2899	0.3067	0.3238	0.3418	0.3649	0.3515
9	0.2772	0.2699	0.2702	0.2706	0.2826	0.2568
10	0.3016	0.3038	0.3047	0.2900	0.2631	0.2305
11	0.3066	0.3169	0.2928	0.2656	0.2633	0.2523
12	0.3196	0.3511	0.3288	0.3162	0.3115	0.2952
13	0.2901	0.3106	0.2898	0.2794	0.2535	0.2213
14	0.2224	0.2541	0.2338	0.2270	0.2197	0.1991
15	0.3696	0.4437	0.4109	0.3715	0.3242	0.2817
16	0.2375	0.2880	0.2524	0.2438	0.2476	0.2302
17	0.1673	0.2109	0.1798	0.1649	0.1702	0.1512
18	0.3139	0.3700	0.3107	0.2668	0.2484	0.2124
19	0.2490	0.2313	0.2124	0.1799	0.1559	0.1495
20	0.1093	0.1080	0.1006	0.0988	0.0983	0.0959

The Gulf menhaden juvenile HSI predictor variables are the same as bay anchovy and include salinity and temperature, the percent marsh vegetation for the polygon, and chlorophyll A concentration from January through July (see Table N1-1; Sable et al. 2017). That is the reason that the HSI results for the two planktivorous forage fish species are generally unsuitable and similar in magnitude, across space and time (see Table N1-5 and Table A1-6). Like the bay anchovy, the low HSI scores across polygons are due to the Delft3D-generated chlorophyll A outputs being considerably lower than the concentration data used to fit the suitability function for the Gulf menhaden (see Figure N1-4 for bay anchovy and Figure 11 in Sable et al. 2017). Over time, the changes in the Gulf menhaden HSI scores are mainly due to decreases in the percent marsh below 20 percent except for polygon 2 (see Figure N1-4b for bay anchovy), and interactions with the varying chlorophyll concentrations by polygon.

Spotted Seatrout

Spotted seatrout early juvenile HSI scores are relatively high and often near optimum values among the polygons (see EIS Figure 4.10-13c and Table N1-6). The projected habitat suitability in all polygons decreases over the simulated decadal years typically by about -0.2 (see Table N1-7). By 2070, the highest habitat suitability scores are in polygons 1 and 2 in upper Barataria, polygon 7, and polygons 17 and 18 along the lower eastern side to the birdfoot delta (see EIS Figure 4.10-13c, Table N1-7). The other polygon HSI scores are still relatively high at values at or above 0.65, with exception of polygon 20 which consistently had the lowest suitability score among the polygons (see Table N1-7). Overall habitat suitability for early juvenile spotted seatrout remains high over time under the No Action Alternative, although suitability does move away from nearly optimum scores that were projected at the beginning of the simulation in 2020 (see Table N1-7).

Table N1-7
Spotted seatrout early juvenile HSI results by polygon and decadal year for the No Action Alternative

	Simulated Year					
Polygons	2020	2030	2040	2050	2060	2070
1	0.8563	0.8601	0.8473	0.8647	0.8662	0.7614
2	0.8675	0.8687	0.8682	0.8692	0.8721	0.8670
3	0.8638	0.8657	0.8652	0.8672	0.6882	0.6490
4	0.8722	0.8718	0.8706	0.8723	0.8150	0.6563
5	0.8747	0.8801	0.8776	0.8073	0.7061	0.6659
6	0.8824	0.8797	0.8785	0.8811	0.7682	0.6967
7	0.8833	0.8861	0.8546	0.8168	0.7721	0.7346
8	0.9084	0.9107	0.8739	0.8223	0.7639	0.7567
9	0.9097	0.8692	0.8176	0.7601	0.6137	0.6794
10	0.9325	0.9284	0.8928	0.8129	0.6995	0.6775
11	0.9610	0.8965	0.8031	0.7203	0.6793	0.6879
12	0.9616	0.9128	0.8111	0.7349	0.6734	0.6775
13	0.8896	0.8681	0.8339	0.7934	0.7085	0.6956
14	0.7329	0.7218	0.7092	0.6999	0.6963	0.6975
15	0.9960	0.9891	0.9233	0.7822	0.7022	0.6912
16	0.9185	0.8874	0.8244	0.7525	0.6981	0.6953
17	0.7531	0.7599	0.7206	0.6775	0.7022	0.6672
18	0.8383	0.8154	0.7707	0.7420	0.7244	0.7208
19	0.8318	0.7946	0.7656	0.7499	0.7247	0.7255
20	0.6541	0.6260	0.5337	0.4548	0.4810	0.4486

The high habitat suitability for early juvenile seatrout is due to near optimum salinity and temperature conditions in September through November, and near optimum percent vegetation (optimum between 25 percent and 80 percent) in most polygons (see Figure N1-5). By the end of the No Action Alternative simulation in 2070, juvenile seatrout habitat suitability is generally reduced by about -0.2 across most polygons because of marsh loss (see Figure N1-5b).

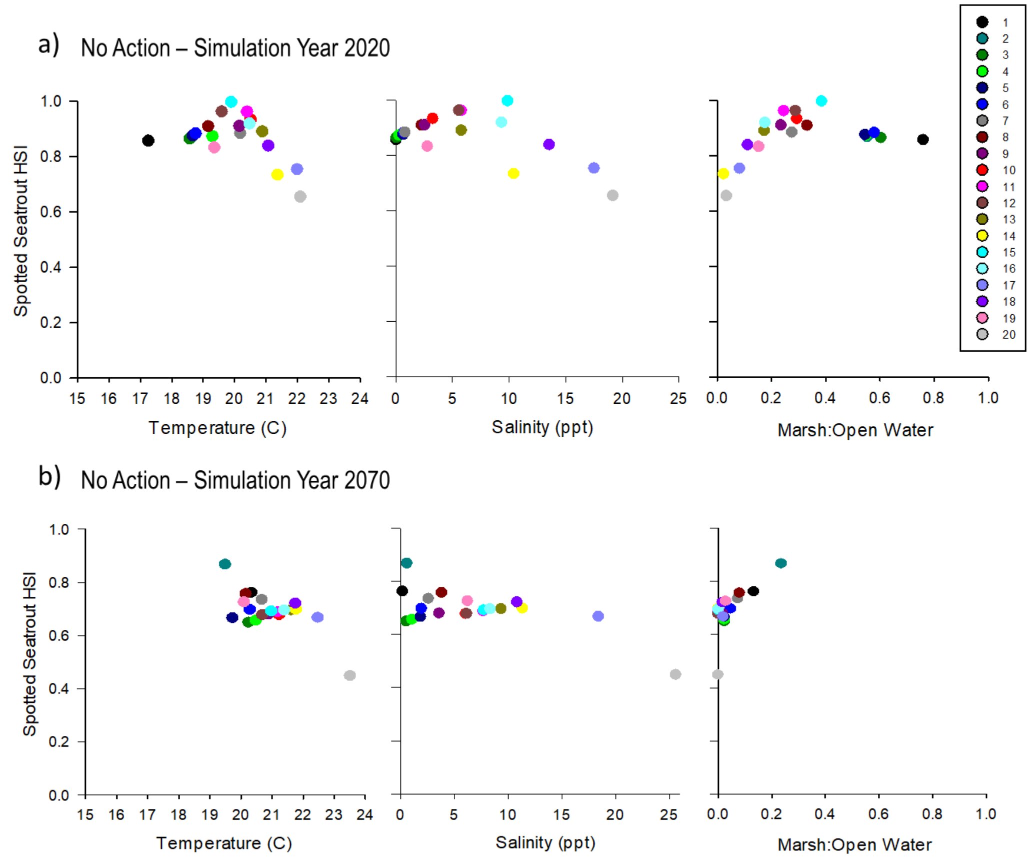


Figure N1-5. Spotted seatrout early juvenile HSI in relation to seasonal temperature, salinity, and the percent marsh in the polygons for 2020 (a) and 2070 (b) under the No Action Alternative.

Atlantic Croaker

Atlantic croaker juvenile habitat suitability is relatively high in the upper and middle estuary polygons at the start of the simulation in 2020, with HSI scores usually above 0.7 and 0.8 (see EIS Figure 4.10-14a, Table N1-8). Polygons 14 and 20 have the lowest suitability scores. The spatial pattern in the HSIs remains generally consistent over the simulated decadal years with high to lower suitability moving from the upper estuary to the low estuary, respectively (see EIS Figure 4.10-14a). The polygons with near optimum suitability scores above 0.8 disappear though over time, with the only near optimum habitat suitability for juvenile croaker in polygon 1 at the very top of the Barataria Basin by decadal year 2060 (see EIS Figure 4.10-14a, Table N1-8).

Although the juvenile croaker HSI results decrease over the 50-year analysis period simulation for all polygons (see Table N1-8), the reduction in croaker suitability by 2070 is usually near or less than -0.2 (see Table N1-8). These reductions mean that habitat suitability is generally reduced from higher suitability to more mid-level suitability that would likely provide less overall capacity for supporting juvenile Atlantic croaker in the Barataria Basin.

Table N1-8
Atlantic croaker early juvenile HSI results by polygon and decadal year for the No Action Alternative.

	Simulated Year					
Polygons	2020	2030	2040	2050	2060	2070
1	0.8810	0.8769	0.8686	0.8603	0.8372	0.7859
2	0.7231	0.7178	0.7140	0.7075	0.6989	0.6793
3	0.7896	0.7740	0.7630	0.7524	0.7122	0.5986
4	0.7847	0.7725	0.7572	0.7377	0.7139	0.6526
5	0.8831	0.8638	0.8518	0.8016	0.7131	0.6528
6	0.8527	0.8300	0.8104	0.7749	0.7120	0.6395
7	0.7098	0.6745	0.6490	0.6139	0.5728	0.5522
8	0.8377	0.8061	0.7913	0.7684	0.7178	0.6780
9	0.7017	0.6607	0.6406	0.6021	0.5607	0.5236
10	0.7395	0.7060	0.6820	0.6446	0.5930	0.5457
11	0.7432	0.7099	0.6827	0.6279	0.5691	0.5366
12	0.8426	0.8083	0.7822	0.7264	0.6459	0.6123
13	0.7074	0.6683	0.6350	0.5496	0.5027	0.4688
14	0.3904	0.3661	0.3468	0.3285	0.3199	0.3180
15	0.8062	0.7732	0.7475	0.7069	0.6328	0.5897
16	0.7608	0.7121	0.6772	0.6246	0.5655	0.5310
17	0.5186	0.4813	0.4475	0.4098	0.3914	0.3785
18	0.6432	0.6080	0.5754	0.4880	0.4527	0.4251
19	0.7180	0.7005	0.6142	0.5591	0.5325	0.5199
20	0.3541	0.3547	0.3502	0.3469	0.3428	0.3380

The juvenile croaker HSI is based on mean salinity from March through May and water depth, with the HSI score equal to the minimum value of either suitability index function (see Table N1-1 and Carruthers et al. 2019 for functions). The pattern in HSI scores among the polygons for croaker is primarily due to depth differences since salinities equal to or less than 15 parts per thousand (ppt) are considered optimum for the croaker (see Figure N1-6 and Carruthers et al. 2019 for functions).

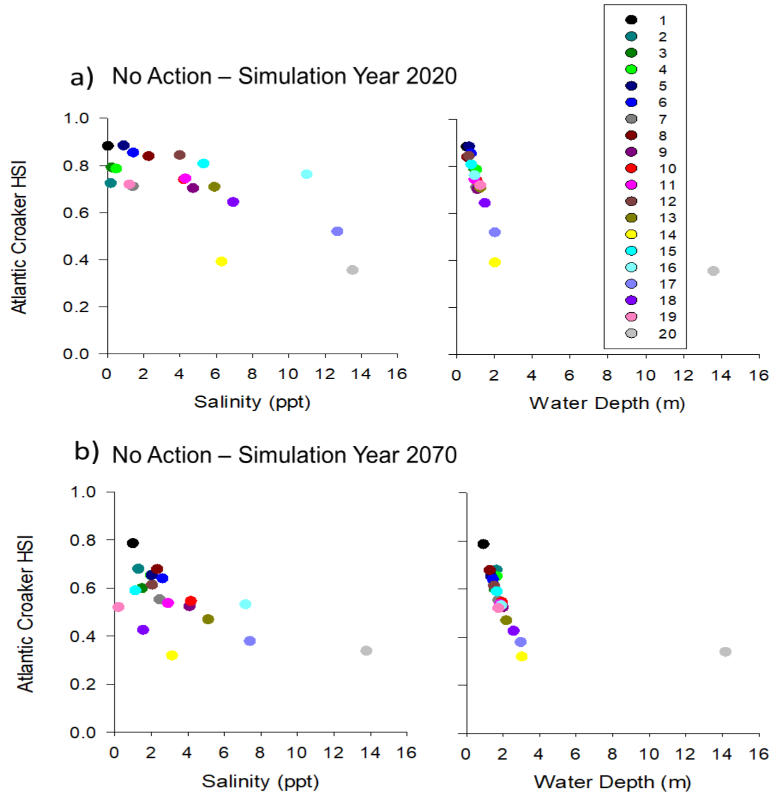


Figure N1-6. **Juvenile Atlantic croaker HSI in relation to seasonal salinity and annual water depth for 2020 (a) and for 2070 (b) under the No Action Alternative.**

Southern Flounder

Southern flounder juvenile habitat suitability is at or very near optimum throughout the Barataria Basin, and the HSIs do not change over time under the No Action Alternative simulation (see EIS Figure 4.10-14b and Table N1-9). The flounder suitability function based on mean annual salinity defines the optimum range as 5 to 20 ppt (see Carruthers et al. 2019 for function). The suitability function for mean temperature from May through August is optimal between 20 and 35 degrees Celsius (Carruthers et al. 2019). These optimum suitability ranges are wide, and most of the polygon conditions are within these ranges to produce near optimum and unchanging HSI results over space and time for juvenile flounder in the Barataria Basin (see EIS Figure 4.10-14b and Figure N1-7). Mean annual salinity within the polygons is controlling the flounder HSI results. The modeled suitability response is clearly evident in Figure N1-7 with reductions in suitability for polygons with mean annual salinities less than 5 ppt.

Table N1-9
Southern flounder HSI results by polygon and decadal year for the No Action Alternative

	Simulated Year					
Polygons	2020	2030	2040	2050	2060	2070
1	0.8639	0.8662	0.8669	0.8696	0.8728	0.8810
2	0.8693	0.8722	0.8737	0.8779	0.8805	0.8913
3	0.8678	0.8721	0.8735	0.8772	0.8795	0.8914
4	0.8781	0.8808	0.8838	0.8875	0.8917	0.9109
5	0.8815	0.8874	0.8912	0.9034	0.9026	0.9211
6	0.9036	0.9008	0.9049	0.9059	0.9107	0.9346
7	0.8921	0.8981	0.9045	0.9168	0.9214	0.9453
8	0.9176	0.9205	0.9266	0.9447	0.9388	0.9591
9	0.9648	0.9543	0.9619	0.9681	0.9633	0.9887
10	0.9650	0.9621	0.9730	0.9989	1.0000	1.0000
11	0.9907	0.9862	0.9990	1.0000	1.0000	1.0000
12	0.9775	0.9696	0.9789	1.0000	0.9806	0.9949
13	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
14	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
15	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
16	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
17	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
18	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
19	0.9226	0.8986	0.9139	0.9334	0.9258	0.9450
20	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

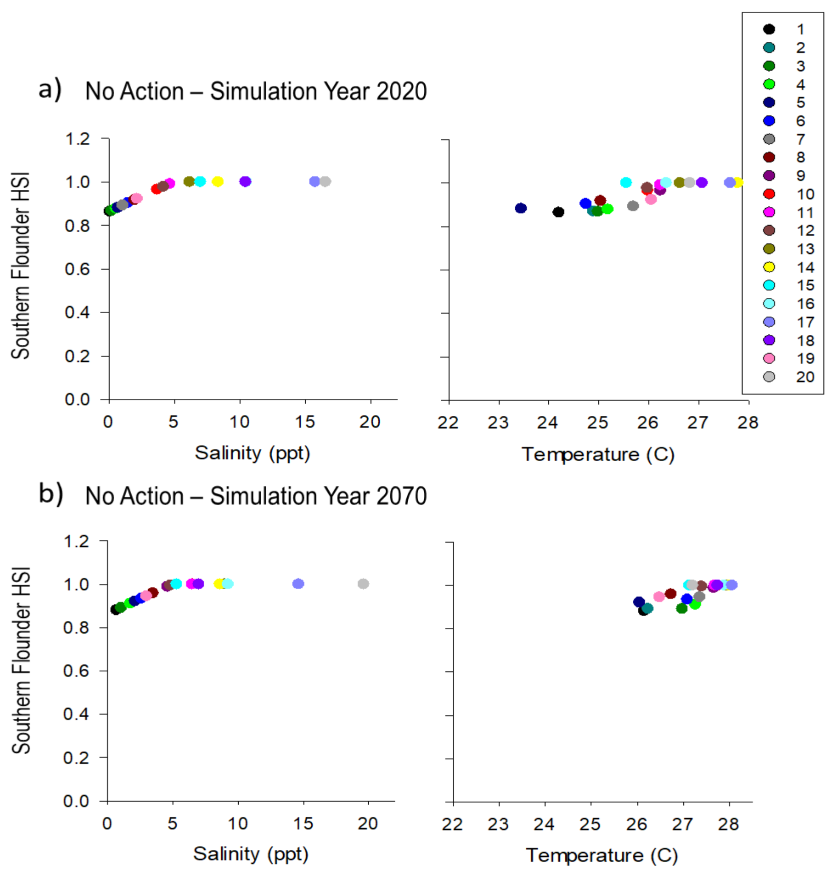


Figure N1-7. **Southern flounder juvenile HSI in relation to the mean annual salinity and summer temperature for 2020 (a) and for 2070 (b) for the No Action Alternative.**

Largemouth Bass

Largemouth bass HSIs are highest in the upper and mid-estuary, with suitability decreasing to unsuitable values greater than or equal to 0.10 in the low estuary and at the birdfoot delta (see EIS Figure 4.10-14c and Table N1-10). The spatial pattern in the largemouth bass HSI is primarily due to salinity, with interacting impacts from the percent marsh vegetation, evident in the polygons (see Figure N1-8a). Over time for the No Action Alternative simulation, habitat suitability scores in the upper and mid-estuary decline to mostly unsuitable values below 0.2 outside of polygon 2 in the upper western region of the Barataria Basin (see EIS Figure 4.10-15c; Table N1-10). The overall decline and contraction in largemouth bass habitat suitability within the Barataria Basin is primarily due to marsh loss under the No Action Alternative, with some interacting salinity evident when mean salinity is above 2.5 and 5 ppt (see Figure N1-8b). Thus, the HSI projects mid-level habitat suitability for largemouth bass in the mid to upper region of the estuary through 2050 (see EIS Figure 4.10-14c), but by 2070 there is no suitable habitat left for bass outside of the upper west side of the Barataria Basin.

Table N1-10
Largemouth bass HSI results by polygon and decadal year for the No Action Alternative.

	Simulated Year					
Polygons	2020	2030	2040	2050	2060	2070
1	0.5139	0.4764	0.5399	0.6765	0.8298	0.1853
2	0.6620	0.6533	0.6620	0.6666	0.6795	0.4870
3	0.6979	0.6562	0.7498	0.6757	0.1922	0.1878
4	0.6538	0.6550	0.6727	0.6737	0.1547	0.1559
5	0.6814	0.6951	0.7484	0.1792	0.2089	0.1937
6	0.5811	0.6063	0.6341	0.6525	0.1638	0.1606
7	0.6419	0.5554	0.3633	0.1468	0.1670	0.1620
8	0.6493	0.6013	0.3320	0.1634	0.1967	0.1865
9	0.3835	0.1719	0.1208	0.1277	0.1401	0.1433
10	0.5689	0.5098	0.2956	0.1256	0.1456	0.1282
11	0.4412	0.1321	0.1319	0.1288	0.1569	0.1413
12	0.5775	0.2484	0.1484	0.1534	0.1857	0.1743
13	0.1083	0.1181	0.1090	0.1048	0.1243	0.1036
14	0.0912	0.1088	0.0960	0.0899	0.1110	0.0969
15	0.5925	0.7288	0.1475	0.1506	0.1822	0.1668
16	0.0719	0.0933	0.0819	0.0891	0.1122	0.1010
17	0.0465	0.0559	0.0488	0.0475	0.0587	0.0540
18	0.0995	0.1315	0.1125	0.1051	0.1254	0.1068
19	0.1454	0.1454	0.1312	0.1215	0.1277	0.1204
20	0.0411	0.0423	0.0380	0.0377	0.0381	0.0373

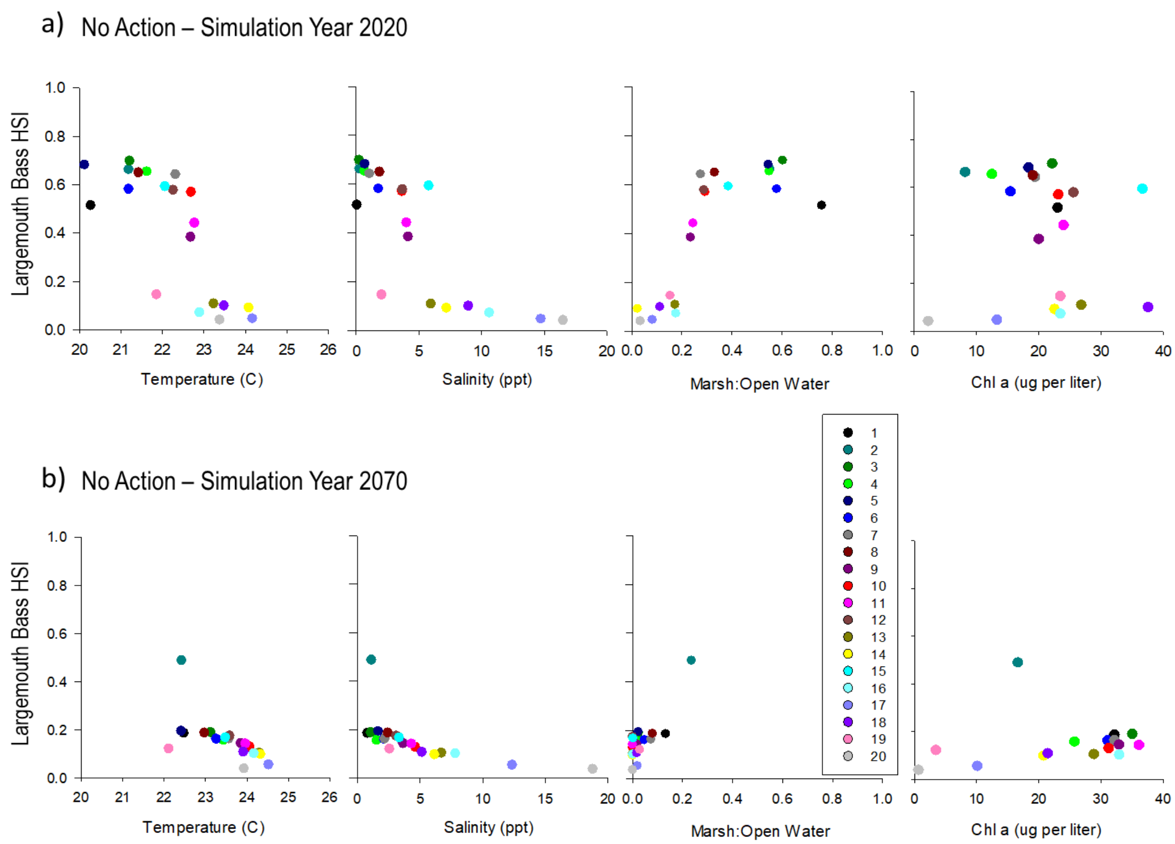


Figure N1-8. **Largemouth bass HSI in relation to seasonal temperature, salinity, annual percent marsh vegetation (Marsh:Open Water), and seasonal chlorophyll A concentration in the polygons for 2020 (a) and for 2070 (b) under the No Action Alternative.**

Eastern Oysters

The oyster HSI analysis was run at the spatial resolution of the Delft3D model grid cells (approximately 1.6 hectares, or 4 acres), because the original 20 CASM polygons appeared too coarse for evaluating oyster suitability, given the sessile (non-mobile) nature of the species. The Water Institute re-ran the oyster HSI for the Delft3D grid (TWI 2019) and additionally evaluated how suitability changed with different Mississippi River hydrographs (for example, average hydrograph vs. spring flood flow conditions vs. drought conditions).

The Eastern oyster HSI results are equal to zero except in the lower estuary, which is expected as no oysters are typically present in the upper estuary. In the lower estuary, suitability is near optimum at the start of the No Action Alternative simulation within cells comprised of open bay waters with higher or varying salinities (see EIS Figure 4.10-15). Over time the suitable habitat for oysters contracts to the western portion of the Barataria Bay, and grid cells that were originally not suitable within this area become suitable because the land cells have converted to open water (see EIS Figure 4.10-15). By 2070, the eastern half of proposed Project area becomes almost completely unsuitable for oysters.

APPLICANT’S PREFERRED ALTERNATIVE

Habitat suitability for ten species was assessed to determine if the Applicant’s Preferred Alternative (75,000 cfs) would result in significant changes over space and time compared to the No Action Alternative. The changes in the HSI values for the Applicant’s Preferred Alternative compared to the No Action Alternative are demonstrated quite clearly by the species-specific HSI maps (see EIS Figures 4.10-16, 4.10-18 and 4.10-19), therefore, tables reporting changes by polygon and decadal year are not repeated for this appendix. Similarly, the determination of impacts from the Applicant’s Preferred Alternative is often described in detail for each species HSI in the EIS document, so only key points of the HSI impacts determination are restated here and further explanation of the HSI changes are provided for some of the species.

Brown Shrimp

The changes in brown shrimp early juvenile suitability are demonstrated in EIS Figure 4.10-16a and discussed in detail within the EIS document. The decrease in brown shrimp habitat suitability on the western side of the Barataria Basin under the Applicant’s Preferred Alternative is primarily due to reduced spring salinity for the region (see Figure N1-9). The modeled function for brown shrimp salinity optimums is around 10 to 15 ppt, with suitability decreasing to about 0.1 to 0.2 at salinities near 0 ppt (see O’Connell et al. 2016b). The projected spring salinity values in the western region of the Barataria Basin under the No Action Alternative ranged from about 7.5 to 10.0 ppt, which are near optimum for the juvenile shrimp (see Figure N1-9). Spring salinities in the region drop to less than 2.5 ppt for the Applicant’s Preferred Alternative (see Figure A1-9). A small increase in habitat suitability for juvenile brown shrimp is projected to occur near the outfall (see EIS Figure 4.10-16a) where marsh is maintained under the Applicant’s Preferred Alternative compared to the loss under the No Action Alternative (see Figure N1-10).

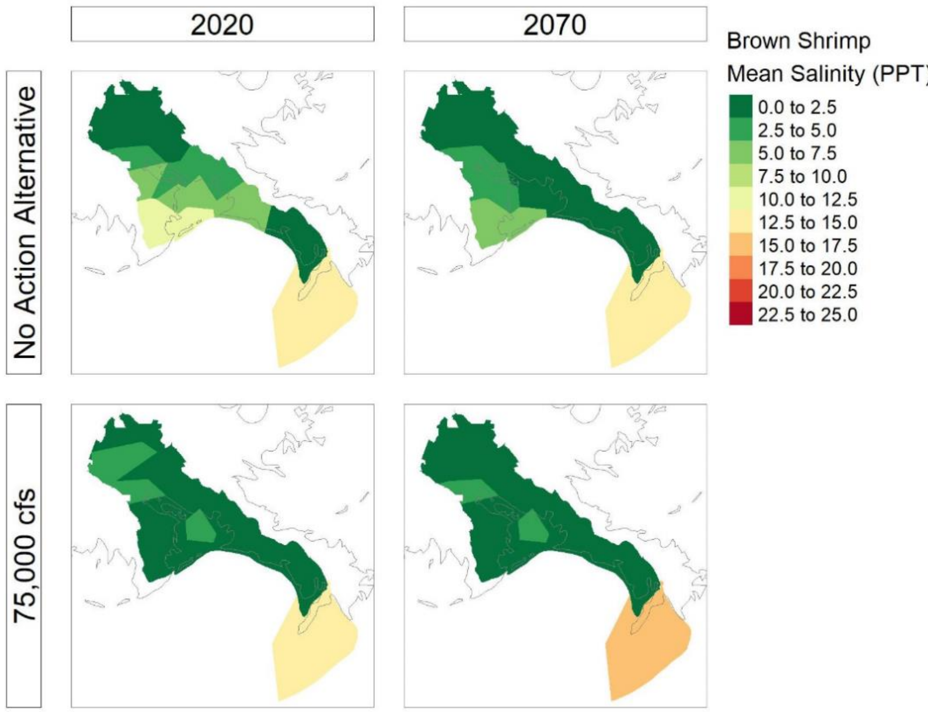


Figure N1-9. **Mean salinity for the 20 polygons from April through June under the No Action Alternative and the Applicant's Preferred Alternative for Years 2020 and 2070.**

White Shrimp

Under the Applicant's Preferred Alternative, habitat suitability for white shrimp early juveniles in the Barataria Basin is projected to change very little, if at all, compared to the No Action Alternative over time (see EIS Figure 4.10-16b). A small increase in habitat suitability for juvenile white shrimp is projected to occur in polygons 8 and 12 at the outfall, where marsh vegetation is maintained under the Applicant's Preferred Alternative compared to the loss under the No Action Alternative. Polygons 8 and 12 had HSI scores of 0.41 and 0.32 by 2070 under the No Action Alternative (see Table N1-3), so the small increase in HSI scores (to 0.52 and 0.47, respectively in Carruthers et al. 2019 – Appendix B) provides slightly more suitable habitat for white shrimp juveniles at the outfall for the Applicant's Preferred Alternative.

Blue Crab

Habitat suitability for blue crab early juveniles in the Barataria Basin changes very little over space and time for the Applicant's Preferred Alternative, except around the Project outfall towards the end of the 50-year analysis period (see EIS Figure 4.10-16c). The increase in habitat suitability over the No Action Alternative becomes apparent in 2040 around the outfall, and the increases to polygons 8 and 12 are on the order of +0.3 by 2070 (see EIS Figure 4.10-16c). The HSI scores for these polygons are above 0.8 and near optimum under the Applicant's Preferred Alternative (see

Appendix B in Carruthers et al. 2019 for polygon scores). Early juvenile blue crab suitability shows the biggest response to the sustained marsh in the outfall region across the species (see EIS Figure 4.10-17). The modeled increase would seem to be relatively impactful given most of the Barataria Basin shows a decline in blue crab suitability over time (see Table N1-4 and similar trend in Appendix B, Carruthers et al. 2019 for the Applicant's Preferred Alternative) with continued marsh loss (see Figure N1-10).

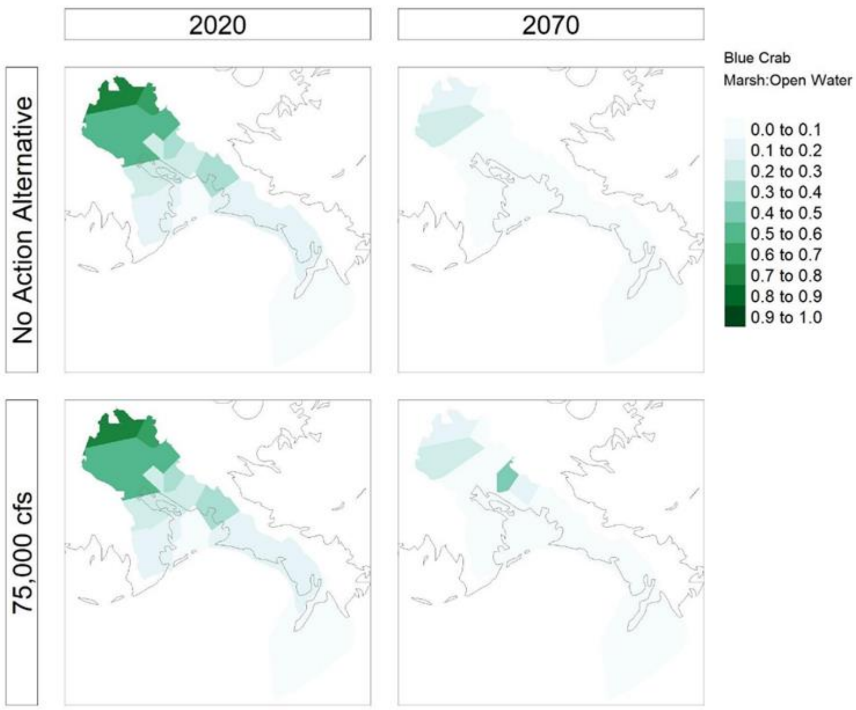


Figure N1-10. The percent marsh vegetation (Marsh:Open Water) by polygon for the No Action Alternative and for the Applicant's Preferred Alternative in Year 2020 and Year 2070. Note this figure is the same as Figure 4.10-14 in the EIS document.

Bay Anchovy

There is no difference in the modeled bay anchovy juvenile habitat suitability in the Barataria Basin under the Applicant's Preferred Alternative compared to the No Action Alternative (see EIS Figure 4.10-18a). The bay anchovy HSI used mean annual salinity and temperature, chlorophyll A, and percent marsh in each polygon. Bay anchovy are abundant in the estuary year-round and are tolerant of a wide range in salinity and temperature conditions.

Gulf Menhaden

The juvenile Gulf menhaden HSI scores, predominately in the mid to lower western region of the Barataria Basin, increase slightly by about 0.1 to 0.2 compared to the No Action Alternative in years 2020 through 2050. By 2060 and 2070, the slight increases to menhaden suitability for these polygons are gone (see EIS Figure 4.10-18b). A small decrease in habitat suitability is projected for polygon 8 at the Project outfall (see EIS Figure 4.10-19b) due to decreased chlorophyll A concentrations from January through July under the Applicant's Preferred Alternative when compared to the No Action Alternative for these same months (see Figure N1-11).

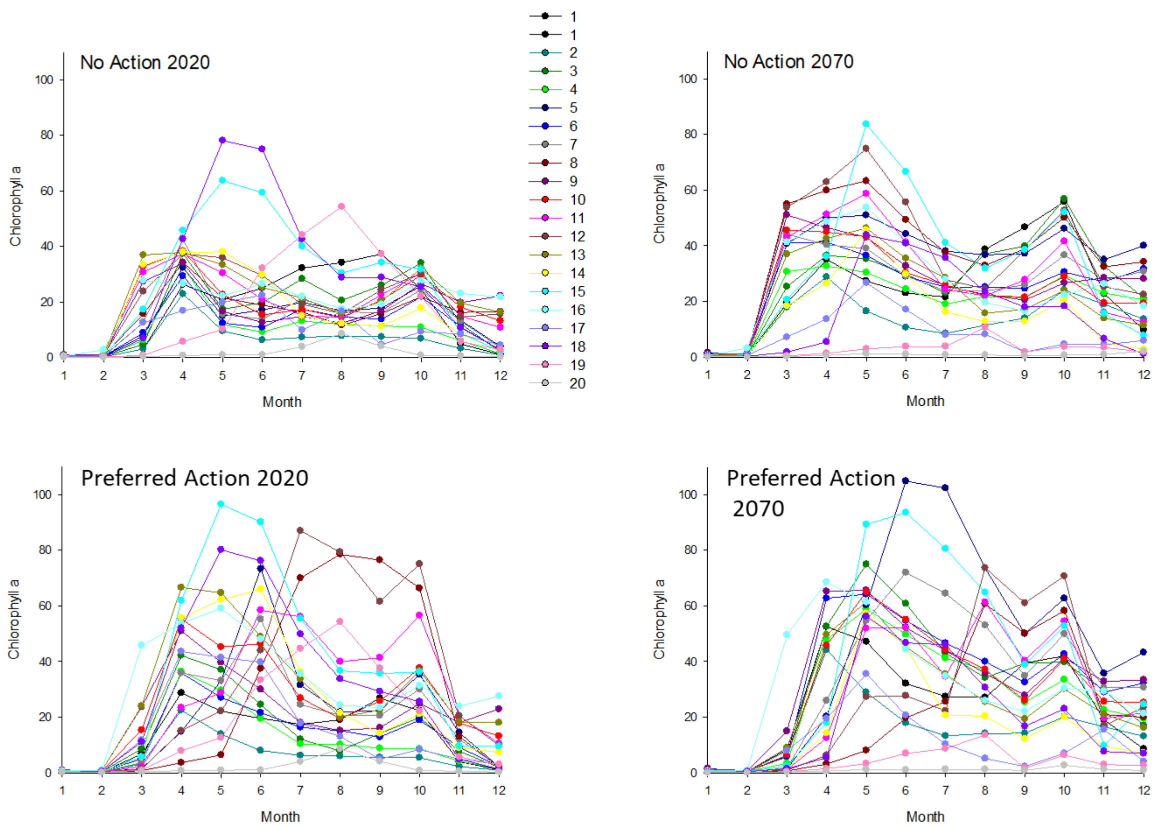


Figure N1-11. Mean monthly chlorophyll A concentration for the 20 polygons that differentially drive the bay anchovy, Gulf menhaden, and largemouth bass HSI scores under (a) the No Action Alternative and (b) the Applicant's Preferred Alternative for Years 2020 and 2070.

Spotted Seatrout

The spotted seatrout early juvenile HSI scores do not change other than small increases between 0.1 and 0.2 in polygons 8 and 12 at the proposed Project outfall in 2060 and 2070 compared to the No Action Alternative (see EIS Figure 4.10-18c). The HSI accounts for mean salinity and temperature from September through November. No significant change in the suitability is expected because the diversion is usually not operating above the 5,000 cfs base flow during this time period. The small increase in seatrout suitability observed in the HSI is due to marsh being maintained under the Applicant's Preferred Alternative compared to the loss of marsh under the No Action Alternative.

Atlantic Croaker

There are no changes in the HSI scores for Atlantic croaker early juveniles under the Applicant's Preferred Alterative (see EIS Figure 4.10-19a), other than a slight increase in suitability at the Project outfall by 2060 and 2070. The Atlantic croaker HSI is driven by mean salinity from March through May, and mean water depth of the polygon. Water depth less than 0.5 meters is optimum, water depth between 0.5 and 2 meters has an HSI score of 0.7, and water depth deeper than 2 meters has an HSI score of 0.3 (see Carruthers et al. 2019). The slight increase in croaker habitat suitability at the outfall is due to the marsh being maintained and mean water depth remaining consistent in the region compared to the No Action Alternative with sediment deposition maintaining elevation within the outfall area.

Southern Flounder

Southern flounder juvenile habitat suitability does not change with the Applicant's Preferred Alternative (see EIS Figure 4.10-19b). The suitability for southern flounder therefore remains near and at optimum across the Barataria Basin for the Applicant's Preferred Alternative, as demonstrated under the No Action Alternative (see Table N1-9). There is a slight decrease in suitability in 2040 compared to the No Action Alternative near the Project outfall, however the decrease disappears by 2050. The flounder HSI is based on mean annual salinity with optimum suitability between 5 and 20 ppt, and mean temperature from May through August with optimum suitability between 20 and 35 degrees Celsius (see Figure N1-7). Simulated salinity and temperature conditions for the Applicant's Preferred Alternative do not vary outside of the wide ranges defined as optimum suitability for flounder in the Barataria Basin.

Largemouth Bass

The juvenile largemouth bass HSI scores increase across the middle estuary polygons under the Applicant's Preferred Alternative compared to the No Action Alternative for years 2020 through 2050 (see EIS Figure 4.10-19c). By 2060 and 2070, more than a +0.5 increase over the No Action Alternative is seen for polygon 8 at the Project outfall (see EIS Figure 4.10-19c). The increase in habitat suitability for bass is primarily due to reduced salinity through the middle estuary polygons, with increased chlorophyll A concentration and sustained marsh in the Project outfall, under the Applicant's Preferred Alternative. The increased HSI for largemouth bass occurs first across the middle estuary in the first 40 years of operation, and then at the Project outfall in later years, with increased chlorophyll A concentration (see Figure N1-11).

Eastern Oysters

The areal extent of suitable HSI scores for Eastern oysters are reduced by about half compared to the No Action Alternative under the Applicant's Preferred Alternative (see EIS Figure 4.10-13d). At the beginning of the Applicant's Preferred Alternative in 2020, suitable habitat scores are evident at the western side of Barataria Bay above the barrier islands, but as salinity is further reduced over time the only suitable oyster habitat that remains is along the barrier islands (see EIS Figure 4.10-20d and 4.10-22).

OTHER ALTERNATIVES

Table 4.10-7 in the EIS document shows HSI scores for brown shrimp, blue crab, and largemouth bass for six polygons by decadal year under the No Action Alternative, and the changes (+/-) in HSI scores for the 50,000 cfs Alternative, the Applicant's Preferred Alternative (75,000 cfs), and the 150,000 cfs Alternative. Polygons 8, 9, 10, 11, 12, and 16 were used to illustrate the changes in HSI scores from the No Action Alternative relative to the other operational alternatives. The polygons in Table 4.10-7 of the EIS form a swath across the middle and lower estuary and were used to compare changes in HSIs among the operational alternatives because they typically show the largest changes for the species. Brown shrimp, blue crab, and largemouth bass are used as examples to illustrate the small and usually incremental changes in the HSI results with increased operations (see EIS Table 4.10-7). These three species had the most detectable changes in the HSI scores for the Applicant's Preferred Alternative (see EIS Figures 4.10-16 and 4.10-19).

REFERENCES

Coastal Protection and Restoration Authority (CPRA). 2017. Louisiana's Comprehensive Master Plan for a Sustainable Coast. Available at: http://coastal.la.gov/a-common-vision/2017-coastal-master-plan/. Accessed April 2017.

Carruthers, T., H. Jung, A. McInnis, M. Bregman. 2019. Confidential Draft Technical Report - Aquatic Suitability Index Calculations for Mid-Barataria EIS. Submitted to the Coastal Protection and Restoration Authority by The Water Institute of the Gulf. May 10. 2019.

Foret, J. D., Nyman, J. A., Rozas, L. P., Rose, K. A., Cowan, J. H., & Baltz, D. (2003). Habitat use module. Ch.10 in Coastal Louisiana Ecosystem Assessment and Restoration (CLEAR) Model of Louisiana Coastal Area (LCA*)* *Comprehensive Ecosystem Restoration Plan. Volume I: Tasks 1–8.* Final Report to Department of Natural Resources, Coastal Restoration Division

Hijuelos, A. C., S. E. Sable, A. M. O' Connell, D. L. Lindquist, J. P. Geaghan, and E. White. 2016a. Developing Species Distribution Models to Identify Hot Spots in Estuarine Habitats. Estuaries and Coasts. doi:10.1007/s12237-016-0199-5

Hijuelos, A. C., Moss, L., Sable, S. E., O'Connell, A. M., and Geaghan, J. P. 2016b. 2017 Coastal Master Plan: C3-18 – Largemouth Bass, Micropterus salmoides, Habitat Suitability Index Model. Version II. (pp. 1-25). Baton Rouge, Louisiana: Coastal Protection and Restoration Authority.

Hijuelos, A. C., Sable, S. E., O'Connell, A. M., and Geaghan, J. P. 2016c. 2017 Coastal Master Plan: C3-12 – Eastern Oyster, Crassostrea virginica, Habitat

Suitability Index Model. Version II. (pp. 1-23). Baton Rouge, Louisiana: Coastal Protection and Restoration Authority.

Nyman, J.A., D.M. Baltz, M.D. Kaller, P.L. Leberg, C. Parsons Richards, R.P. Romaire, and T.M. Soniat. 2013. Likely changes in habitat quality for fish and wildlife in coastal Louisiana during the next 50 years. Journal of Coastal Research Special Issue 67:60-74. DOI: 10.2112/SI_67_5.

O'Connell, A. M., Hijuelos, A. C., Sable, S. E., and Geaghan, J. P. 2016a. 2017 Coastal Master Plan Modeling: C3-12 – Blue Crab, Callinectes sapidus, Habitat Suitability Index Model. Version II. (pp. 1-26). Baton Rouge, Louisiana: Coastal Protection and Restoration Authority.

O'Connell, A. M., Hijuelos, A. C., Sable, S. E., and Geaghan, J. P. 2016b. 2017 Coastal Master Plan: C3-13 – Brown Shrimp, Farfantepenaeus aztecus, Habitat Suitability Index Model. Version II. (pp. 1-34). Baton Rouge, Louisiana: Coastal Protection and Restoration Authority.

O'Connell, A. M., Hijuelos, A. C., Sable, S. E., and Geaghan, J. P. 2016c. 2017 Coastal Master Plan: C3-14 – White Shrimp, Litopenaeus setiferus, Habitat Suitability Index Model. Version II. (pp. 1-32). Baton Rouge, Louisiana: Coastal Protection and Restoration Authority.

Sable, S. E., Hijuelos, A. C., O'Connell, A. M., and Geaghan, J. P. 2016a. 2017 Coastal Master Plan: C3-17 – Bay Anchovy, Anchoa mitchilli, Habitat Suitability Index Model. Version II. (pp. 1-31). Baton Rouge, Louisiana: Coastal Protection and Restoration Authority.

Sable, S. E., Hijuelos, A. C., O'Connell, A. M., and Geaghan, J. P. 2017. 2017 Coastal Master Plan: Attachment C3-15: Gulf Menhaden, Brevoortia patronus, Habitat Suitability Index Models. Version Final. (pp. 1-30). Baton Rouge, Louisiana: Coastal Protection and Restoration Authority.

Sable, S. E., Hijuelos, A. C., O'Connell, A. M., and Geaghan, J. P. 2016b. 2017 Coastal Master Plan: C3-16 – Spotted Seatrout, Cynoscion nebulosus, Habitat Suitability Index Model. Version II. (pp. 1-29). Baton Rouge, Louisiana: Coastal Protection and Restoration Authority.

TWIG. 2019. Technical Memorandum: Hysteresis – Detailed Oyster Habitat Suitability Index Results for Mid-Barataria EIS. Prepared for CPRA.U.S. Fish and Wildlife Service (USFWS). 1980. Ecological Services Manual – Habitat as a Basis for Environmental Assessment. 101 ESM. Division of Ecological Services, USFWS, Department of the Interior.

Salinity Time Series
Applicant's Preferred Alternative

Appendix N-1 – Aquatic Resources

Salinity Time Series

Applicant's Preferred Alternative

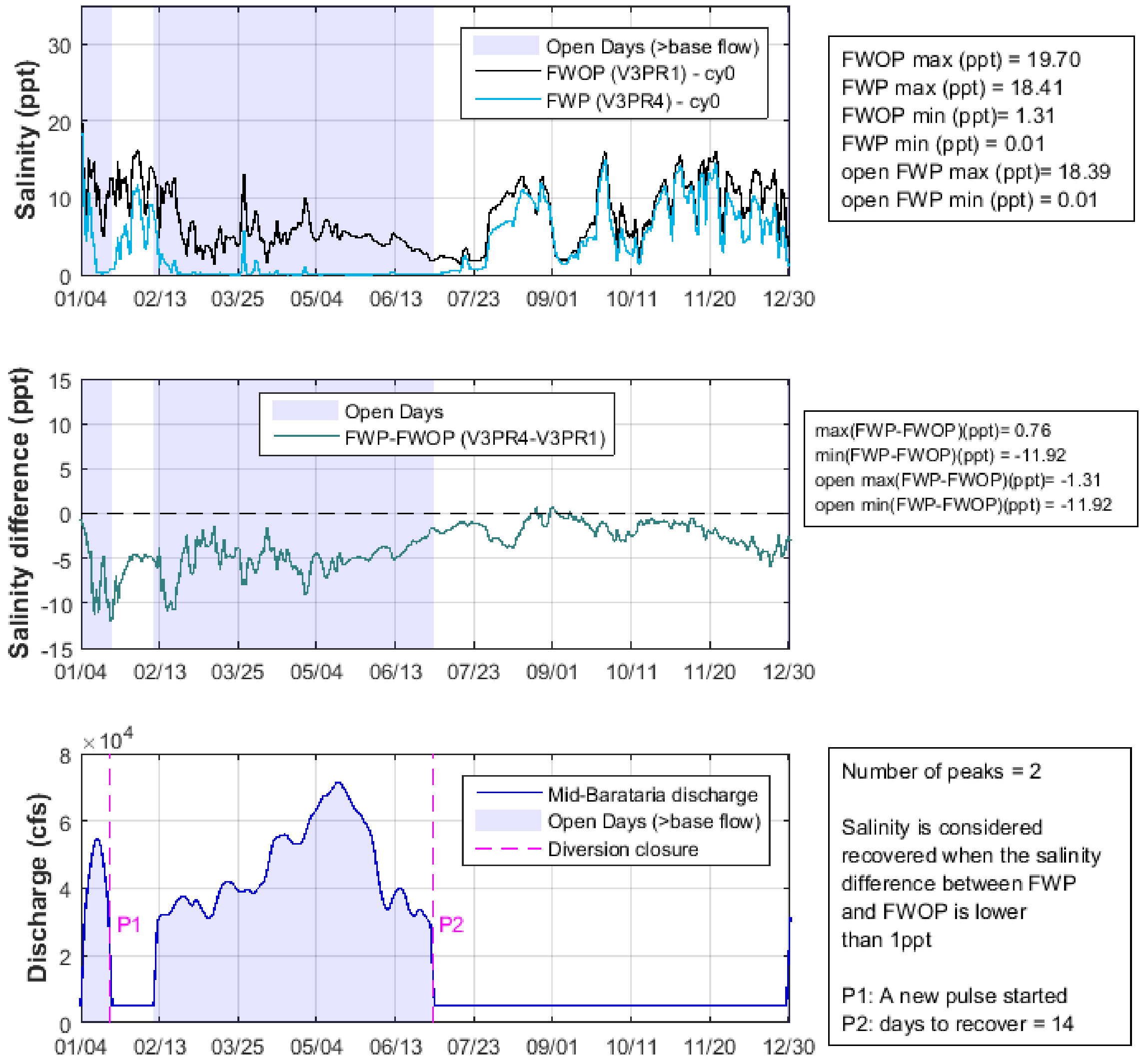


Figure 1a: Barataria Bay North of Grand Isle.

Applicant's Preferred Alternative – Years 2020-2029

*Diversion Scenario V3PR4, cycle 0 – FWP 75,000 cfs

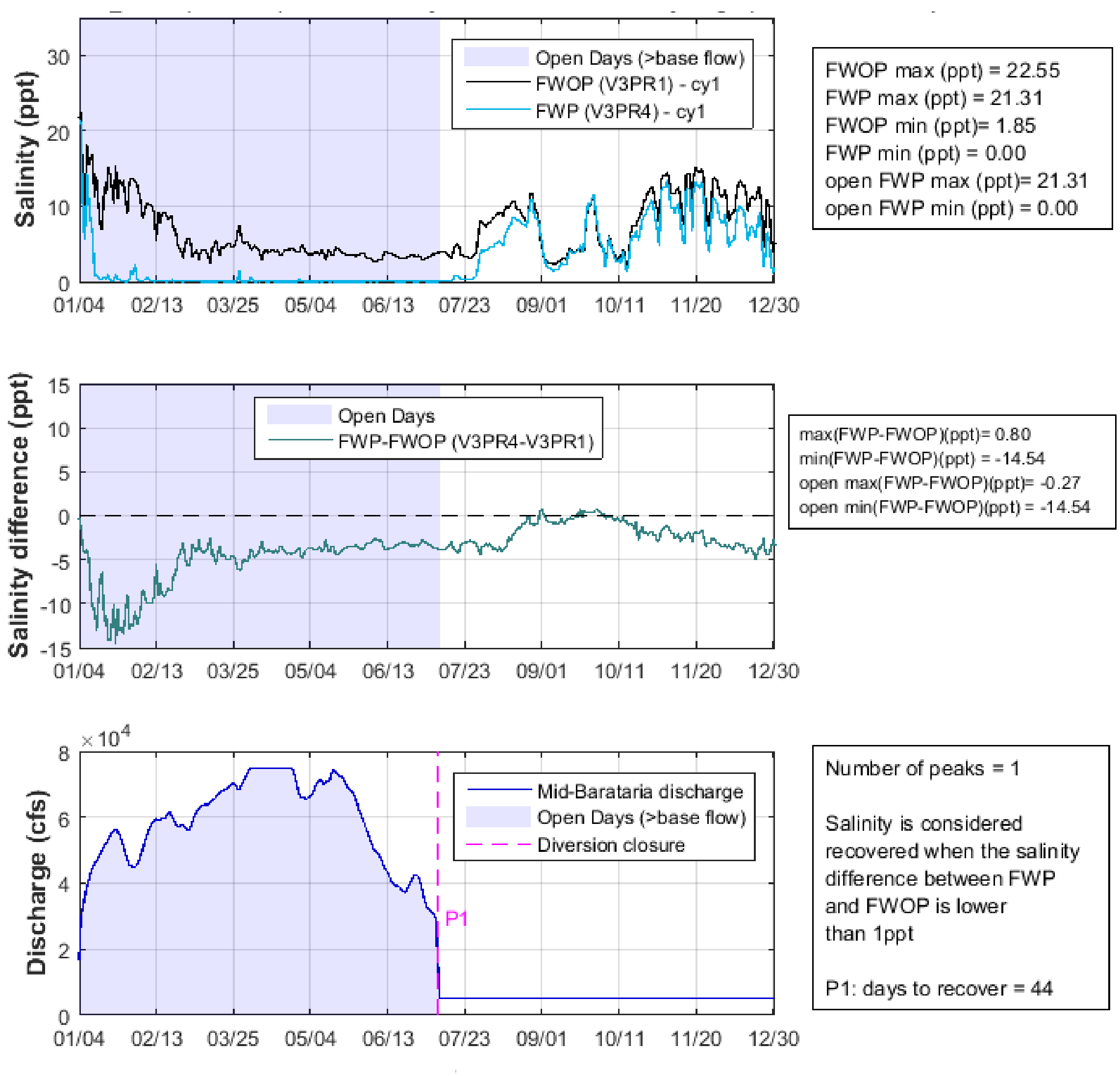


Figure 1b: Barataria Bay North of Grand Isle.

Applicant's Preferred Alternative – Years 2030-2039

*Diversion Scenario V3PR4, cycle 1 – FWP 75,000 cfs

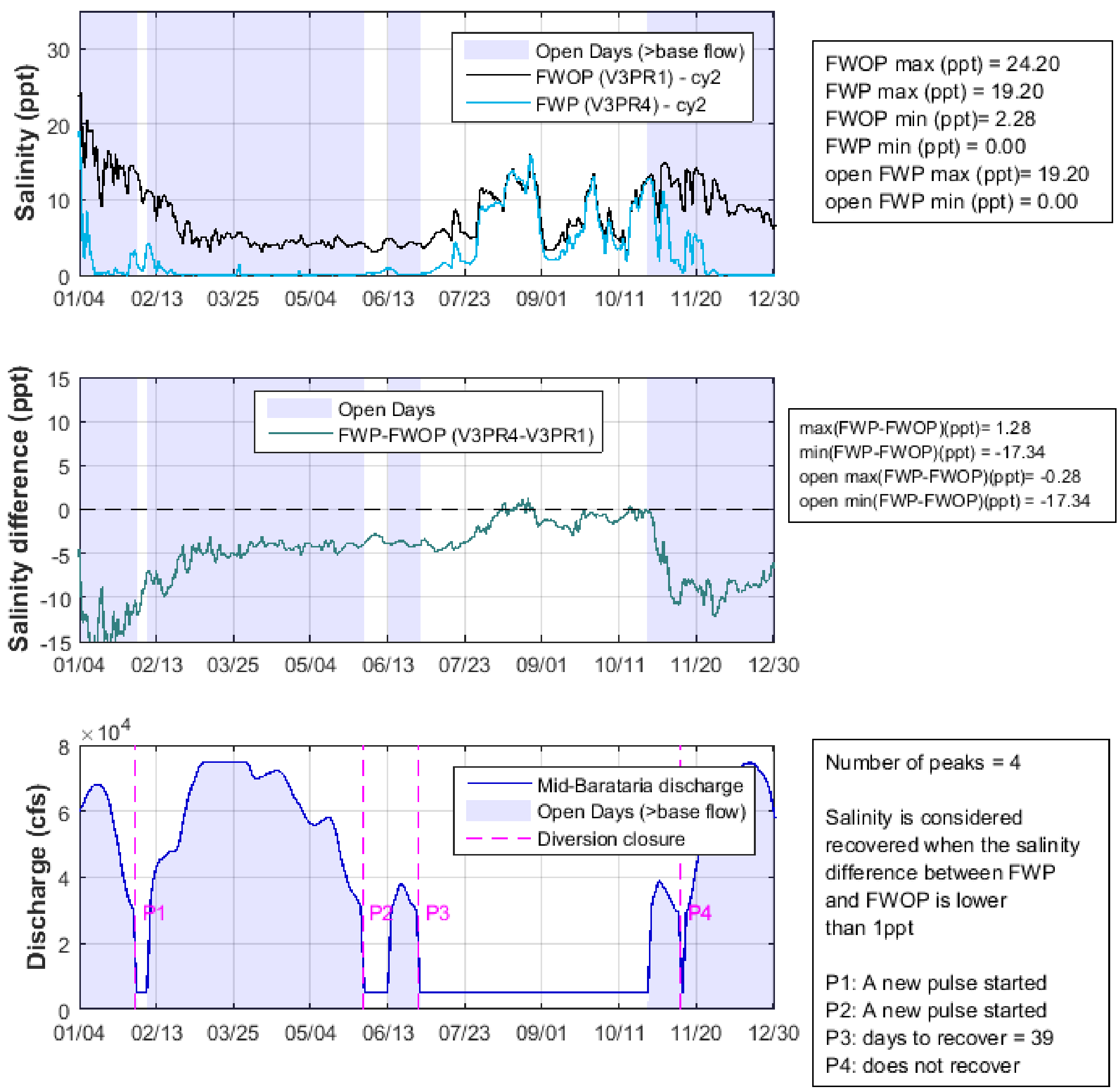


Figure 1c: Barataria Bay North of Grand Isle.

Applicant's Preferred Alternative – Years 2040-2049

*Diversion Scenario V3PR4, cycle 2 – FWP 75,000 cfs

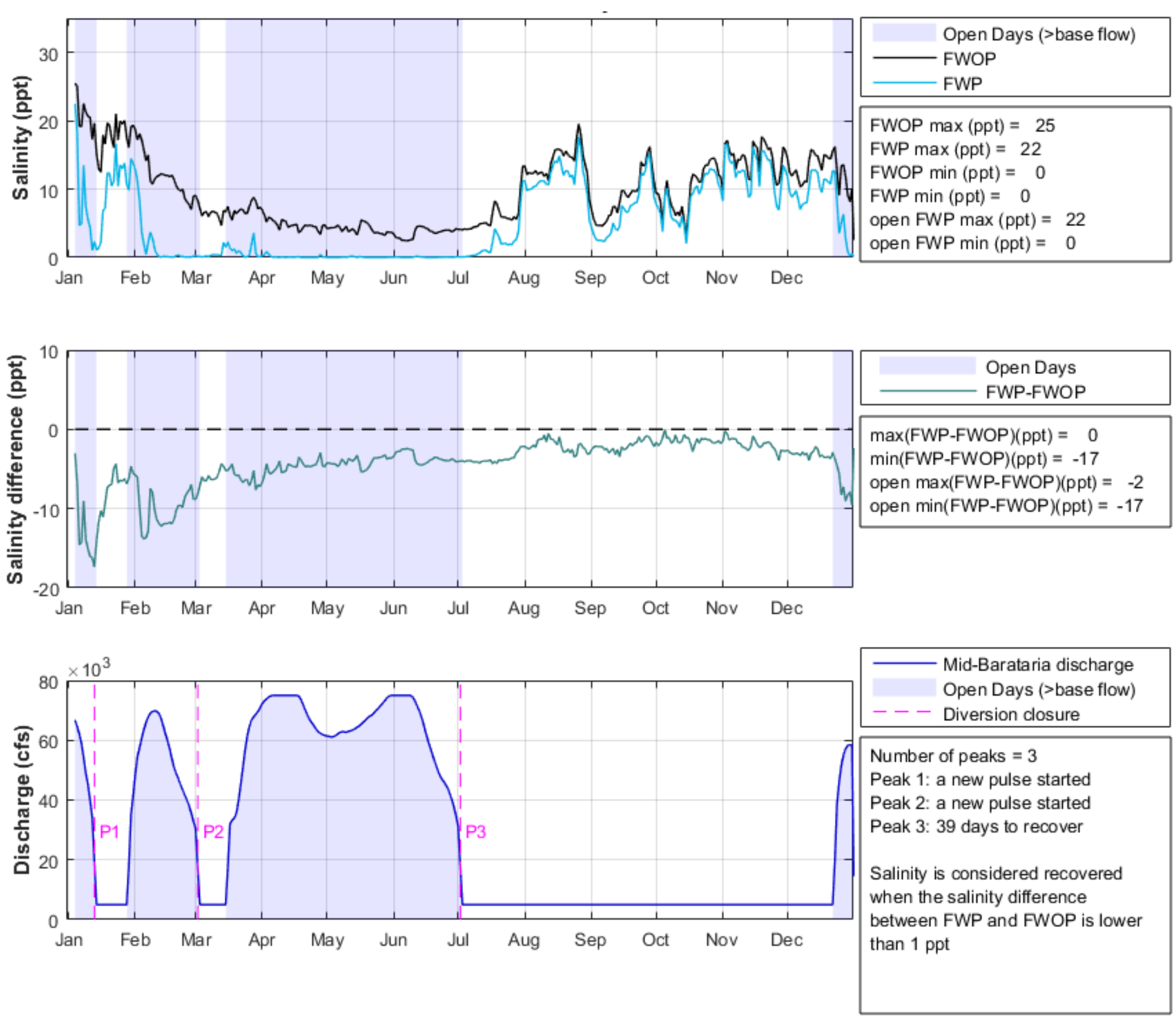


Figure 1d: Barataria Bay North of Grand Isle.

Applicant's Preferred Alternative – Years 2050-2059

*Diversion Scenario V3PR4, cycle 3 – FWP 75,000 cfs

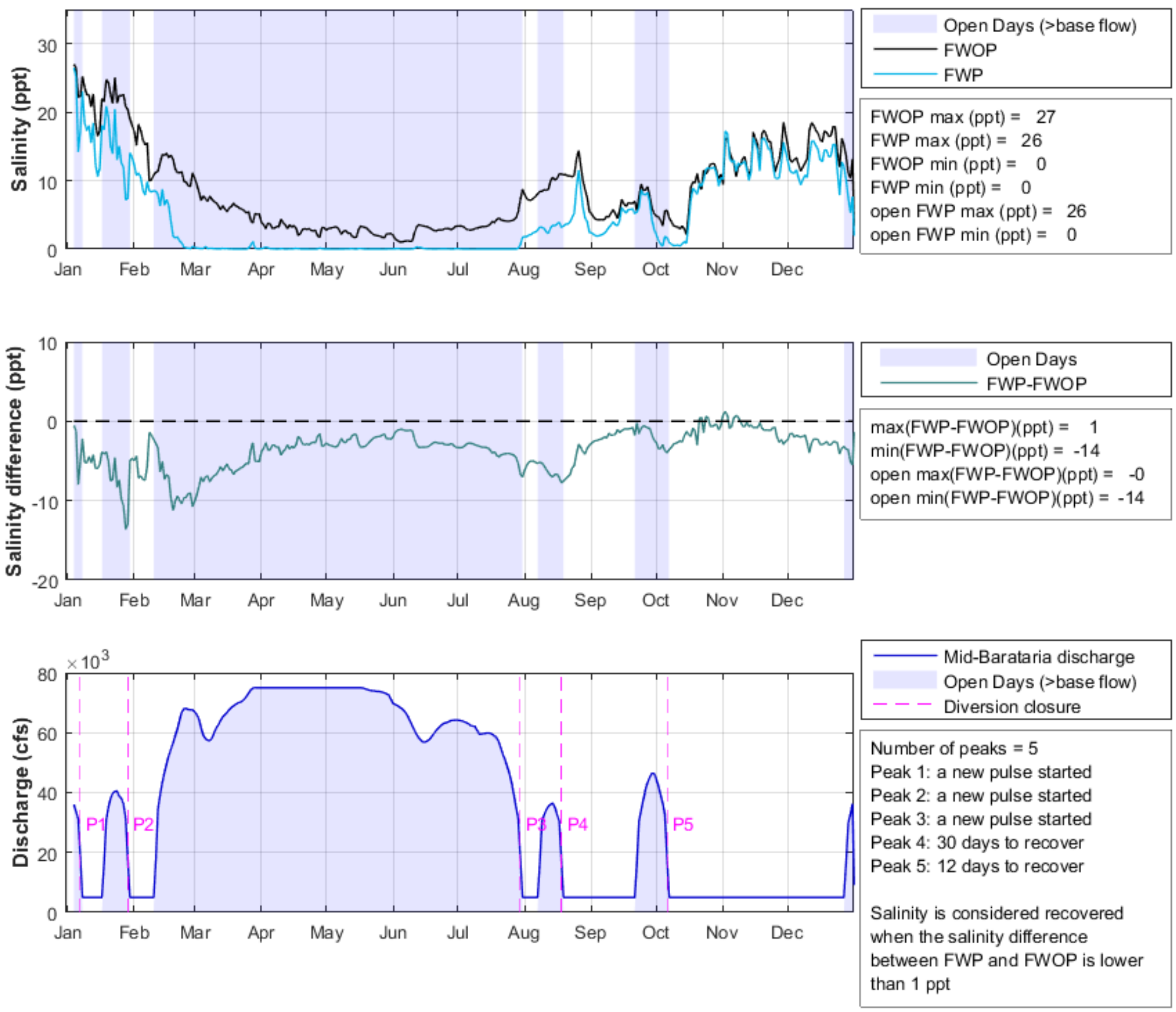


Figure 1e: Barataria Bay North of Grand Isle.

Applicant's Preferred Alternative – Years 2060-2069

*Diversion Scenario V3PR4, cycle 4 – FWP 75,000 cfs

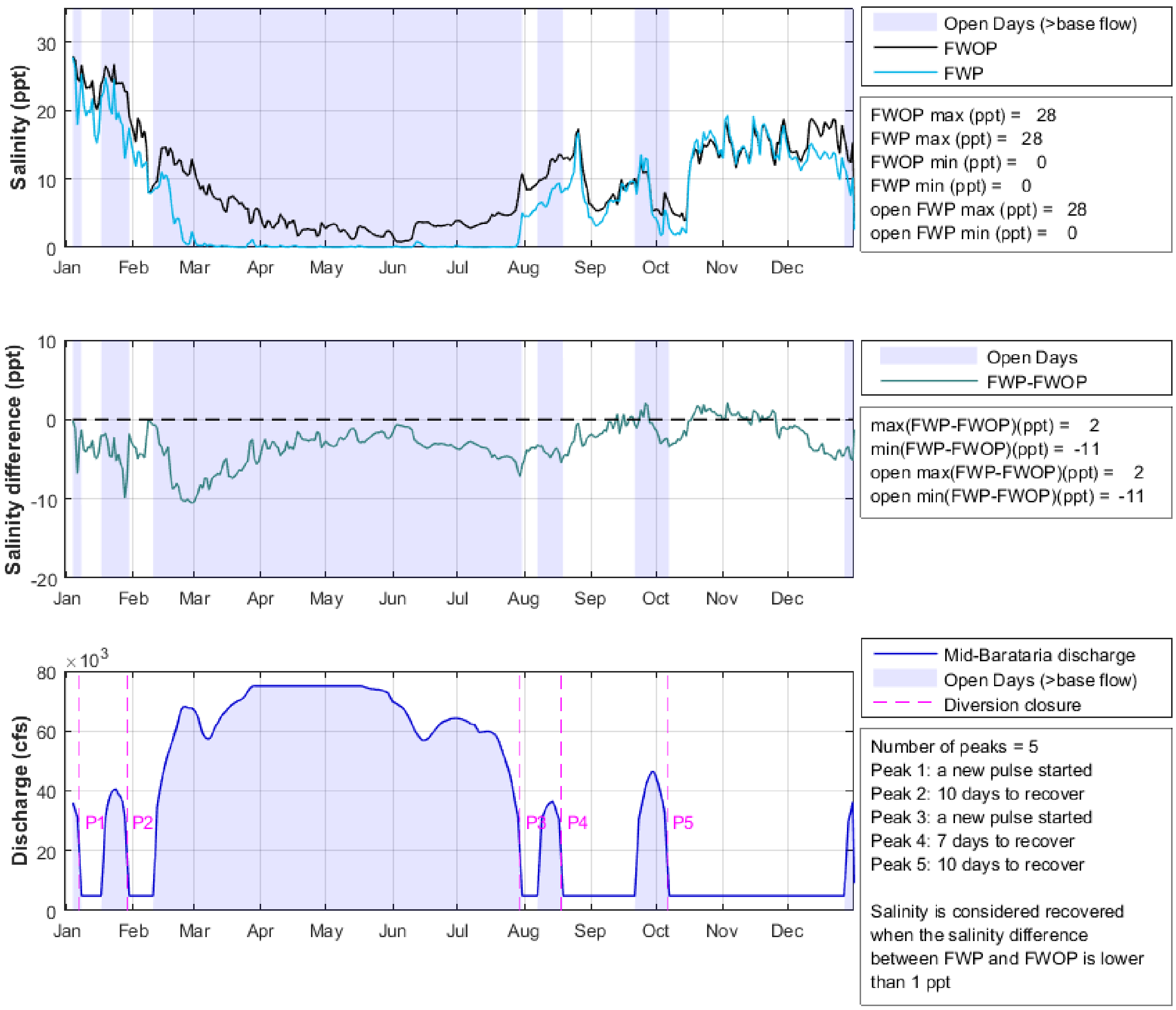


Figure 1f: Barataria Bay North of Grand Isle.

Applicant's Preferred Alternative – Year 2070

*Diversion Scenario V3PR4, cycle 5 – FWP 75,000 cfs

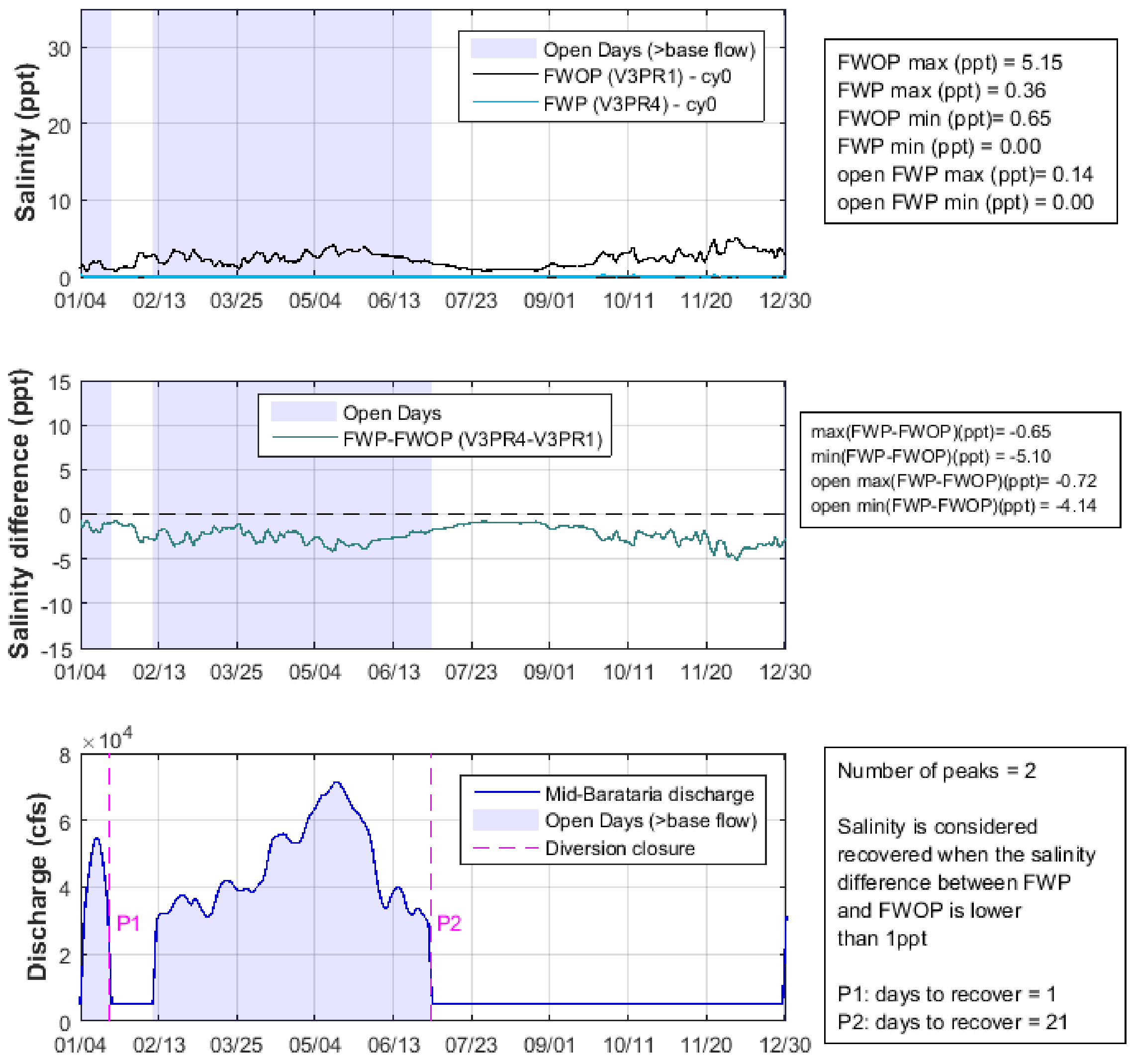


Figure 2a: HWQ08

Applicant's Preferred Alternative – Years 2020-2029

*Diversion Scenario V3PR4, cycle 0 – FWP 75,000 cfs

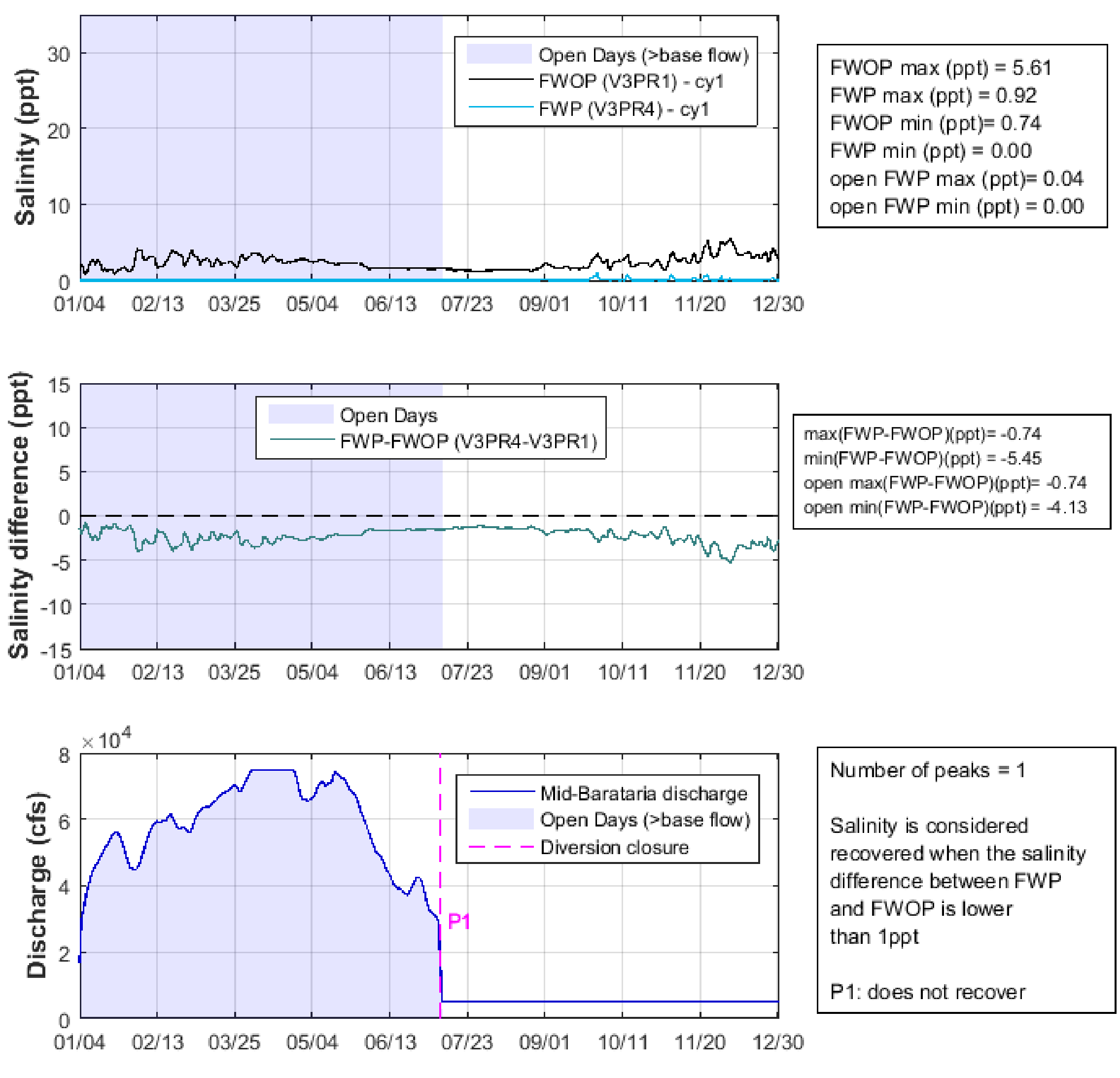


Figure 2b: HWQ08

Applicant's Preferred Alternative – Years 2030-2039

*Diversion Scenario V3PR4, cycle 1 – FWP 75,000 cfs

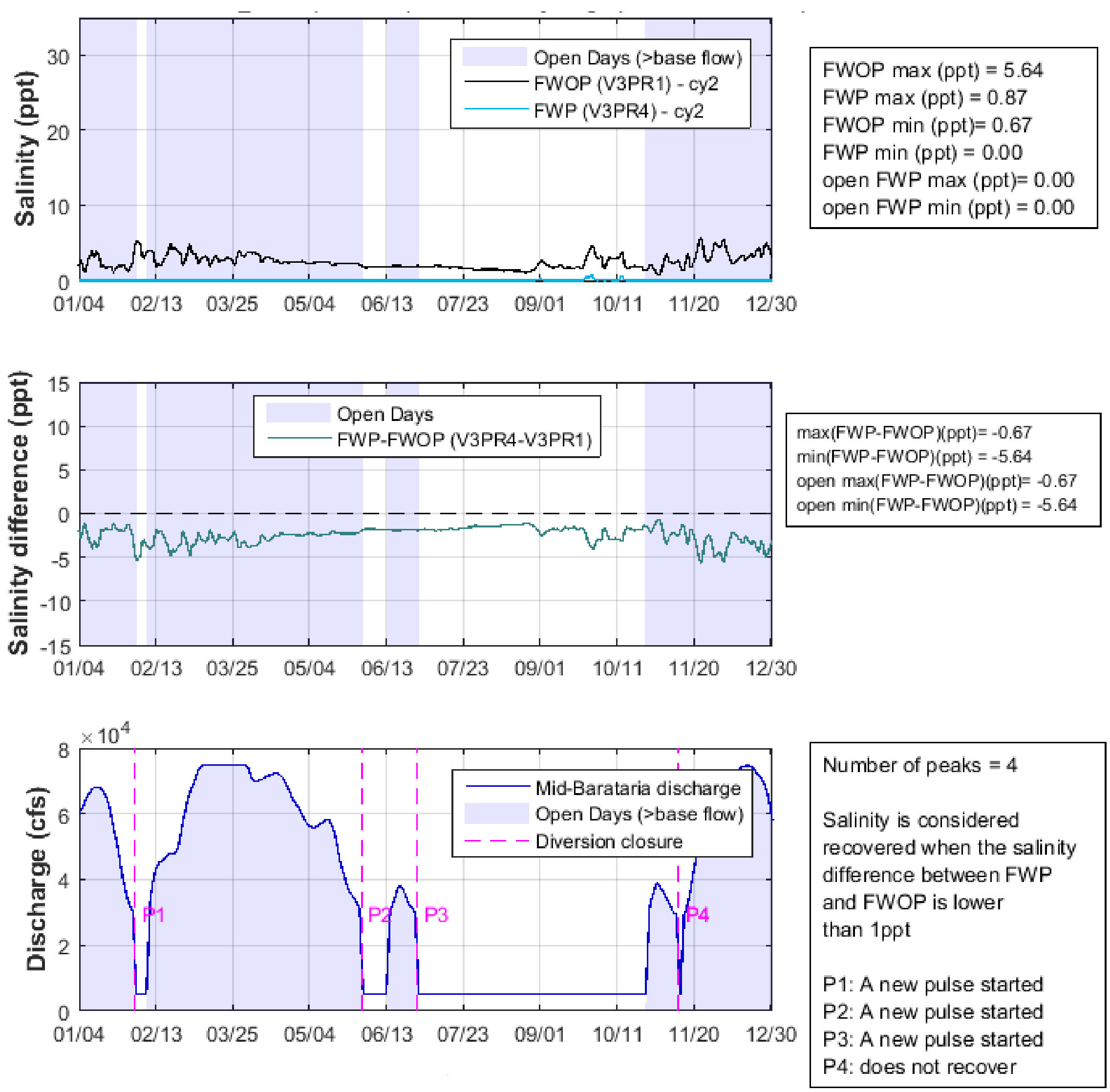


Figure 2c: HWQ08

Applicant's Preferred Alternative – Years 2040-2049

*Diversion Scenario V3PR4, cycle 2 – FWP 75,000 cfs

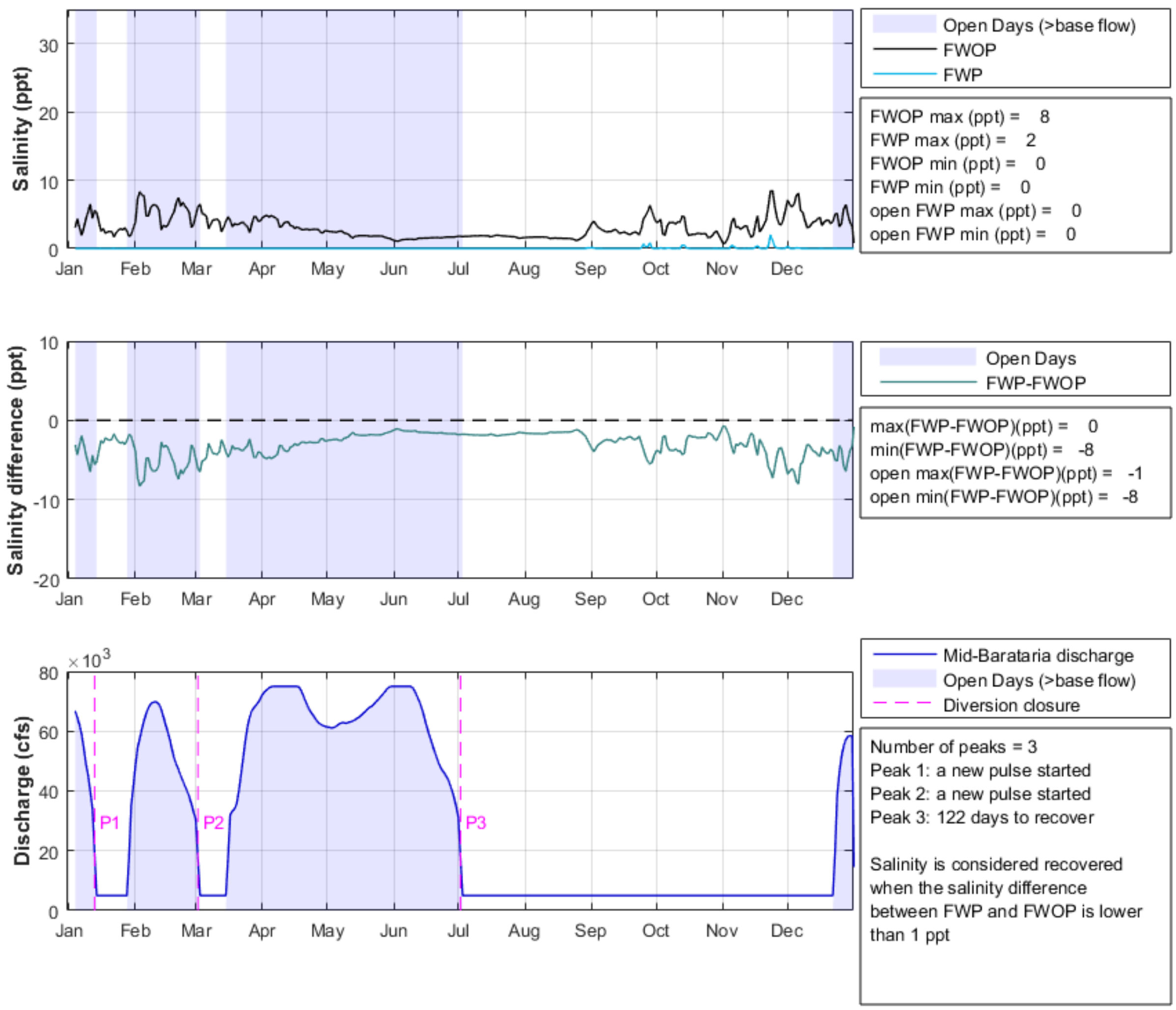


Figure 2d: HWQ08

Applicant's Preferred Alternative – Years 2050-2059

*Diversion Scenario V3PR4, cycle 3 – FWP 75,000 cfs

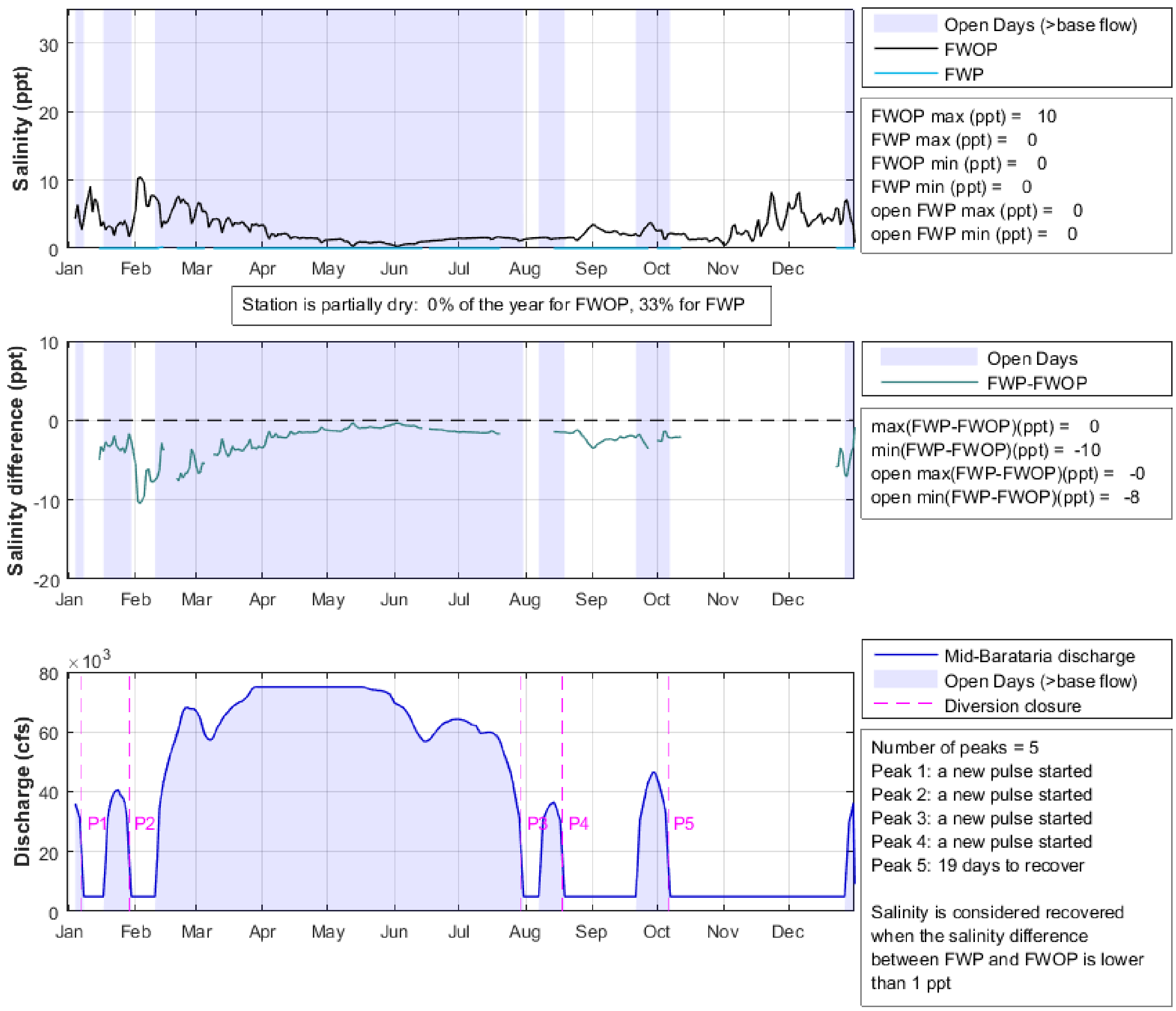


Figure 2e: HWQ08

Applicant's Preferred Alternative – Years 2060-2069

*Diversion Scenario V3PR4, cycle 4 – FWP 75,000 cfs

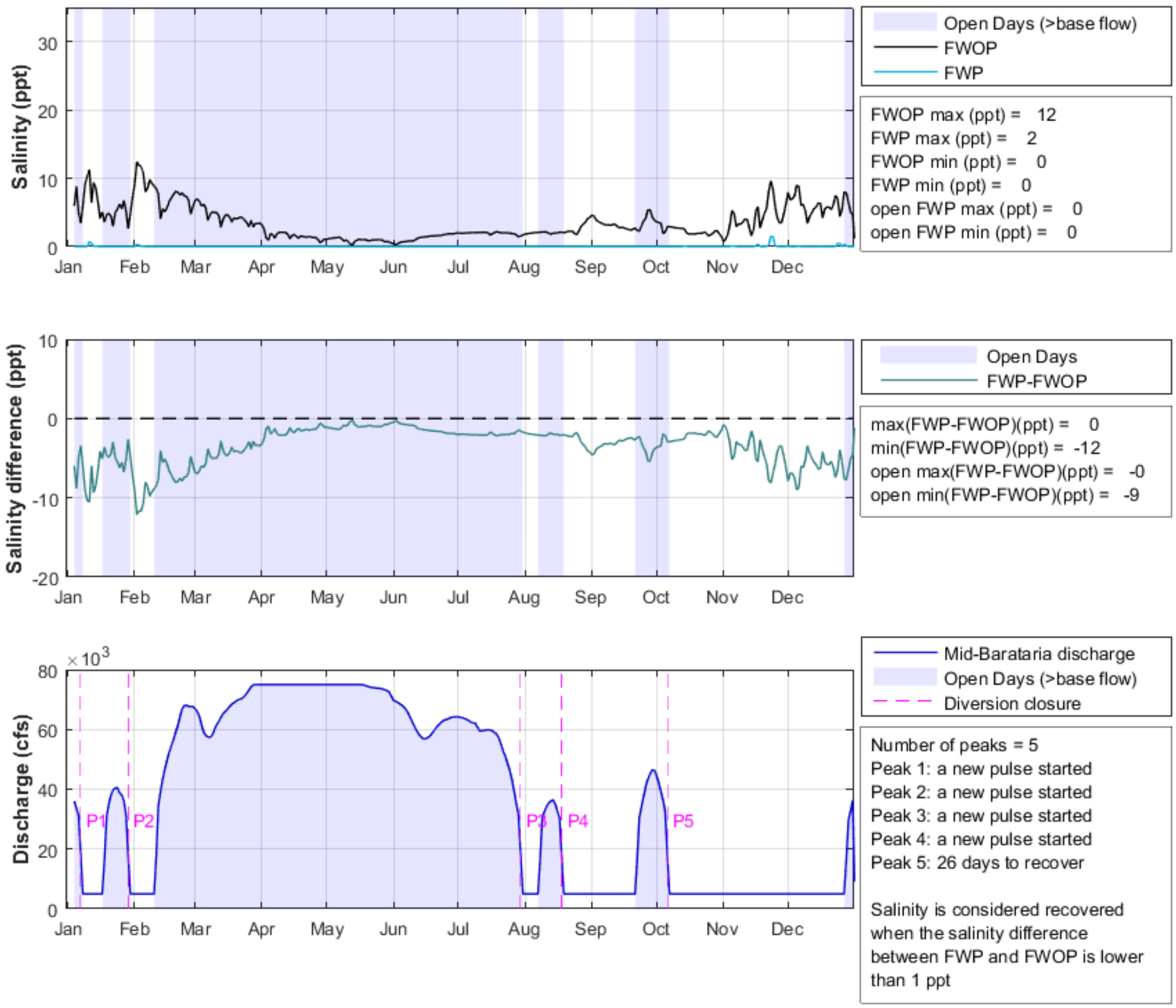


Figure 2f: HWQ08

Applicant's Preferred Alternative – Year 2070

*Diversion Scenario V3PR4, cycle 5 – FWP 75,000 cfs

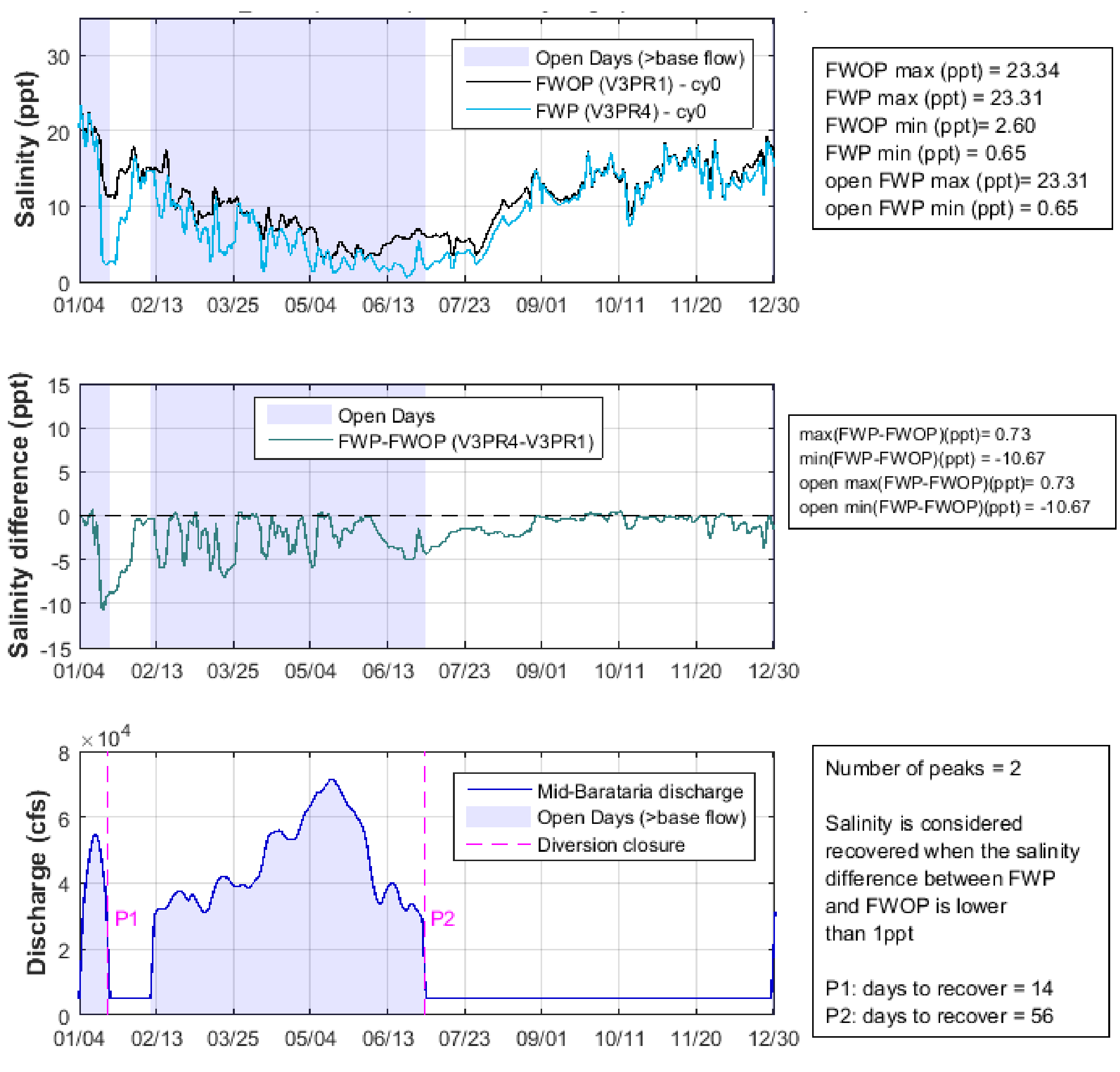


Figure 3a: HWQ14

Applicant's Preferred Alternative – Years 2020-2029

*Diversion Scenario V3PR4, cycle 0 – FWP 75,000 cfs

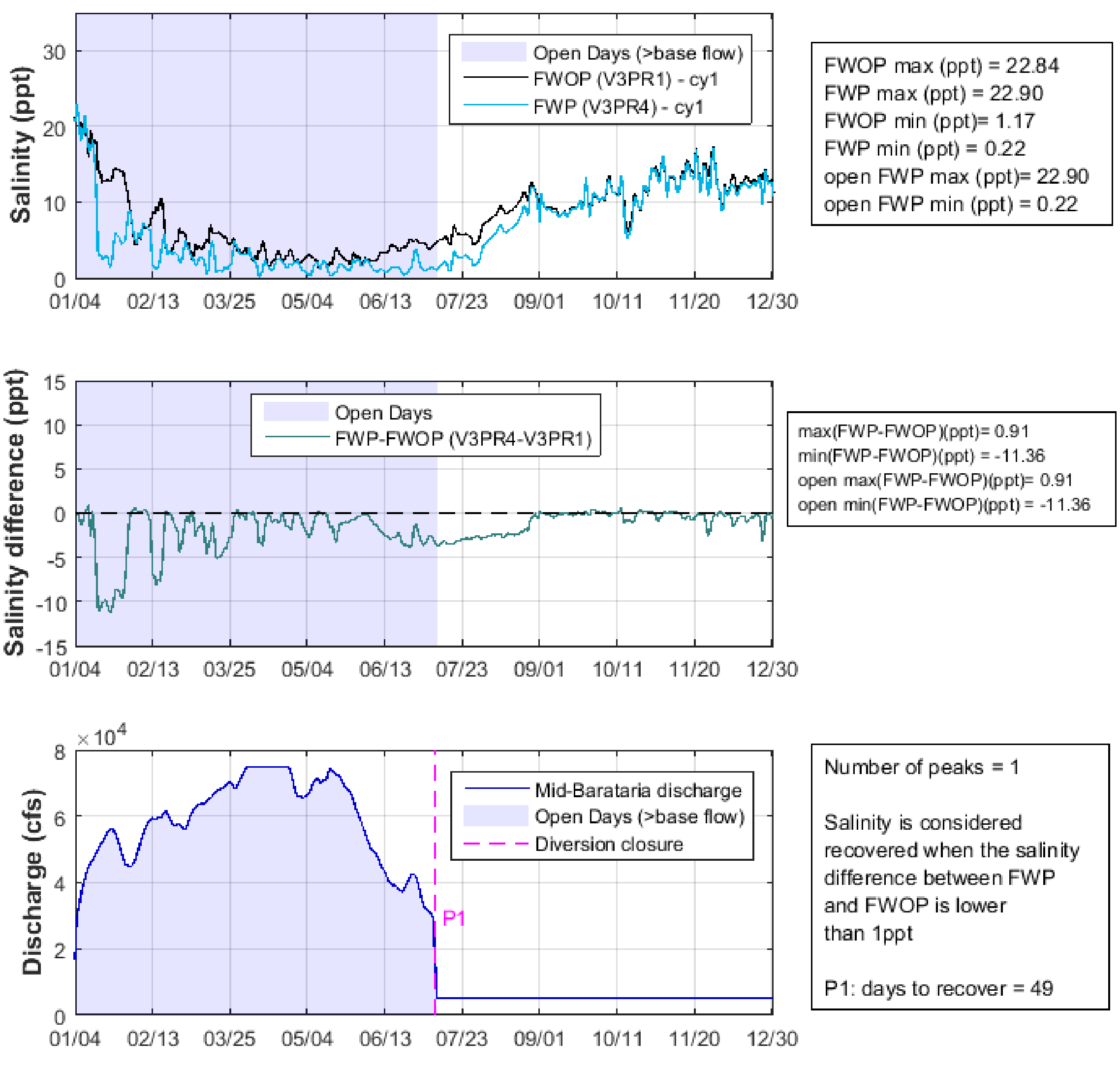


Figure 3b: HWQ14

Applicant's Preferred Alternative – Years 2030-2039

*Diversion Scenario V3PR4, cycle 1 – FWP 75,000 cfs

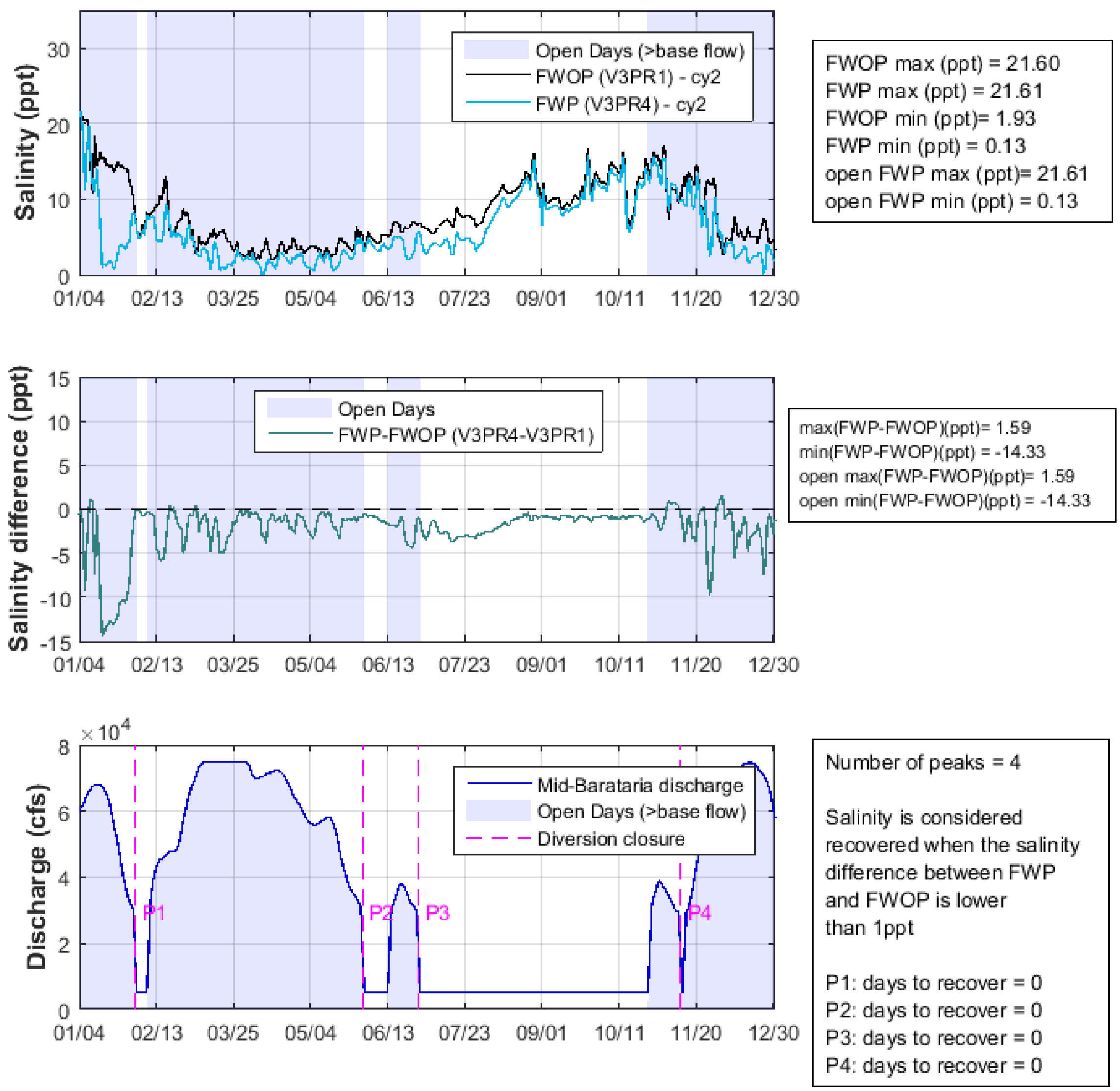


Figure 3c: HWQ14

Applicant's Preferred Alternative – Years 2040-2049

*Diversion Scenario V3PR4, cycle 2 – FWP 75,000 cfs

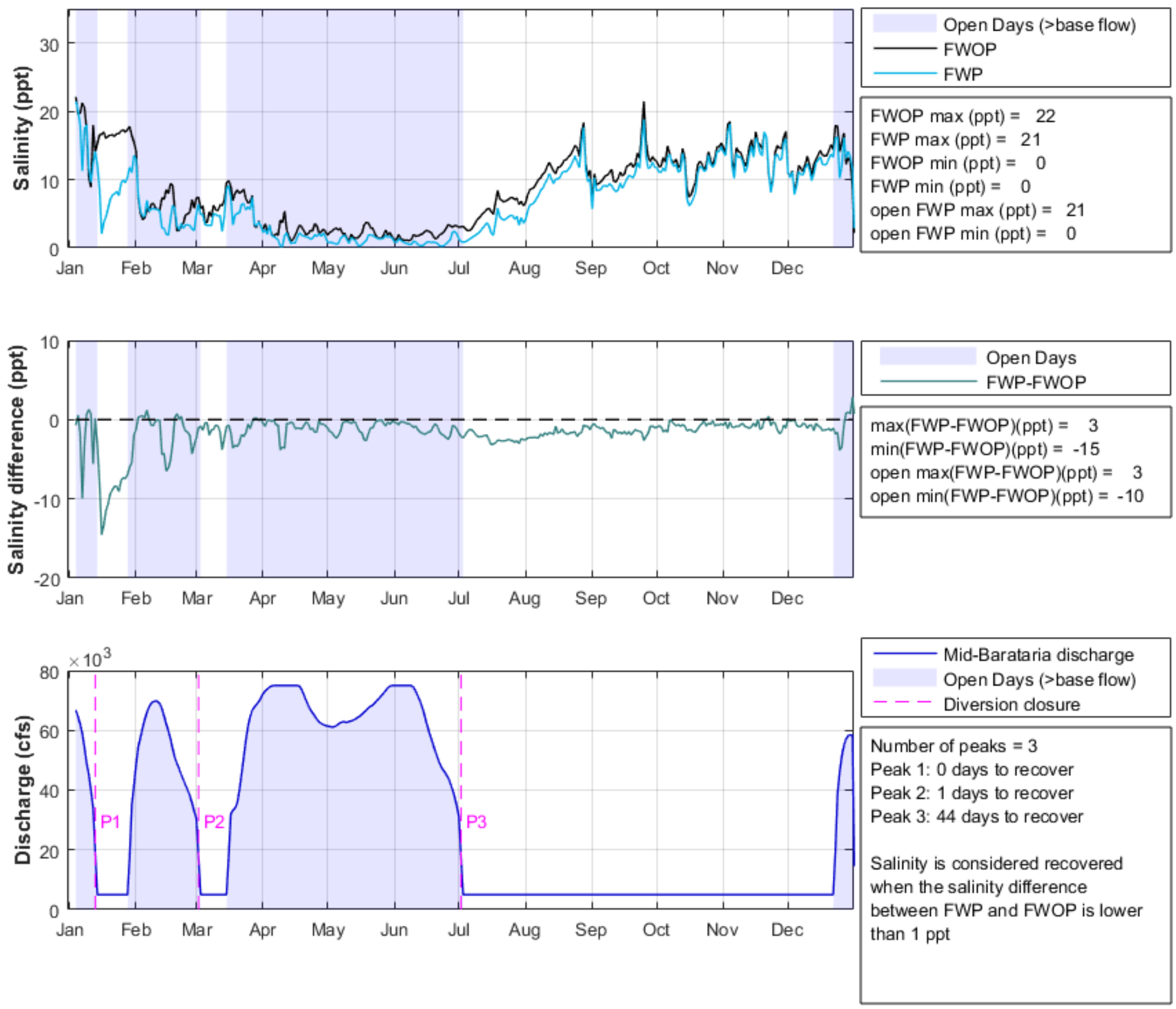


Figure 3d: HWQ14

Applicant's Preferred Alternative – Years 2050-2059

*Diversion Scenario V3PR4, cycle 3 – FWP 75,000 cfs

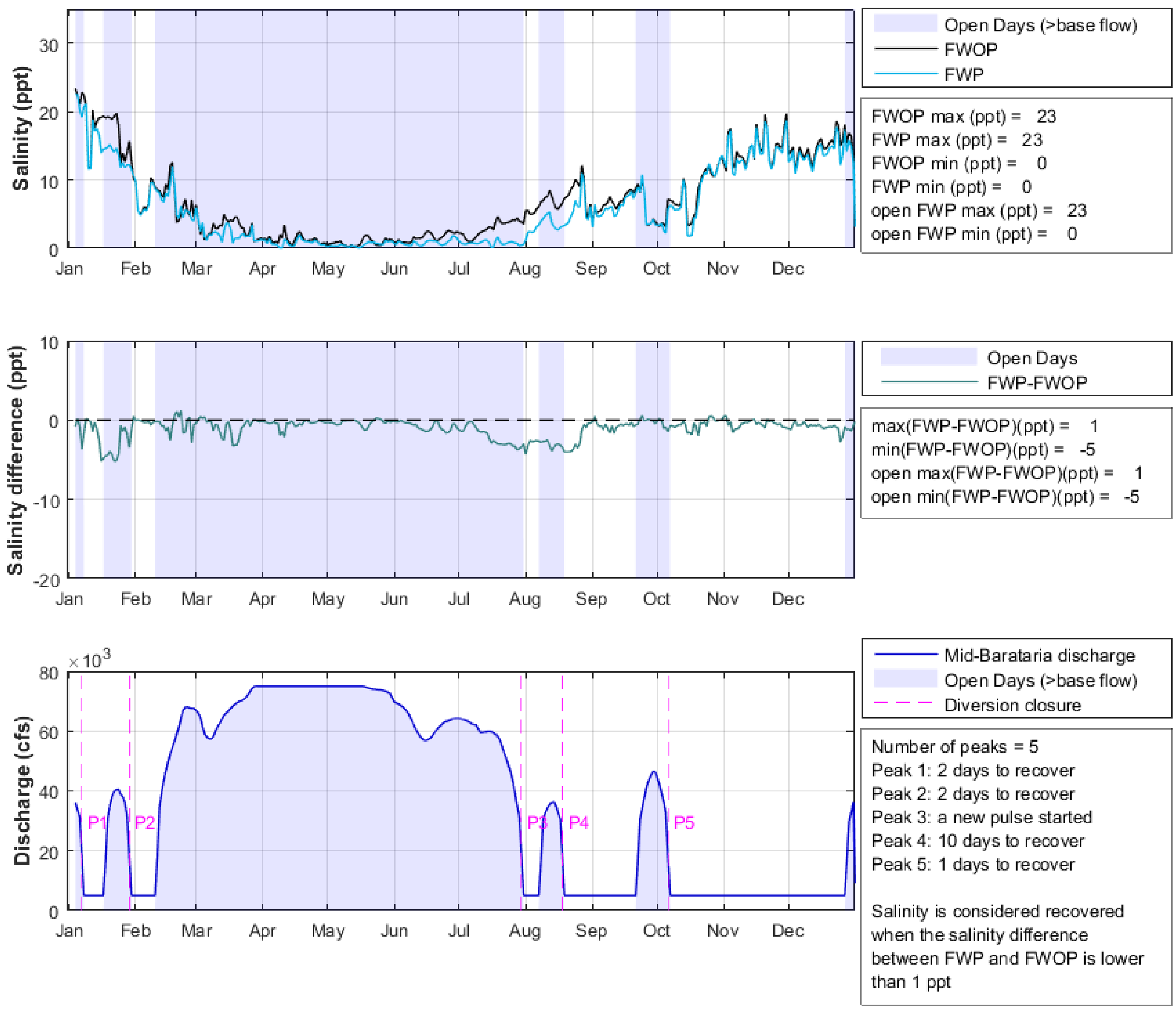


Figure 3e: HWQ14

Applicant's Preferred Alternative – Years 2060-2069

*Diversion Scenario V3PR4, cycle 4 – FWP 75,000 cfs

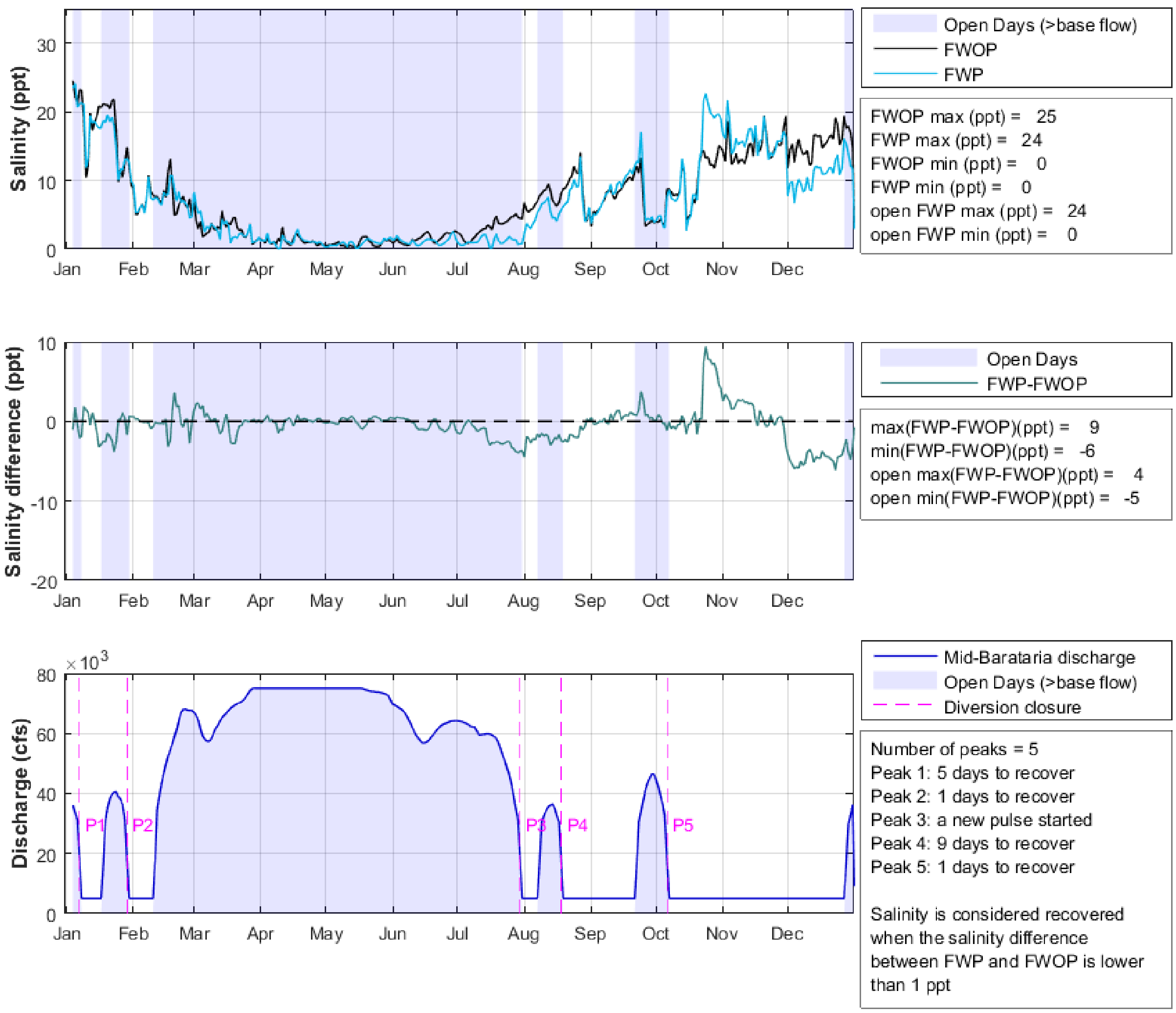


Figure 3f: HWQ14

Applicant's Preferred Alternative – Year 2070

*Diversion Scenario V3PR4, cycle 5 – FWP 75,000 cfs

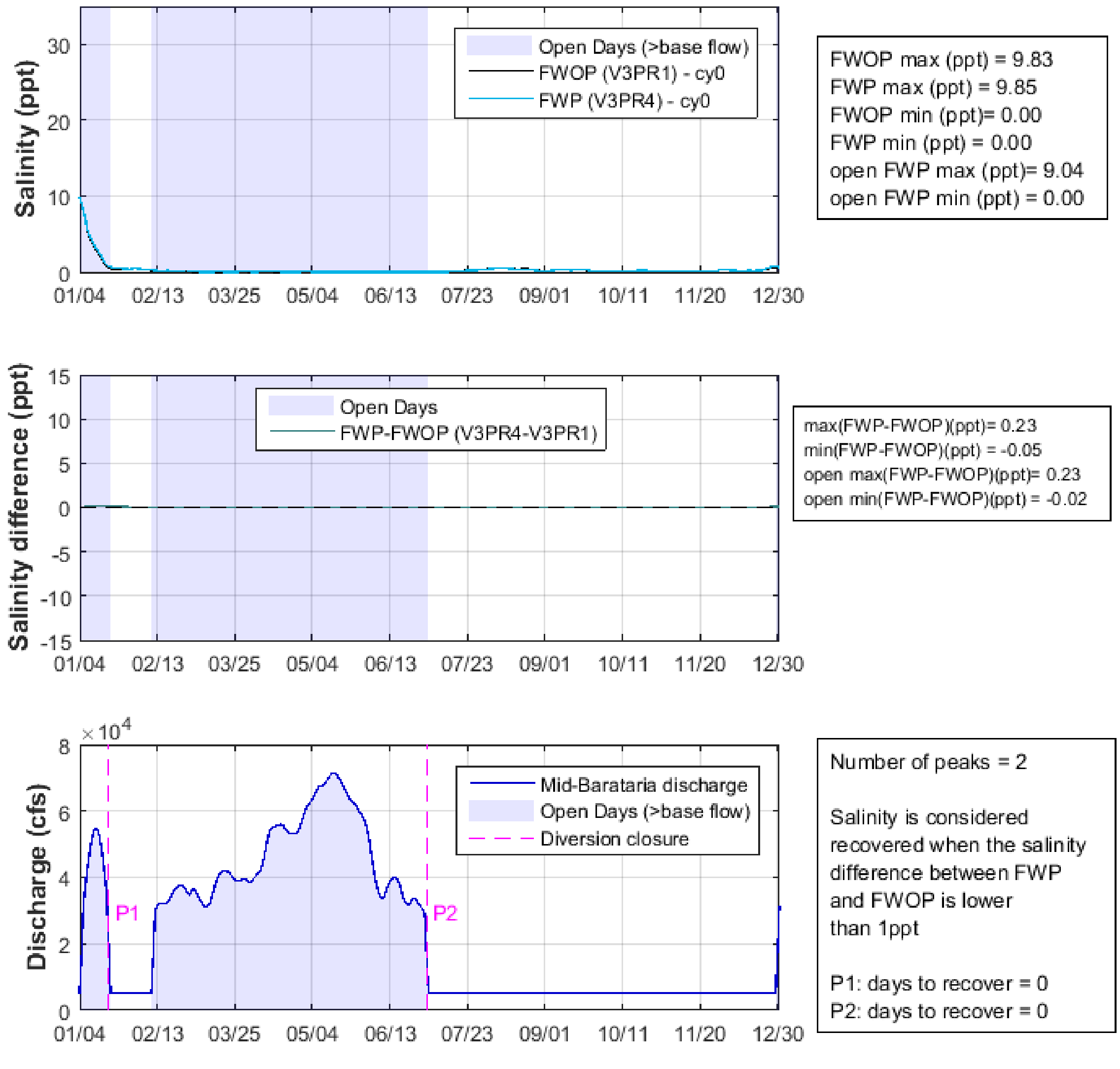


Figure 4a: HWQ16

Applicant's Preferred Alternative – Years 2020-2029

*Diversion Scenario V3PR4, cycle 0 – FWP 75,000 cfs

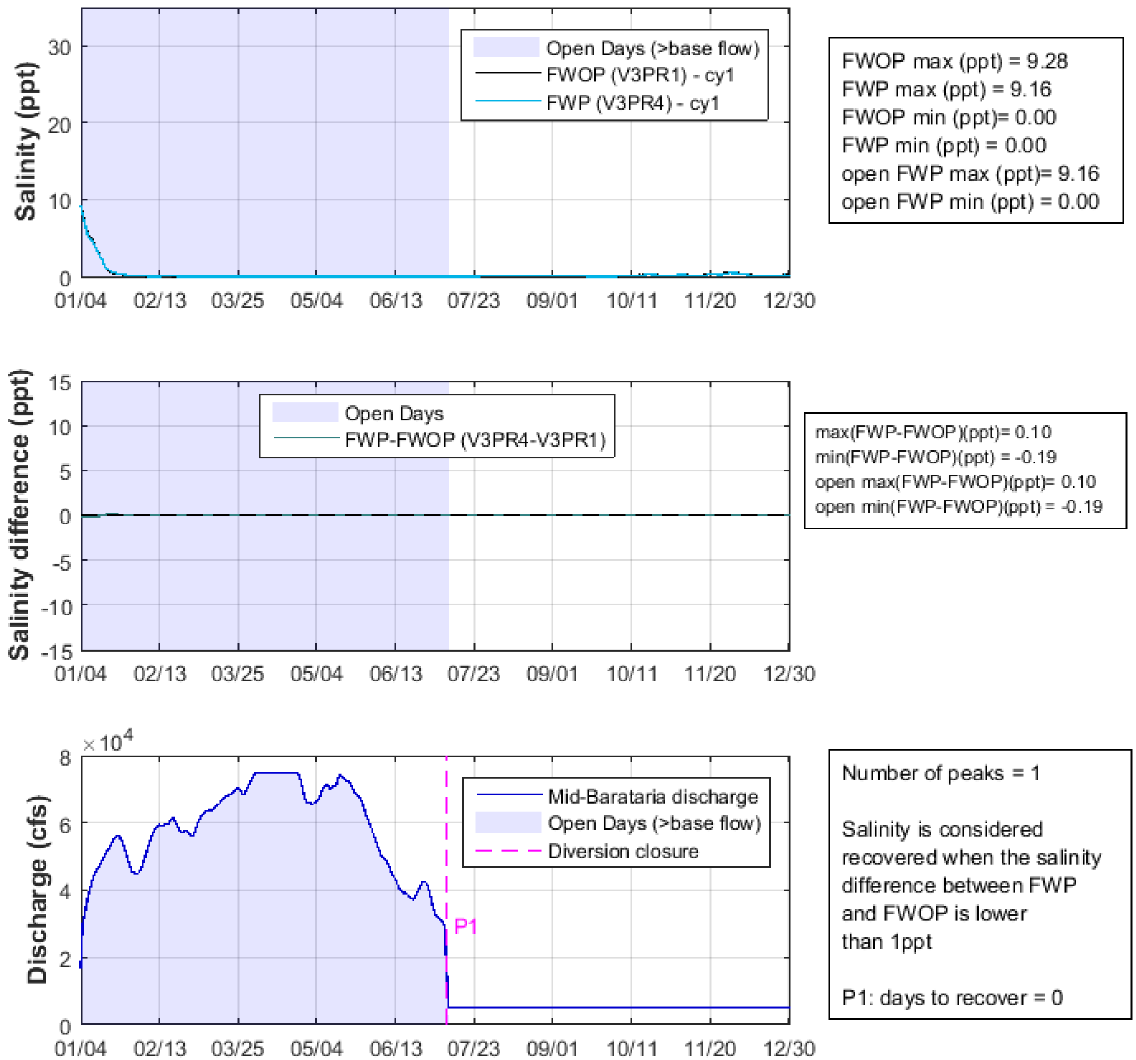


Figure 4b: HWQ16

Applicant's Preferred Alternative – Years 2030-2039

*Diversion Scenario V3PR4, cycle 1 – FWP 75,000 cfs

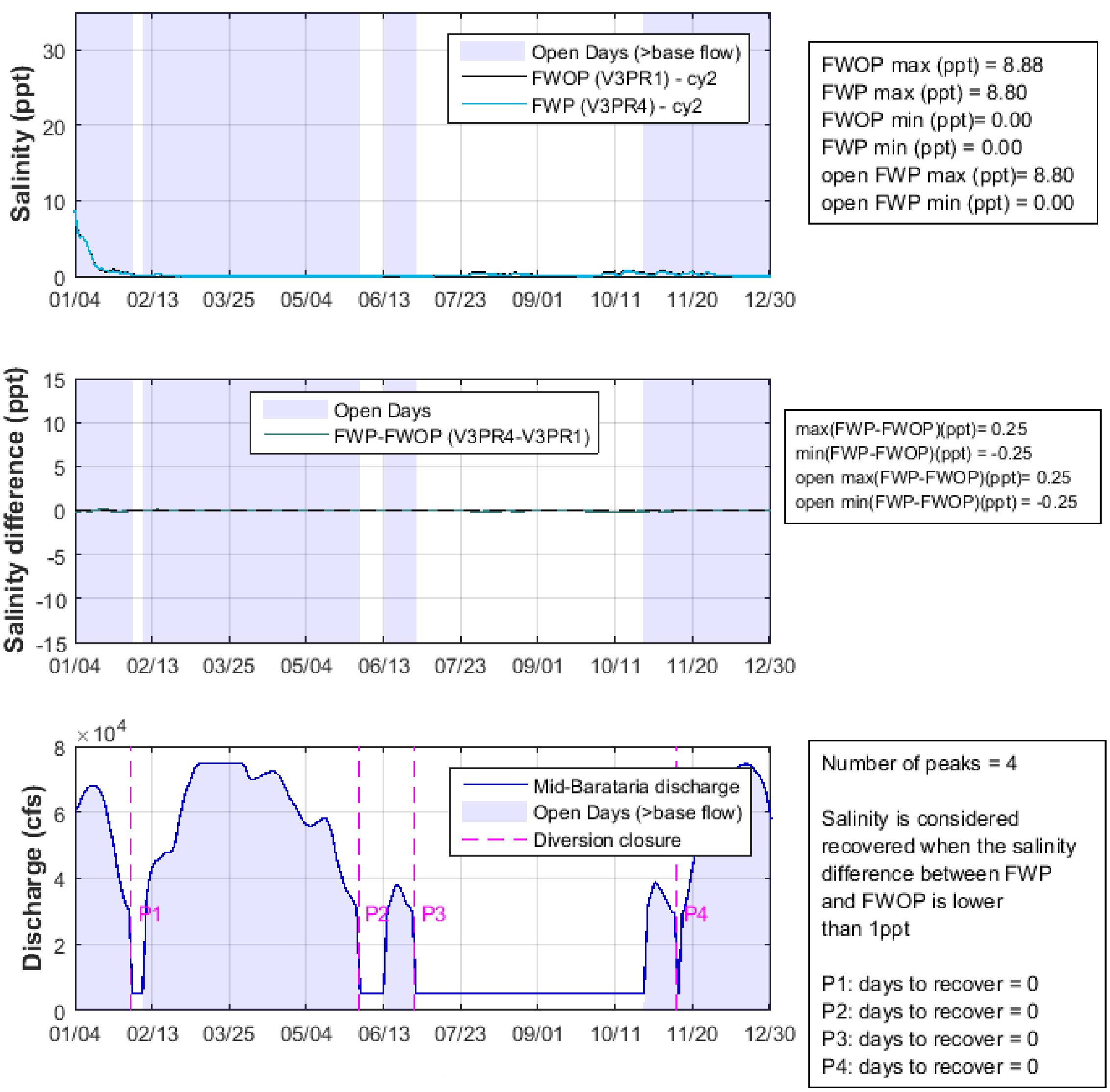


Figure 4c: HWQ16

Applicant's Preferred Alternative – Years 2040-2049

*Diversion Scenario V3PR4, cycle 2 – FWP 75,000 cfs

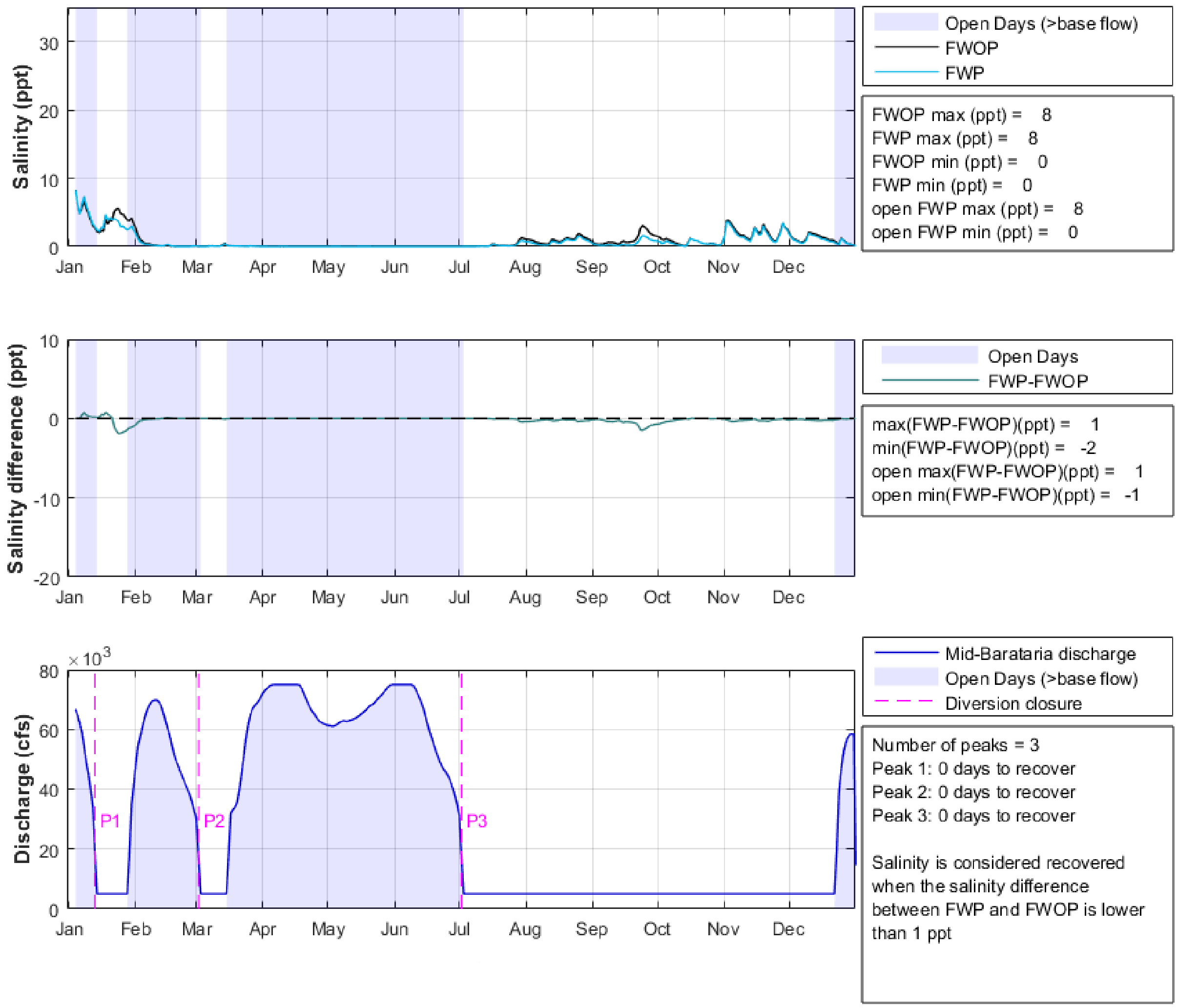


Figure 4d: HWQ16

Applicant's Preferred Alternative – Years 2050-2059

*Diversion Scenario V3PR4, cycle 3 – FWP 75,000 cfs

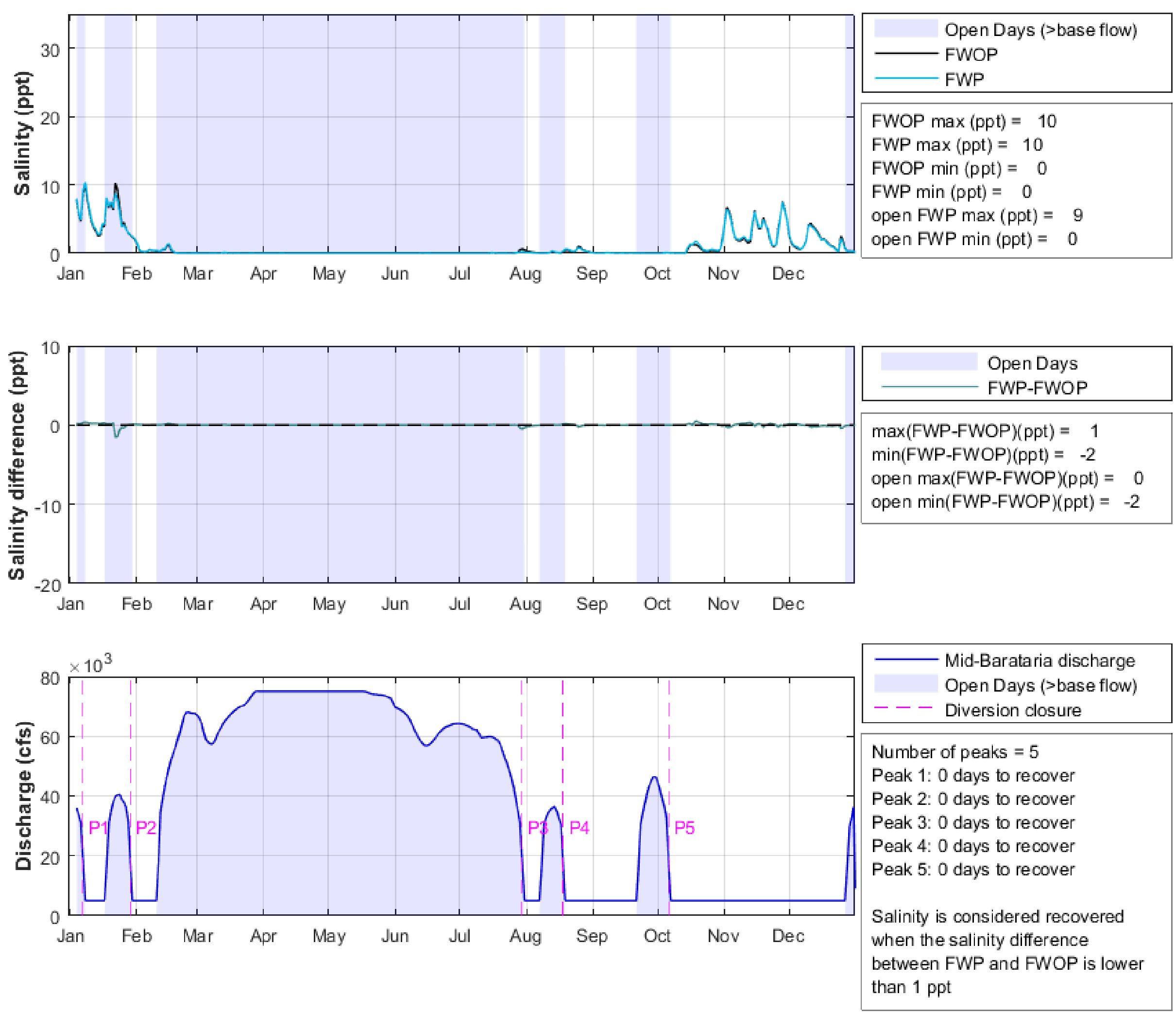


Figure 4e: HWQ16

Applicant's Preferred Alternative – Years 2060-2069

*Diversion Scenario V3PR4, cycle 4 – FWP 75,000 cfs

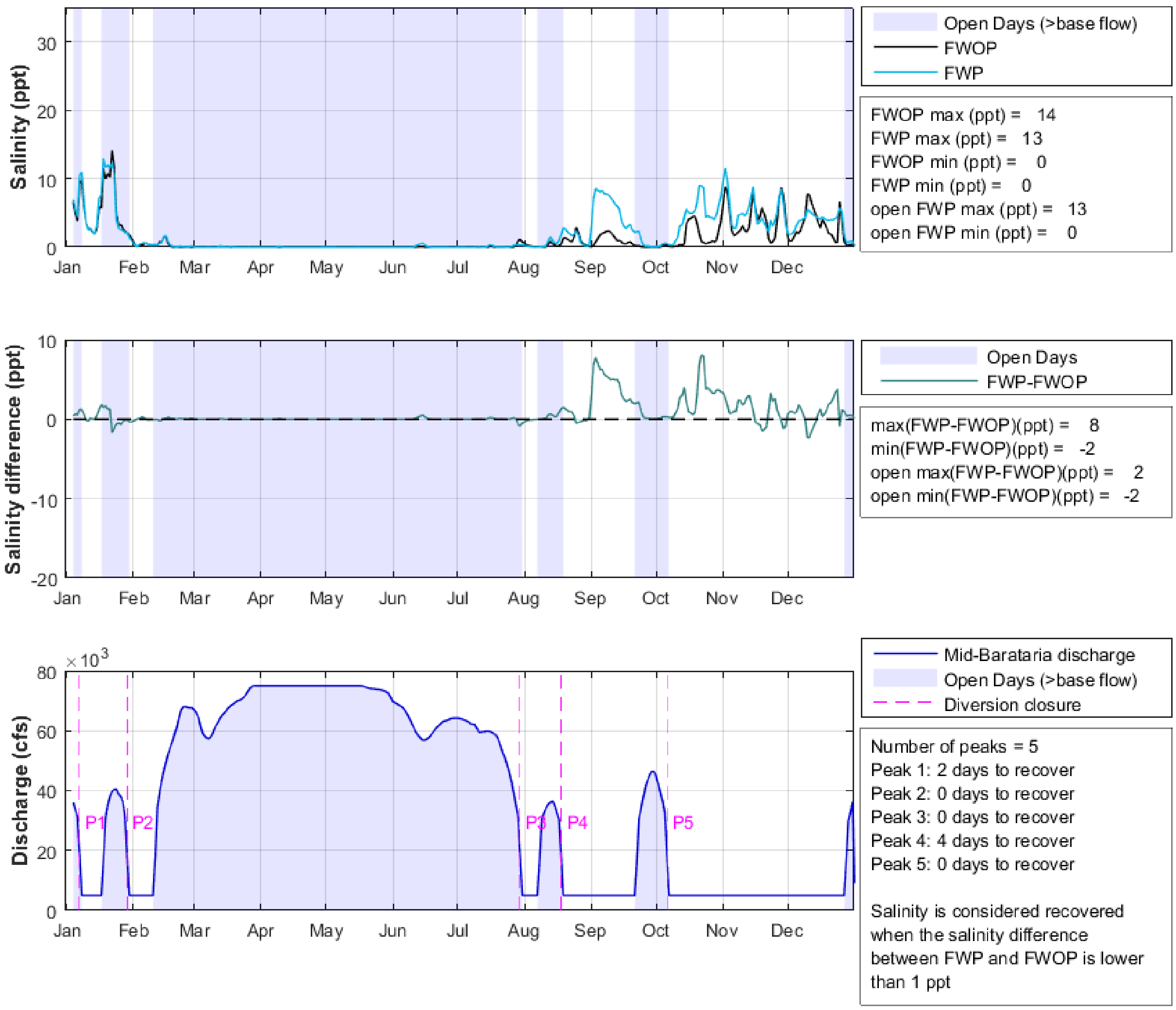


Figure 4f: HWQ16

Applicant's Preferred Alternative – Year 2070

*Diversion Scenario V3PR4, cycle 5 – FWP 75,000 cfs

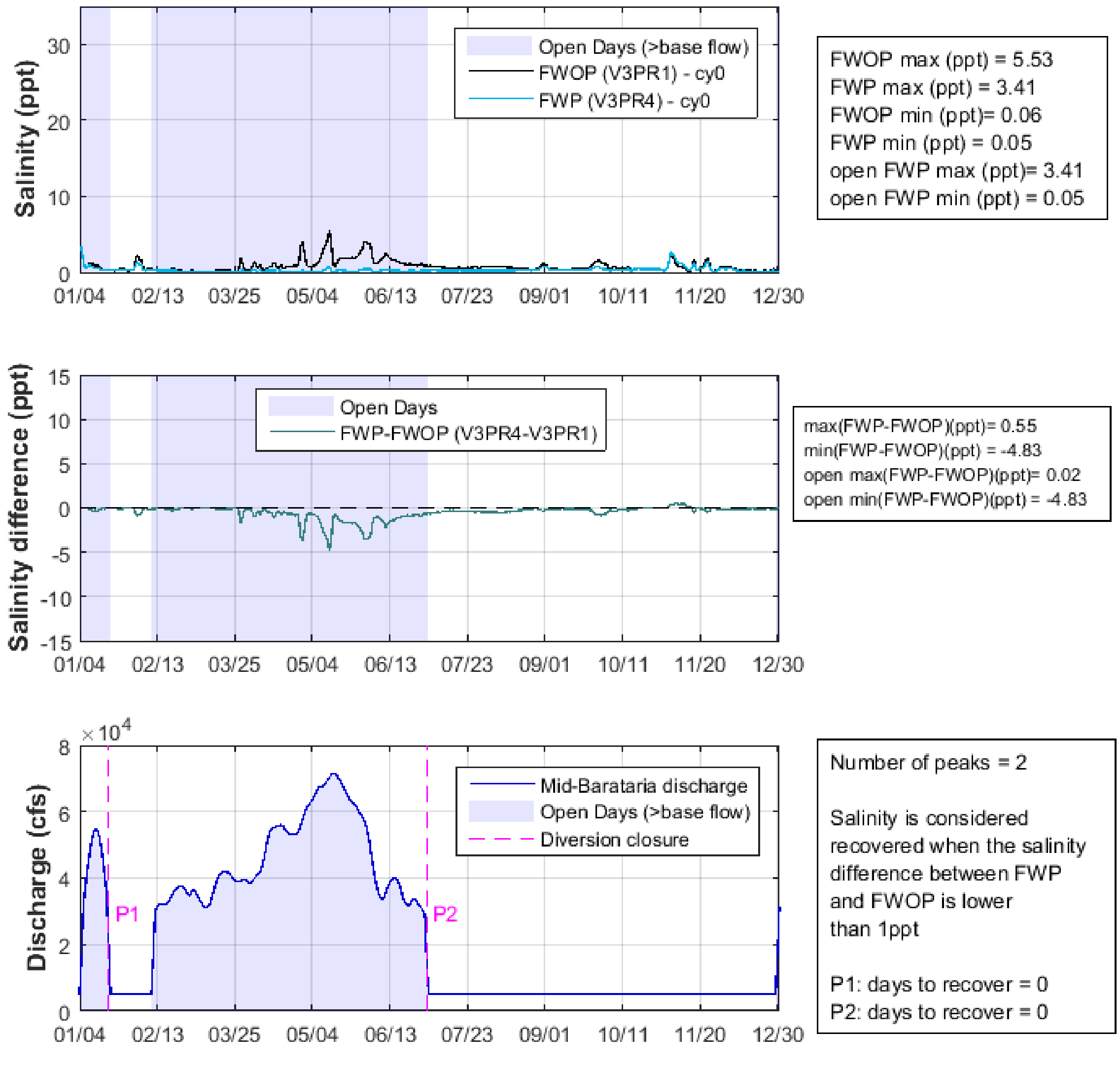


Figure 5a: Little Lake Near Cutoff LA

Applicant's Preferred Alternative – Years 2020-2029

*Diversion Scenario V3PR4, cycle 0 – FWP 75,000 cfs

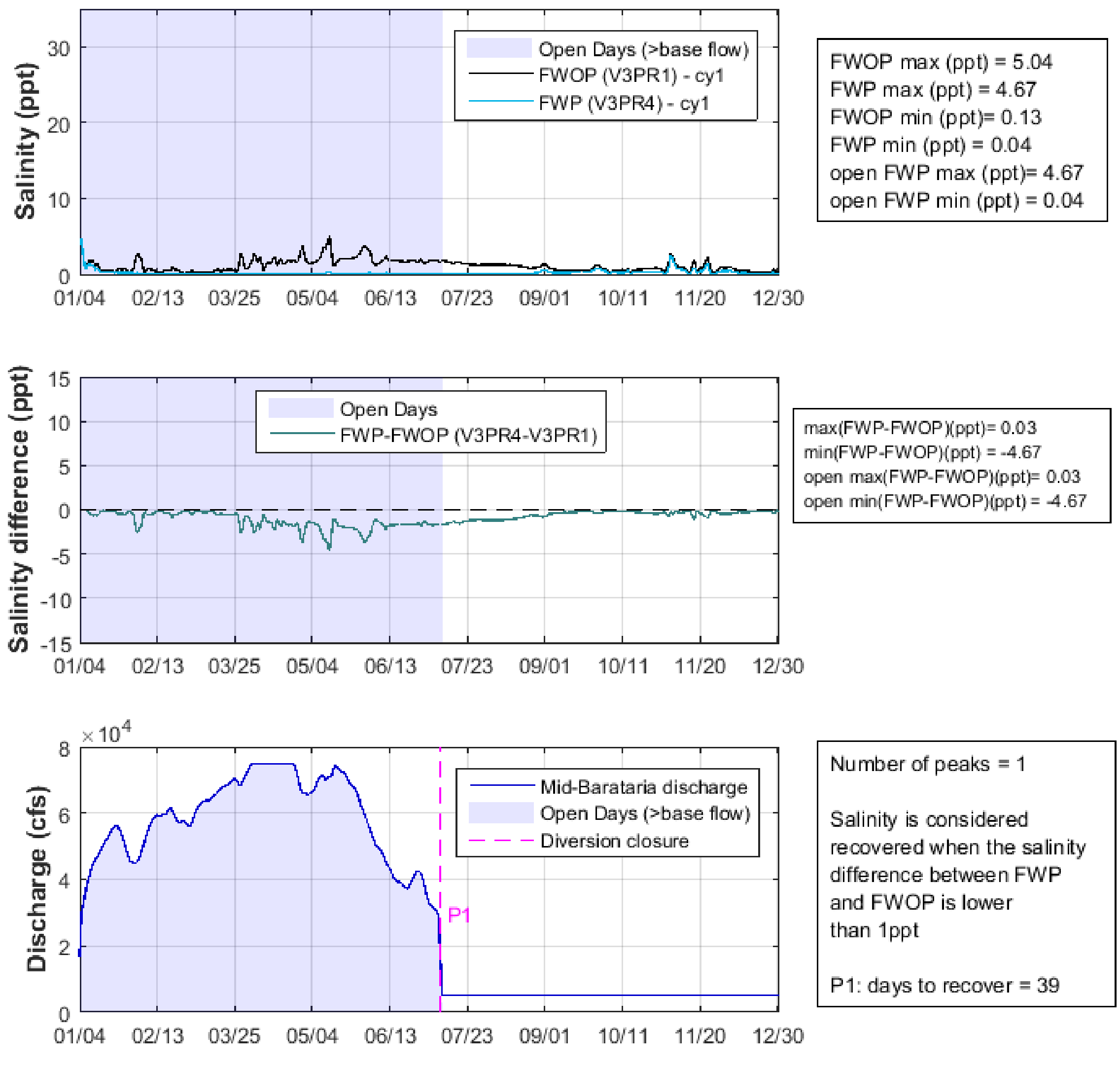


Figure 5b: Little Lake Near Cutoff LA

Applicant's Preferred Alternative – Years 2030-2039

*Diversion Scenario V3PR4, cycle 1 – FWP 75,000 cfs

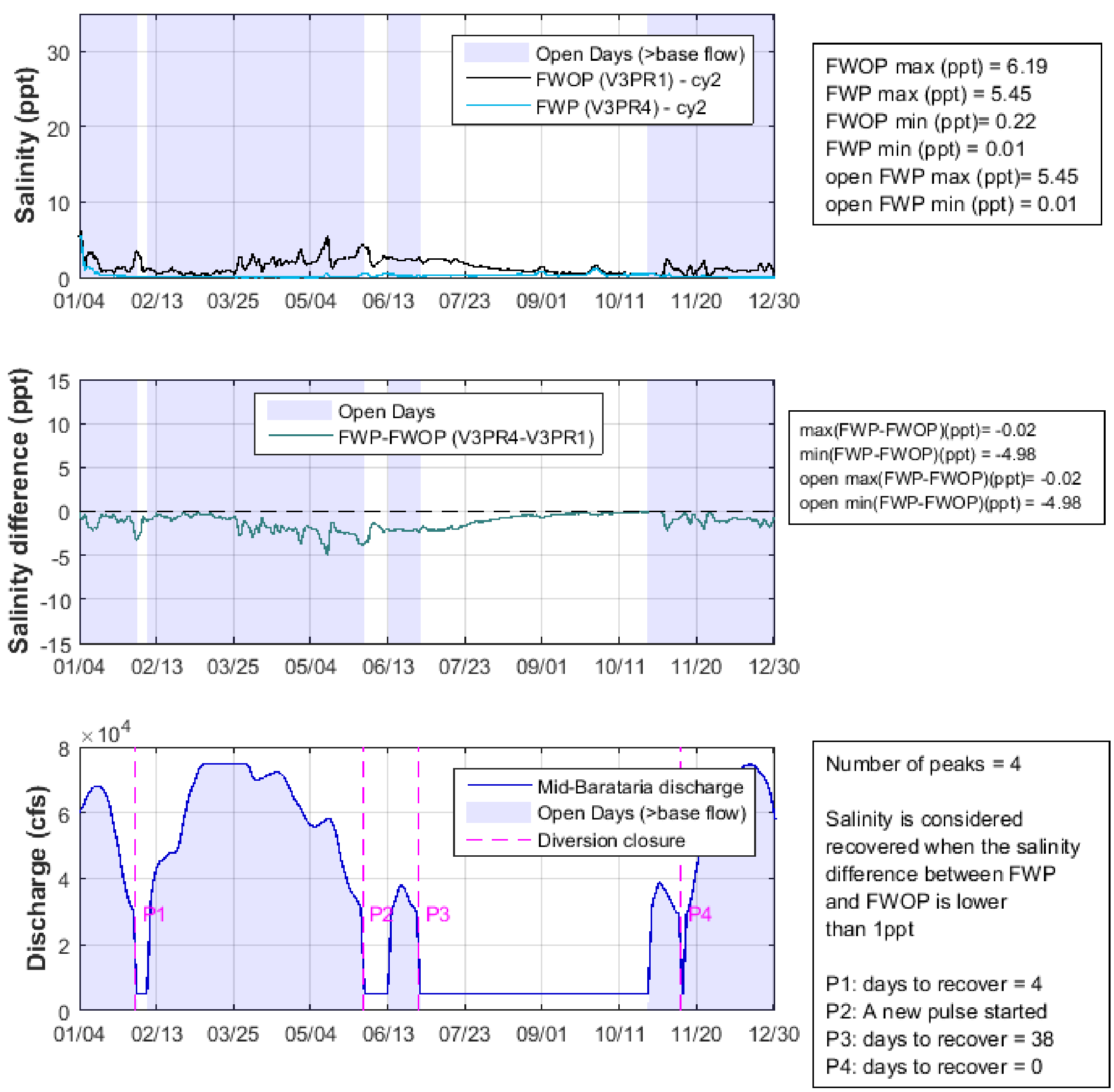


Figure 5c: Little Lake Near Cutoff LA

Applicant's Preferred Alternative – Years 2040-2049

*Diversion Scenario V3PR4, cycle 2 – FWP 75,000 cfs

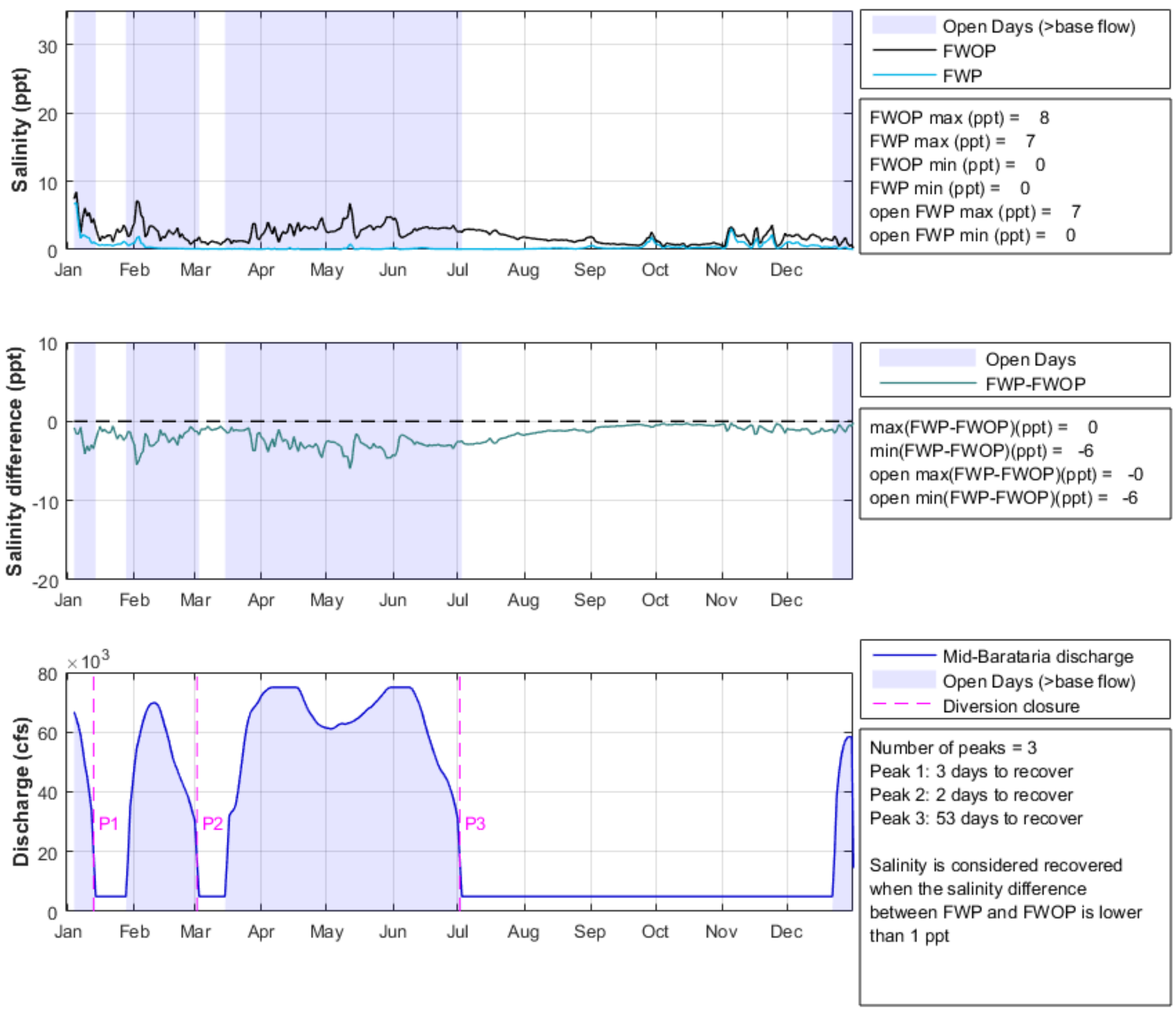


Figure 5d: Little Lake Near Cutoff LA

Applicant's Preferred Alternative – Years 2050-2059

*Diversion Scenario V3PR4, cycle 3 – FWP 75,000 cfs

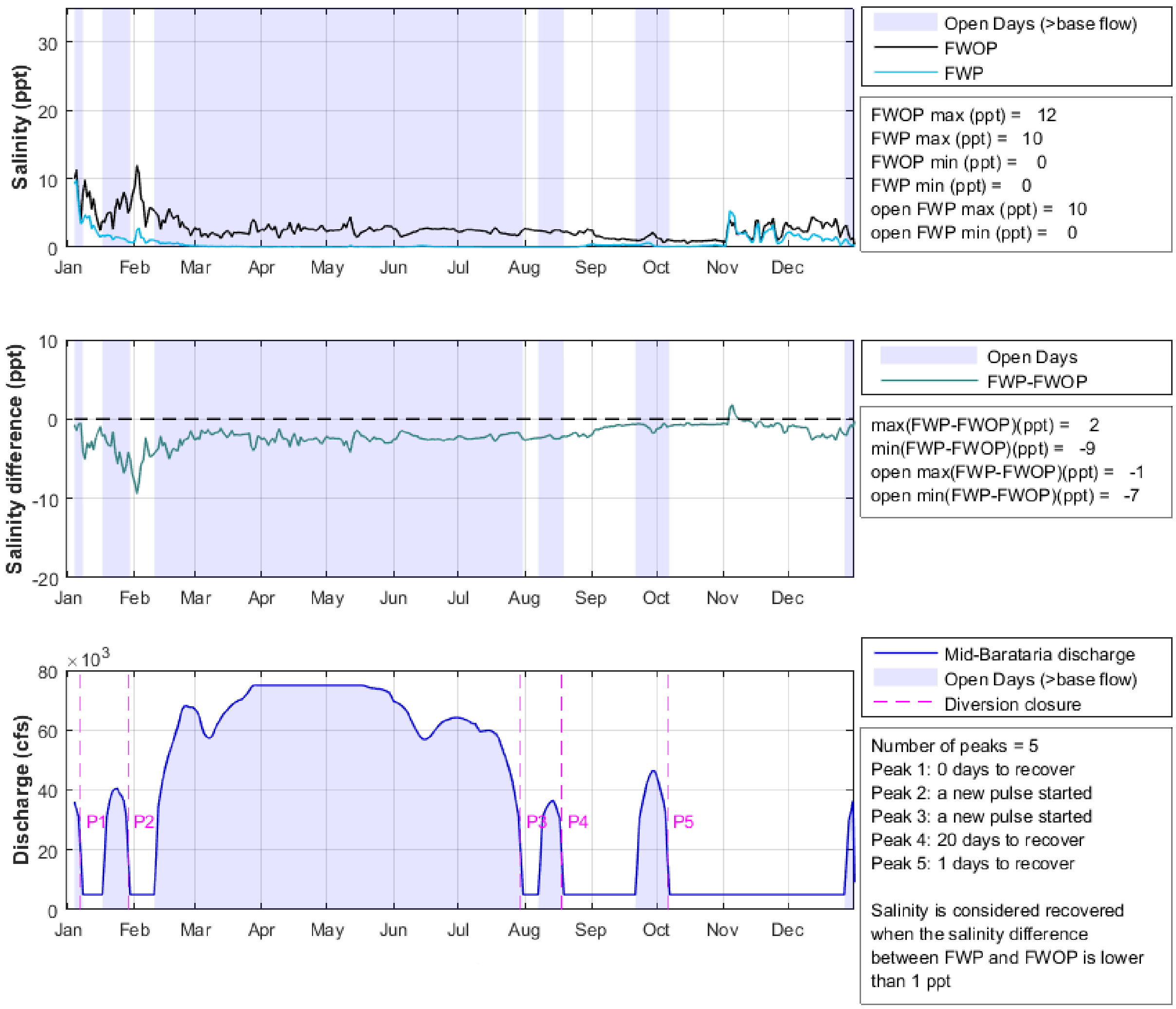


Figure 5e: Little Lake Near Cutoff LA

Applicant's Preferred Alternative – Years 2060-2069

*Diversion Scenario V3PR4, cycle 4 – FWP 75,000 cfs

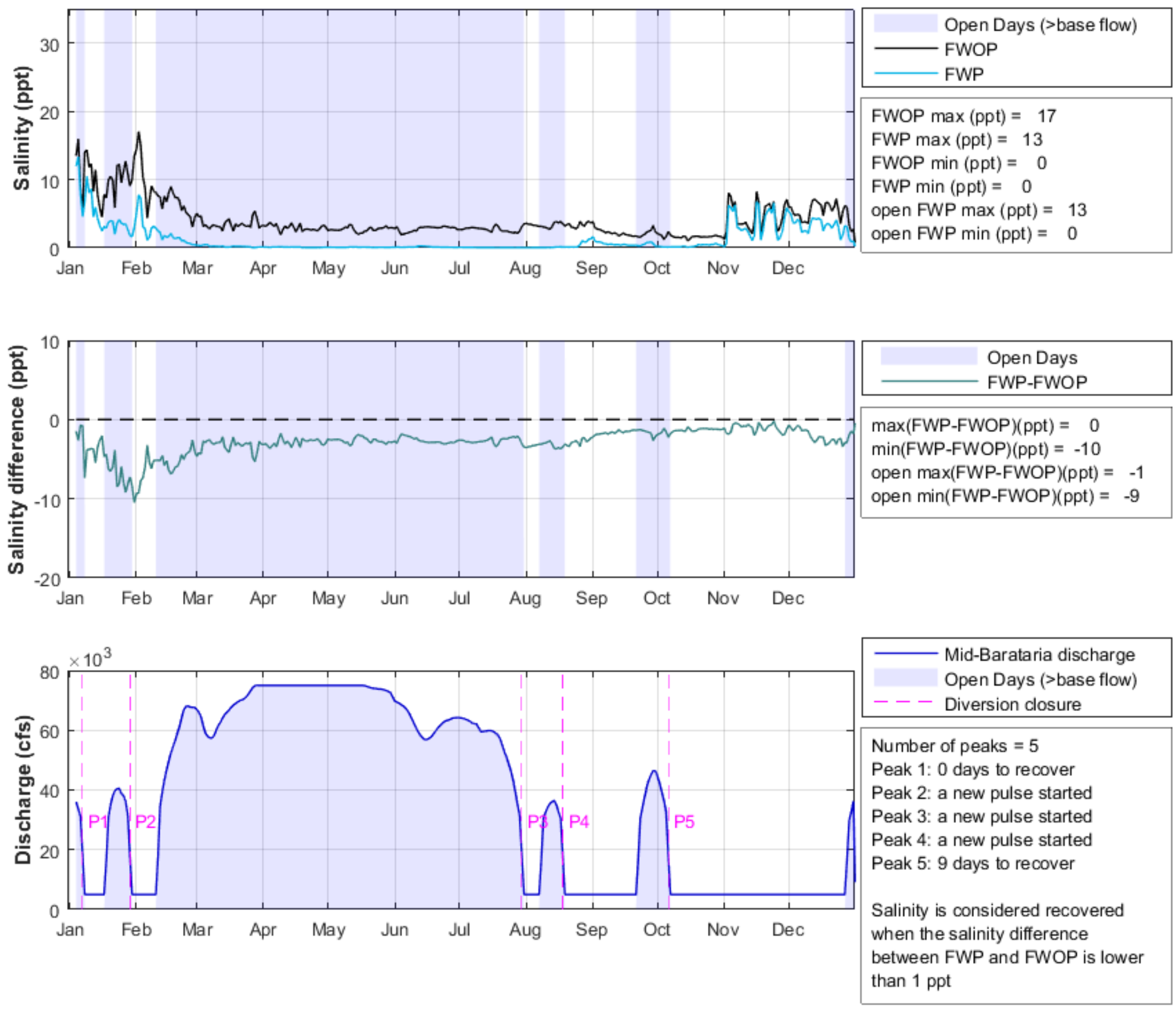


Figure 5f: Little Lake Near Cutoff LA

Applicant's Preferred Alternative – Year 2070

*Diversion Scenario V3PR4, cycle 5 – FWP 75,000 cfs

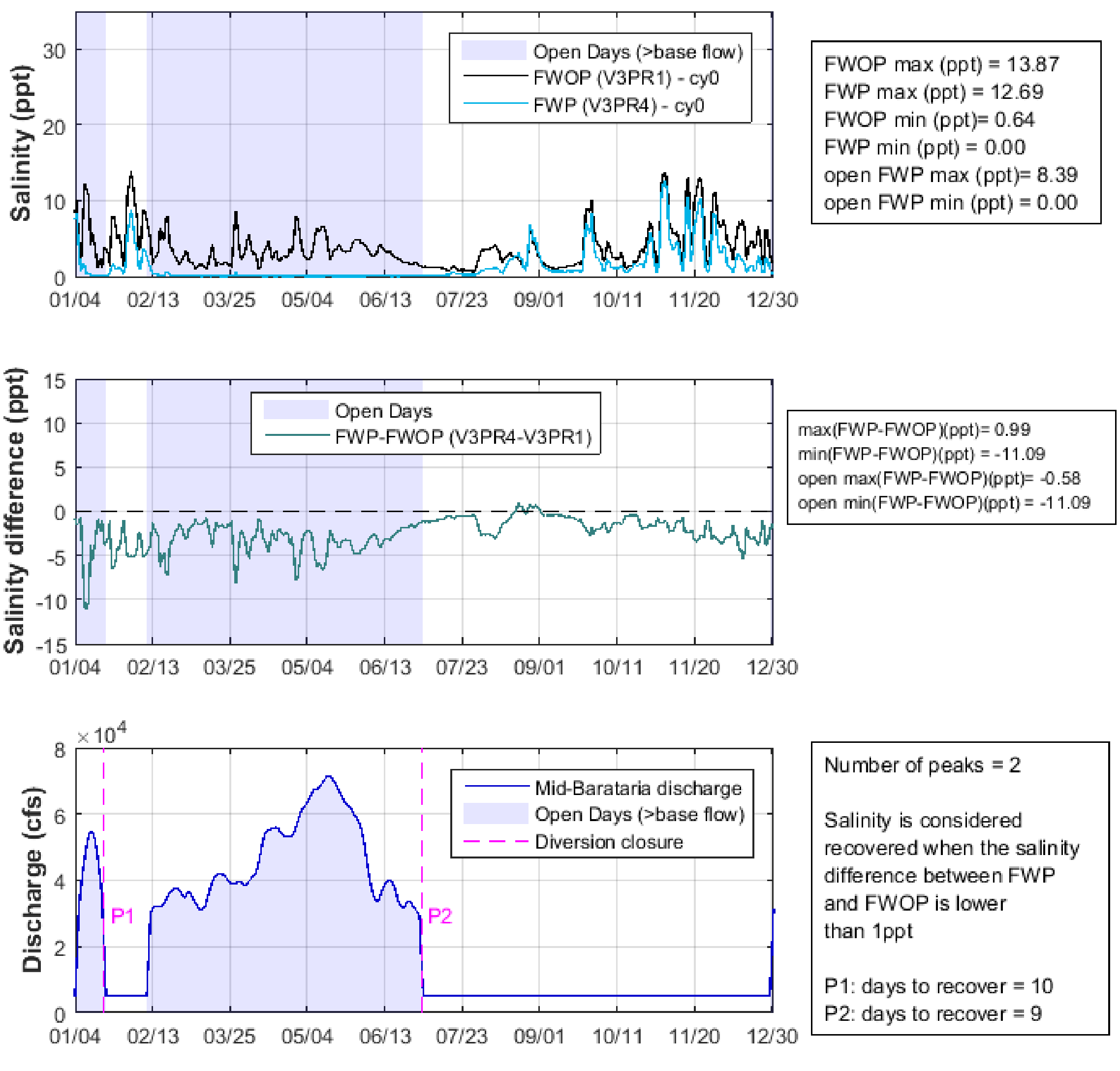


Figure 6a: Barataria Waterway S of Lafitte

Applicant's Preferred Alternative – Years 2020-2029

*Diversion Scenario V3PR4, cycle 0 – FWP 75,000 cfs

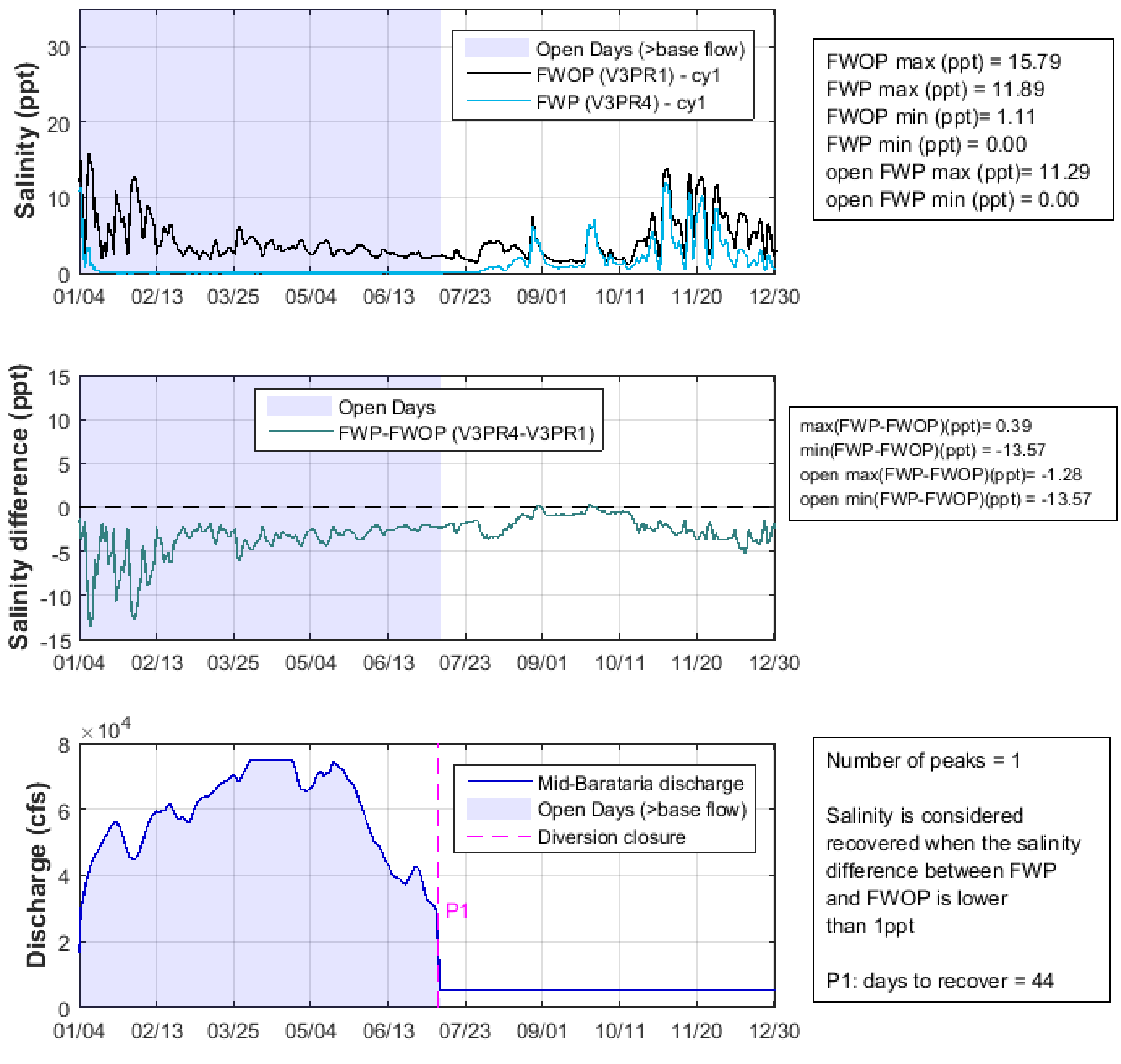


Figure 6b: Barataria Waterway S of Lafitte

Applicant's Preferred Alternative – Years 2030-2039

*Diversion Scenario V3PR4, cycle 1 – FWP 75,000 cfs

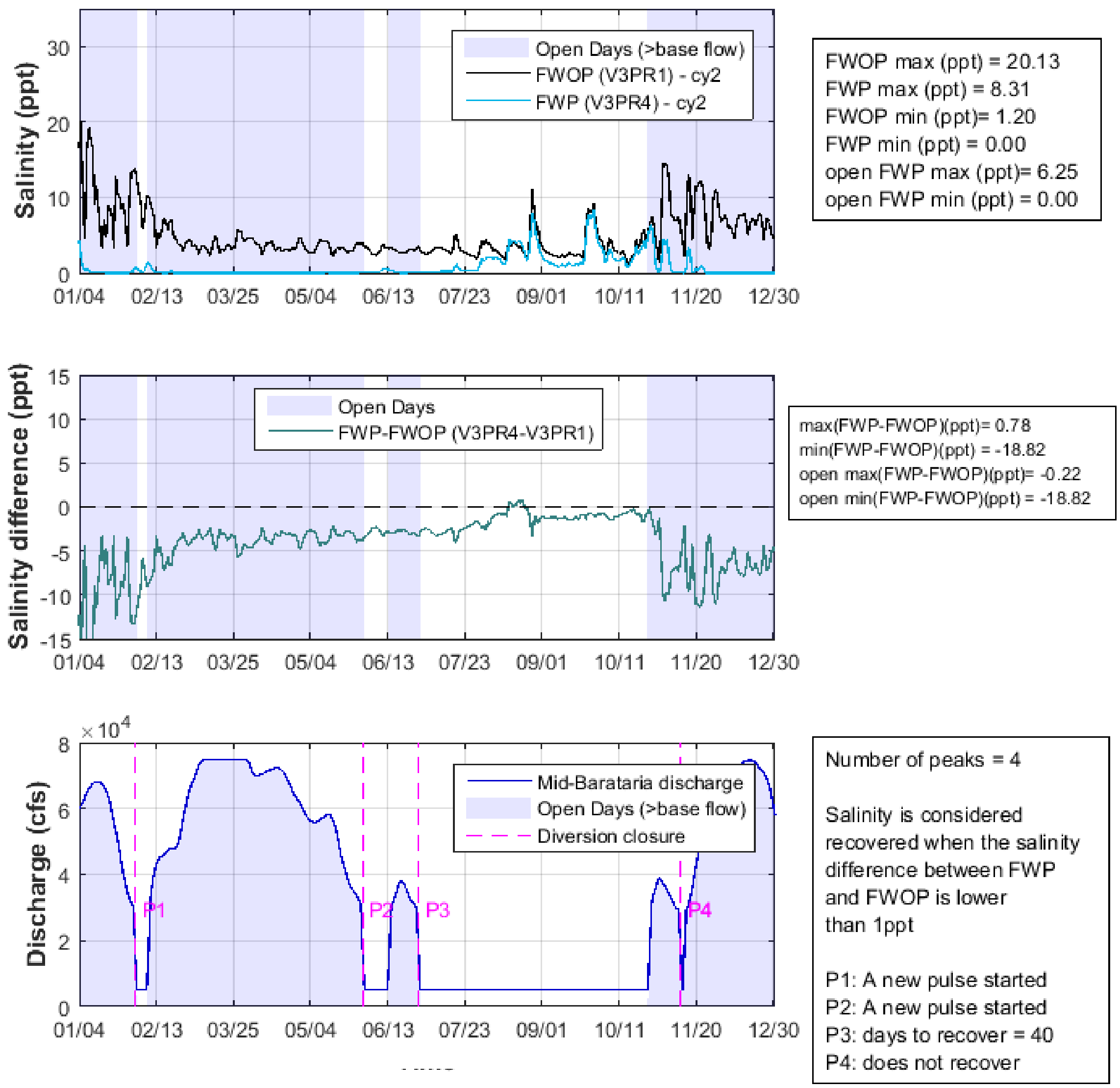


Figure 6c: Barataria Waterway S of Lafitte

Applicant's Preferred Alternative – Years 2040-2049

*Diversion Scenario V3PR4, cycle 2 – FWP 75,000 cfs

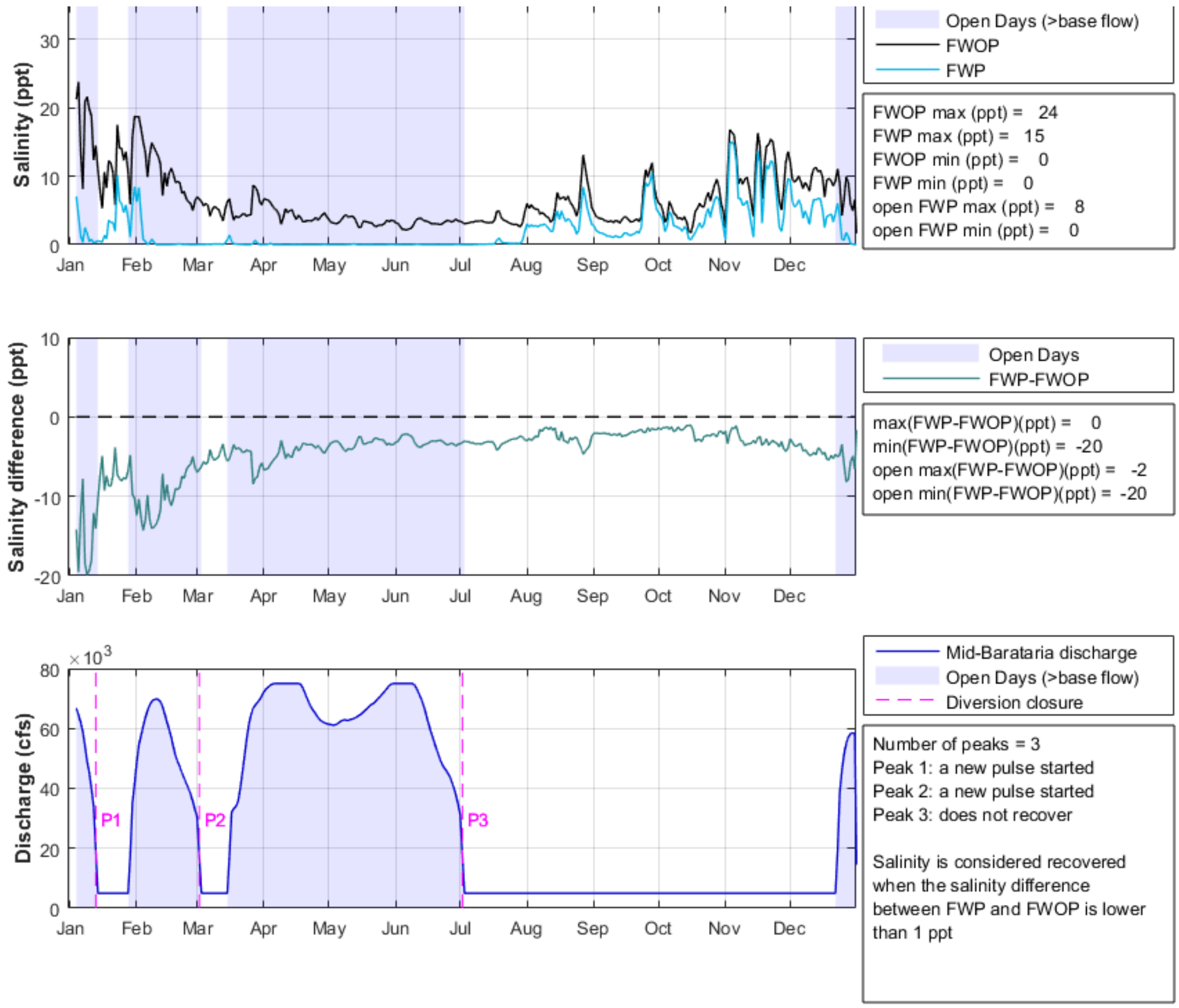


Figure 6d: Barataria Waterway S of Lafitte

Applicant's Preferred Alternative – Years 2050-2059

*Diversion Scenario V3PR4, cycle 3 – FWP 75,000 cfs

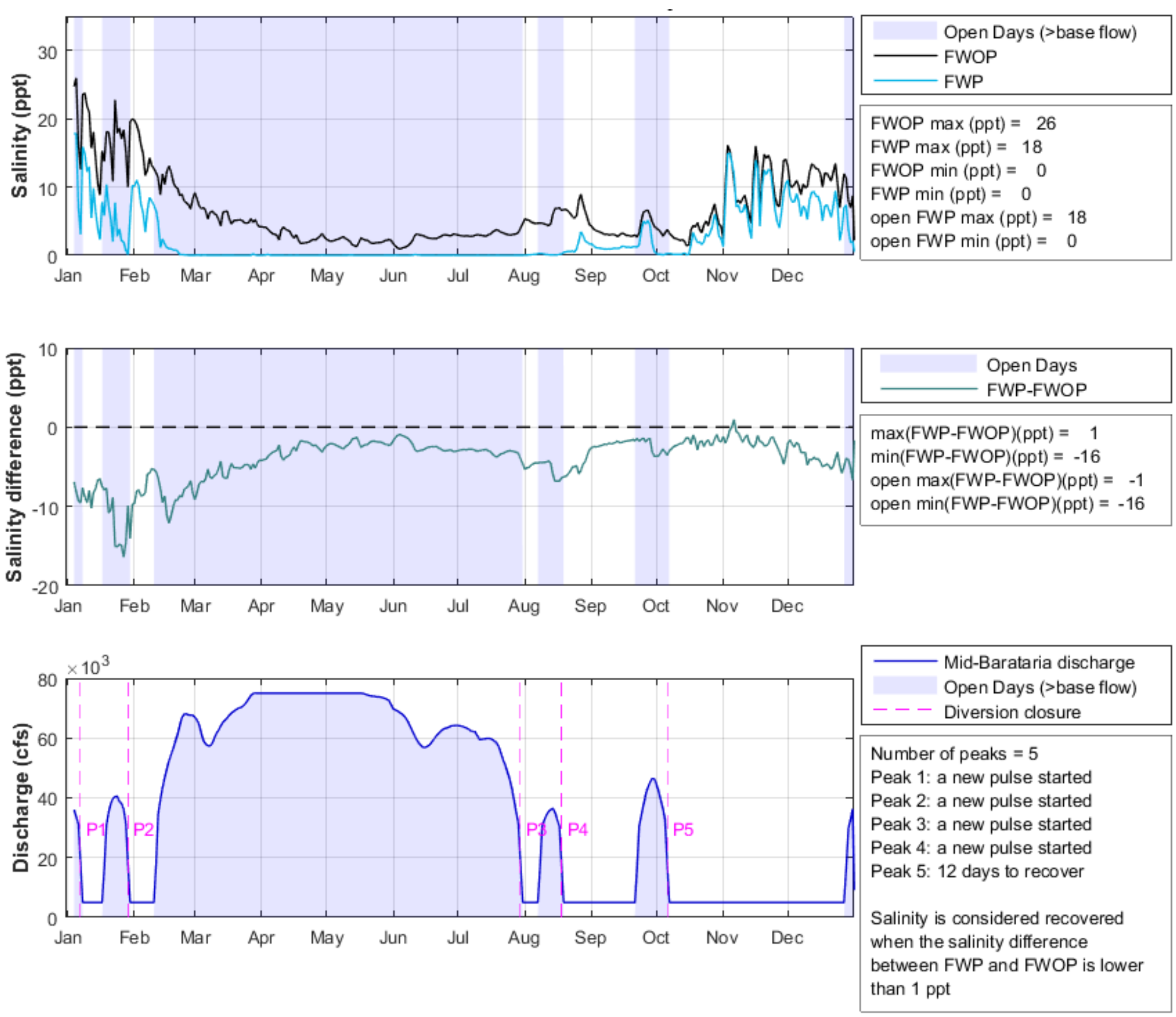


Figure 6e: Barataria Waterway S of Lafitte

Applicant's Preferred Alternative – Years 2060-2069

*Diversion Scenario V3PR4, cycle 4 – FWP 75,000 cfs

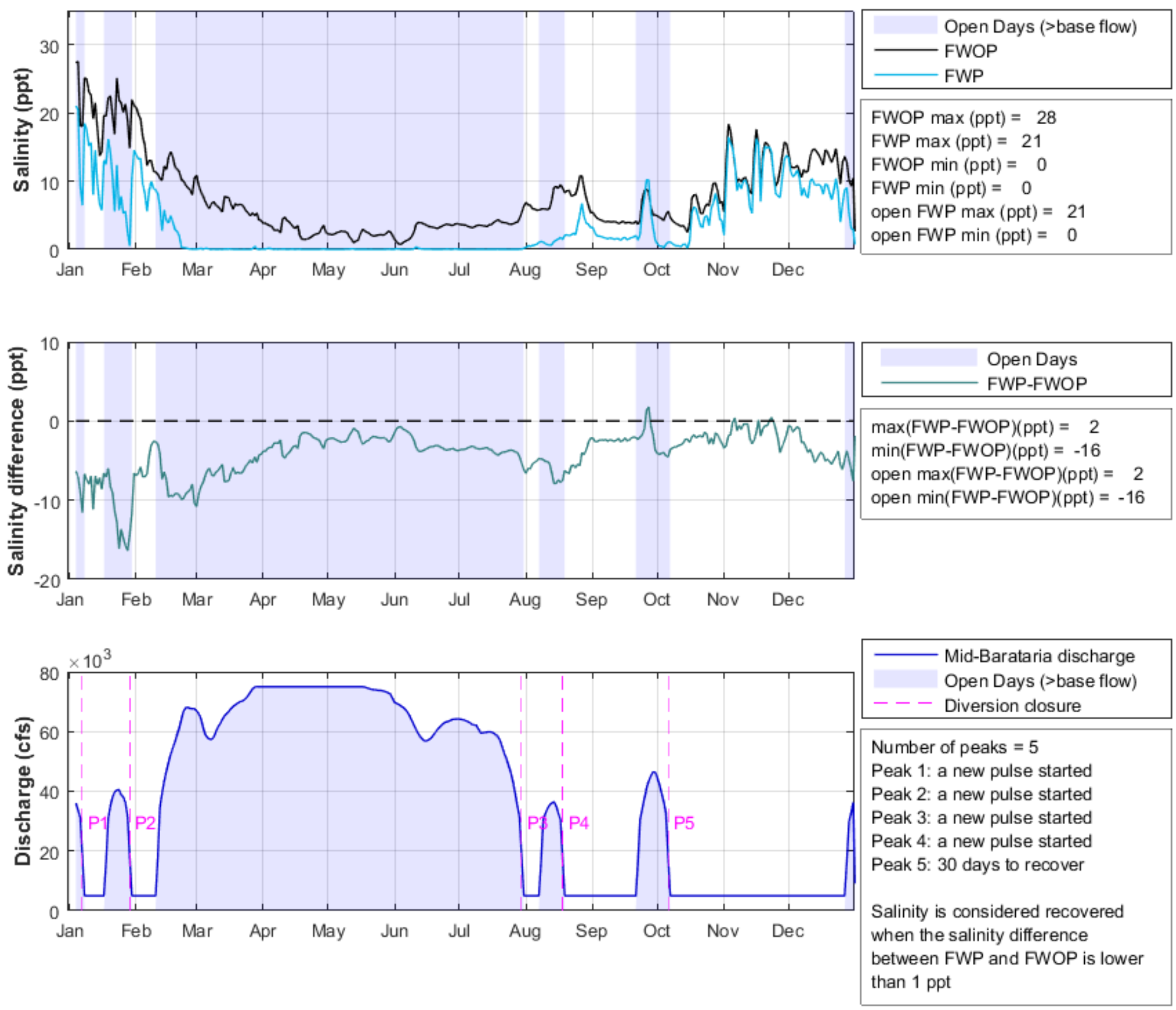


Figure 6f: Barataria Waterway S of Lafitte

Applicant's Preferred Alternative – Year 2070

*Diversion Scenario V3PR4, cycle 5 – FWP 75,000 cfs

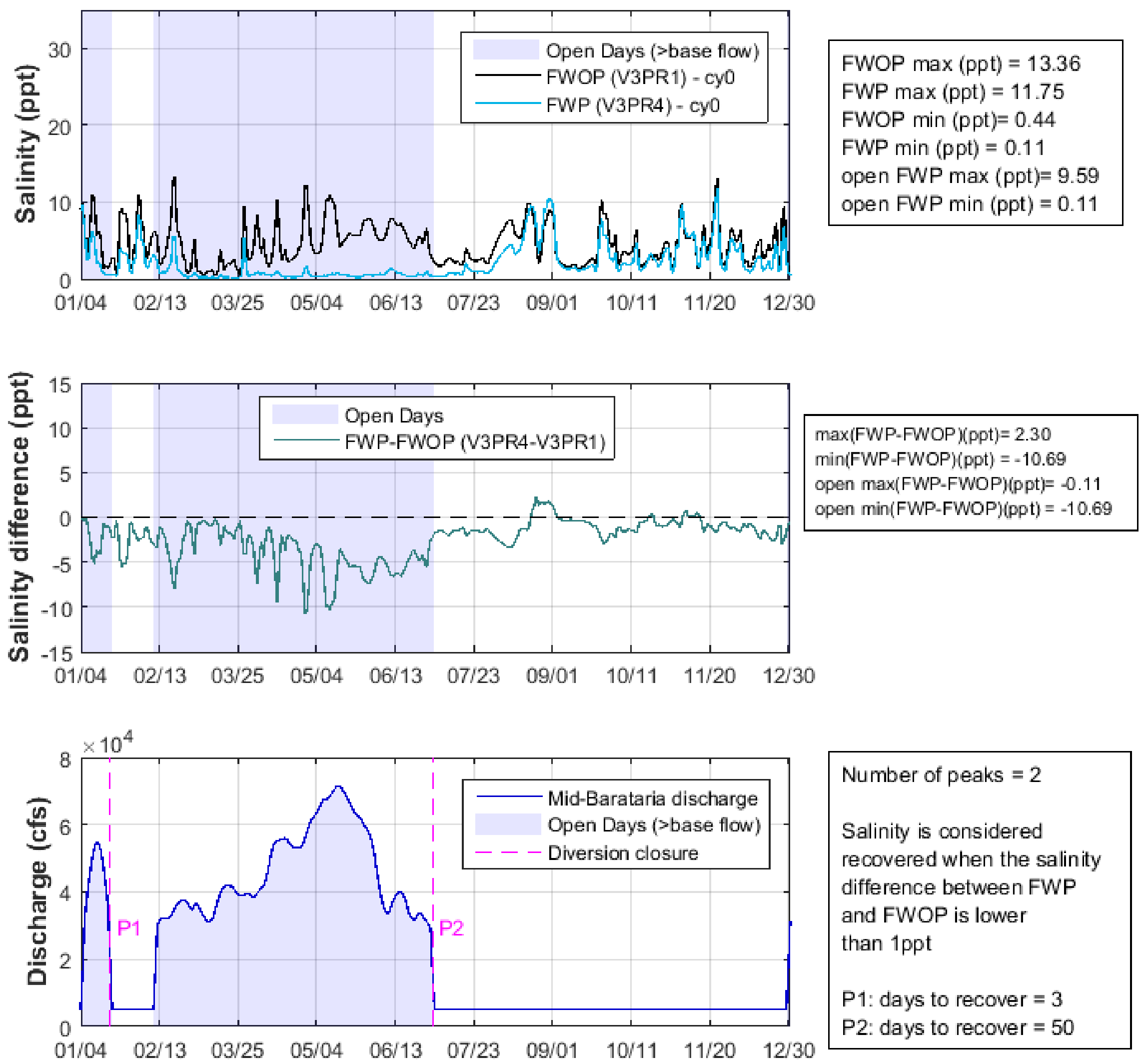


Figure 7a: Hackberry Bay NW of Grand Isle

Applicant's Preferred Alternative – Years 2020-2029

*Diversion Scenario V3PR4, cycle 0 – FWP 75,000 cfs

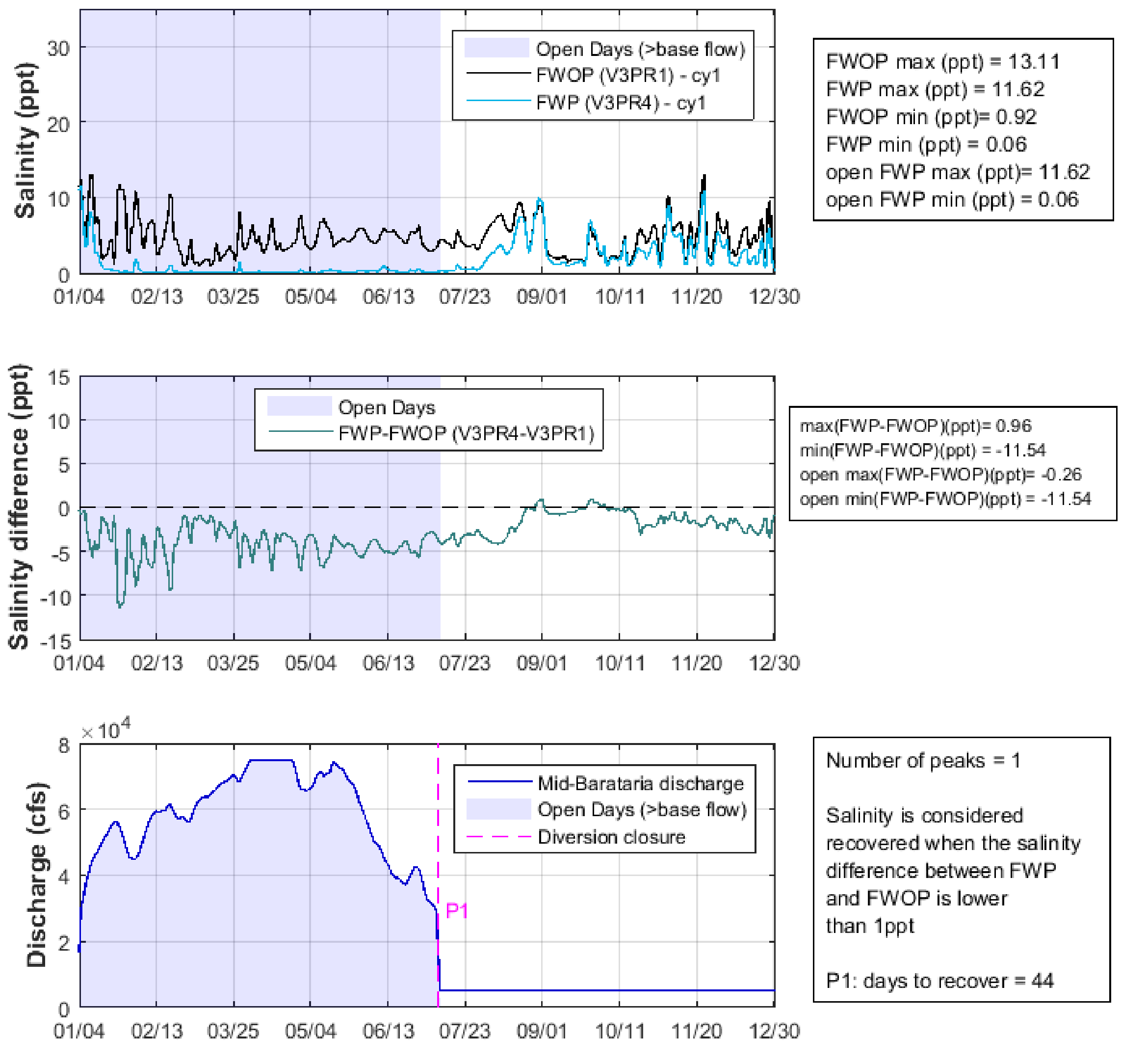


Figure 7b: Hackberry Bay NW of Grand Isle

Applicant's Preferred Alternative – Years 2030-2039

*Diversion Scenario V3PR4, cycle 1 – FWP 75,000 cfs

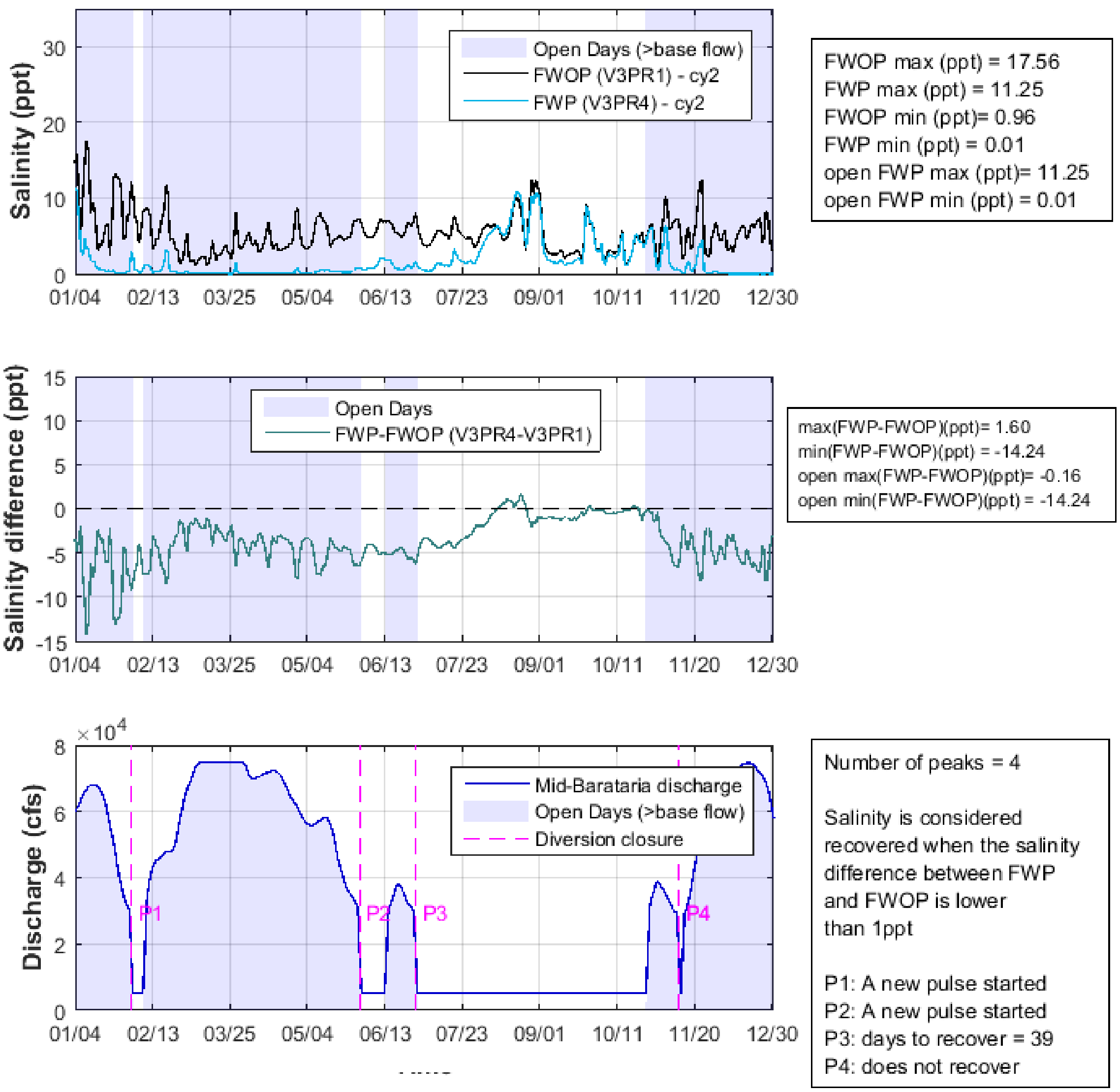


Figure 7c: Hackberry Bay NW of Grand Isle

Applicant's Preferred Alternative – Years 2040-2049

*Diversion Scenario V3PR4, cycle 2 – FWP 75,000 cfs

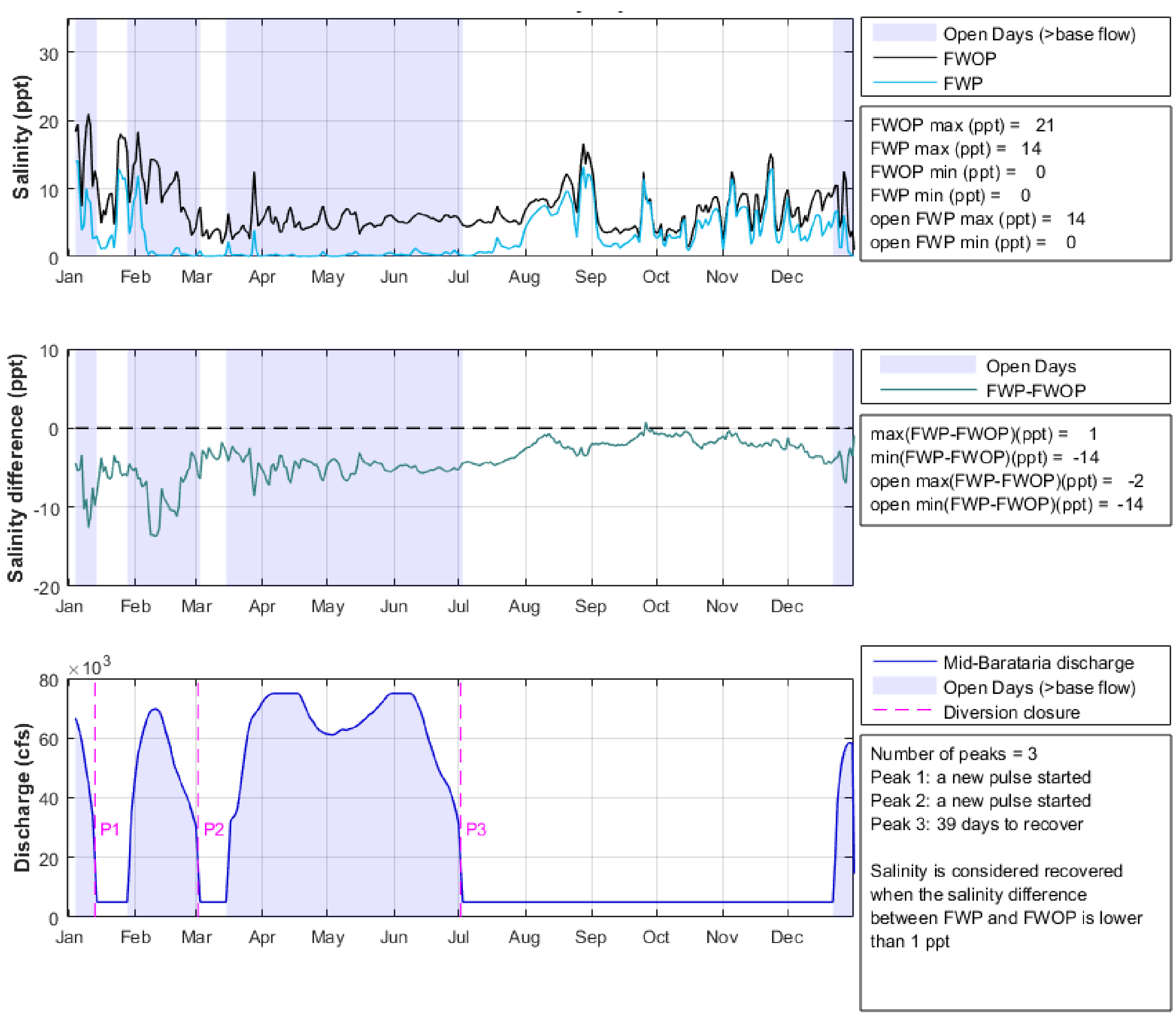


Figure 7d: Hackberry Bay NW of Grand Isle

Applicant's Preferred Alternative – Years 2050-2059

*Diversion Scenario V3PR4, cycle 3 – FWP 75,000 cfs

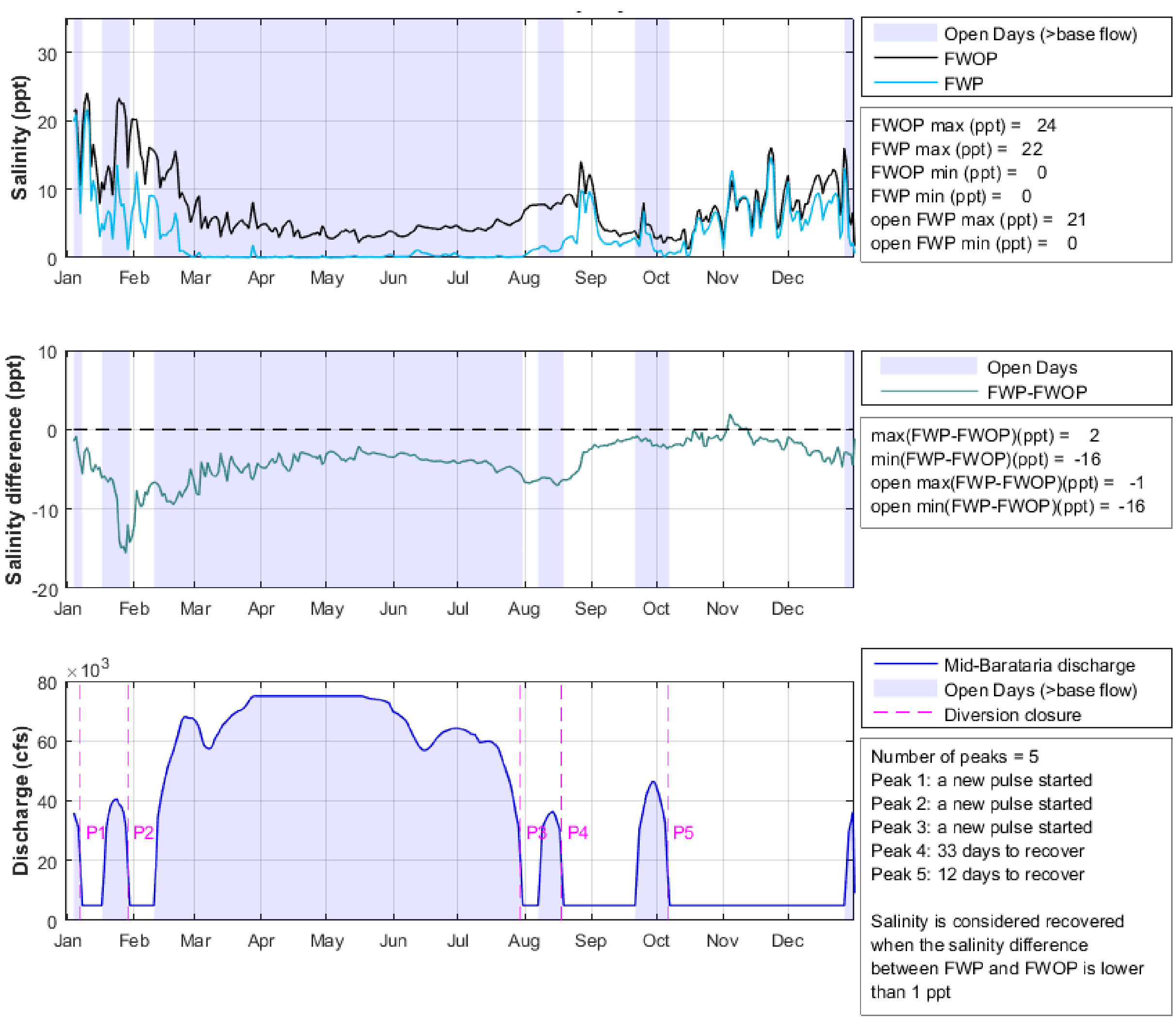


Figure 7e: Hackberry Bay NW of Grand Isle

Applicant's Preferred Alternative – Years 2060-2069

*Diversion Scenario V3PR4, cycle 4 – FWP 75,000 cfs

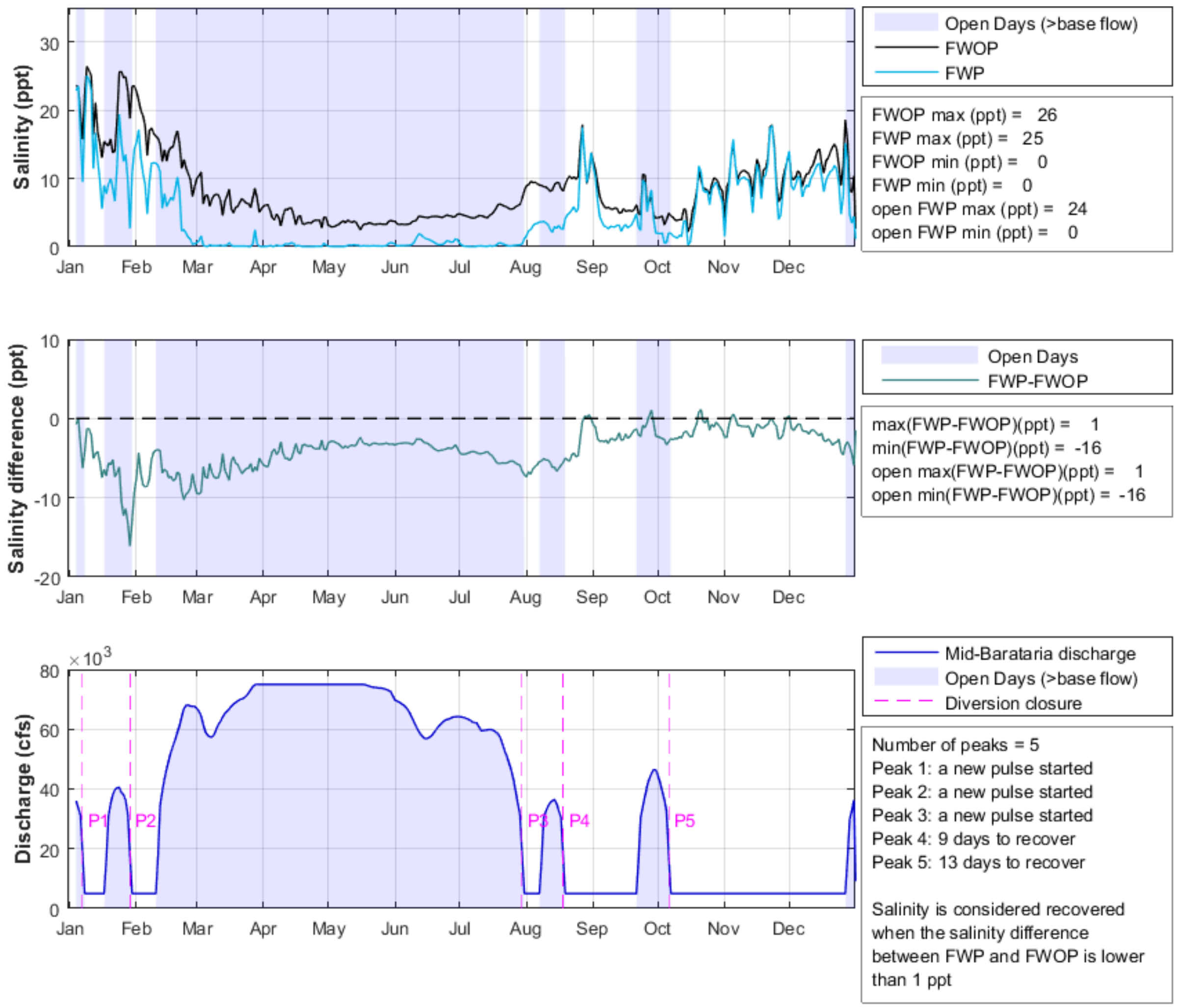


Figure 7f: Hackberry Bay NW of Grand Isle

Applicant's Preferred Alternative – Year 2070

*Diversion Scenario V3PR4, cycle 5 – FWP 75,000 cfs

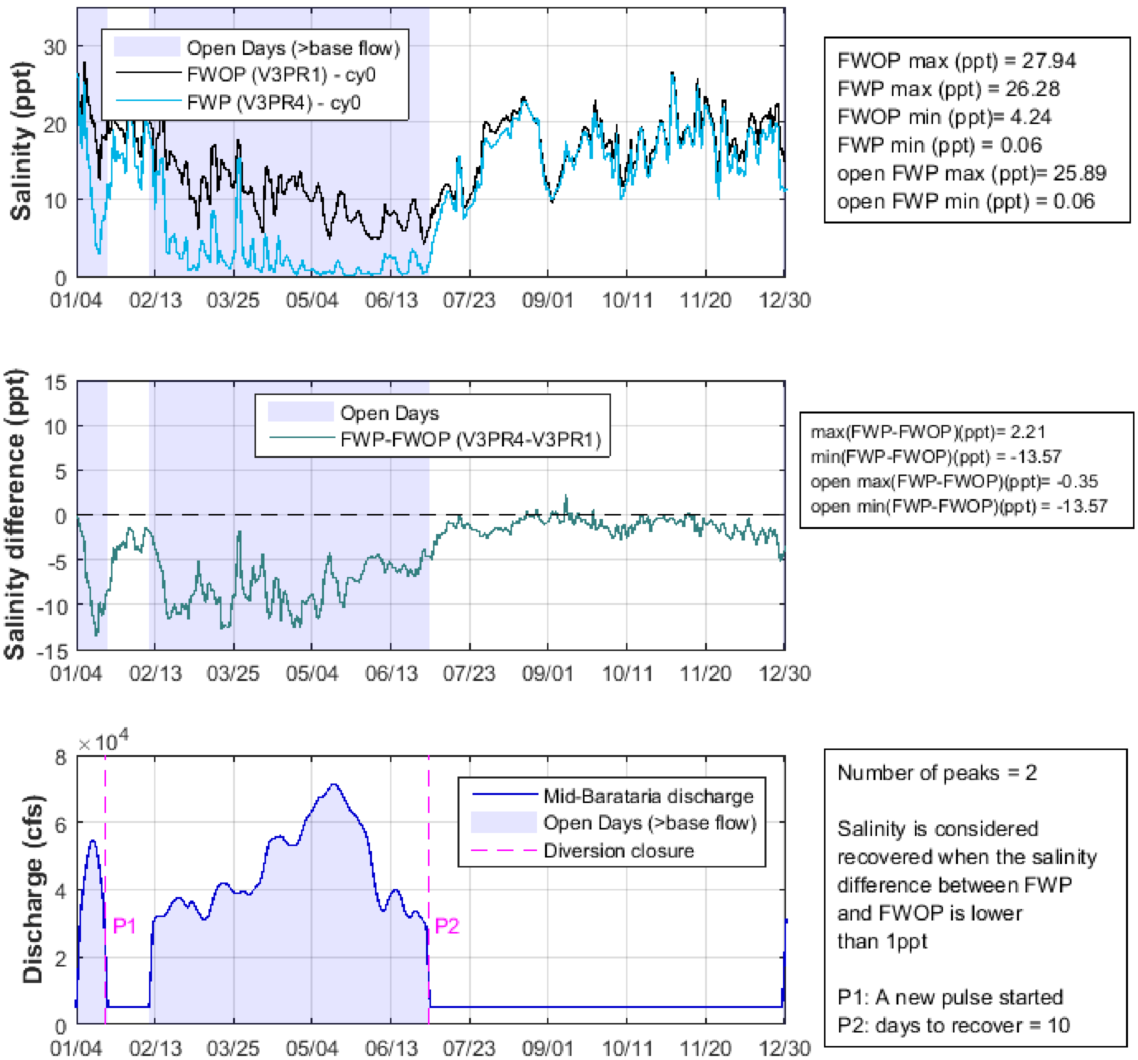


Figure 8a: Barataria Bay near Grand Terre Island

Applicant's Preferred Alternative – Years 2020-2029

*Diversion Scenario V3PR4, cycle 0 – FWP 75,000 cfs

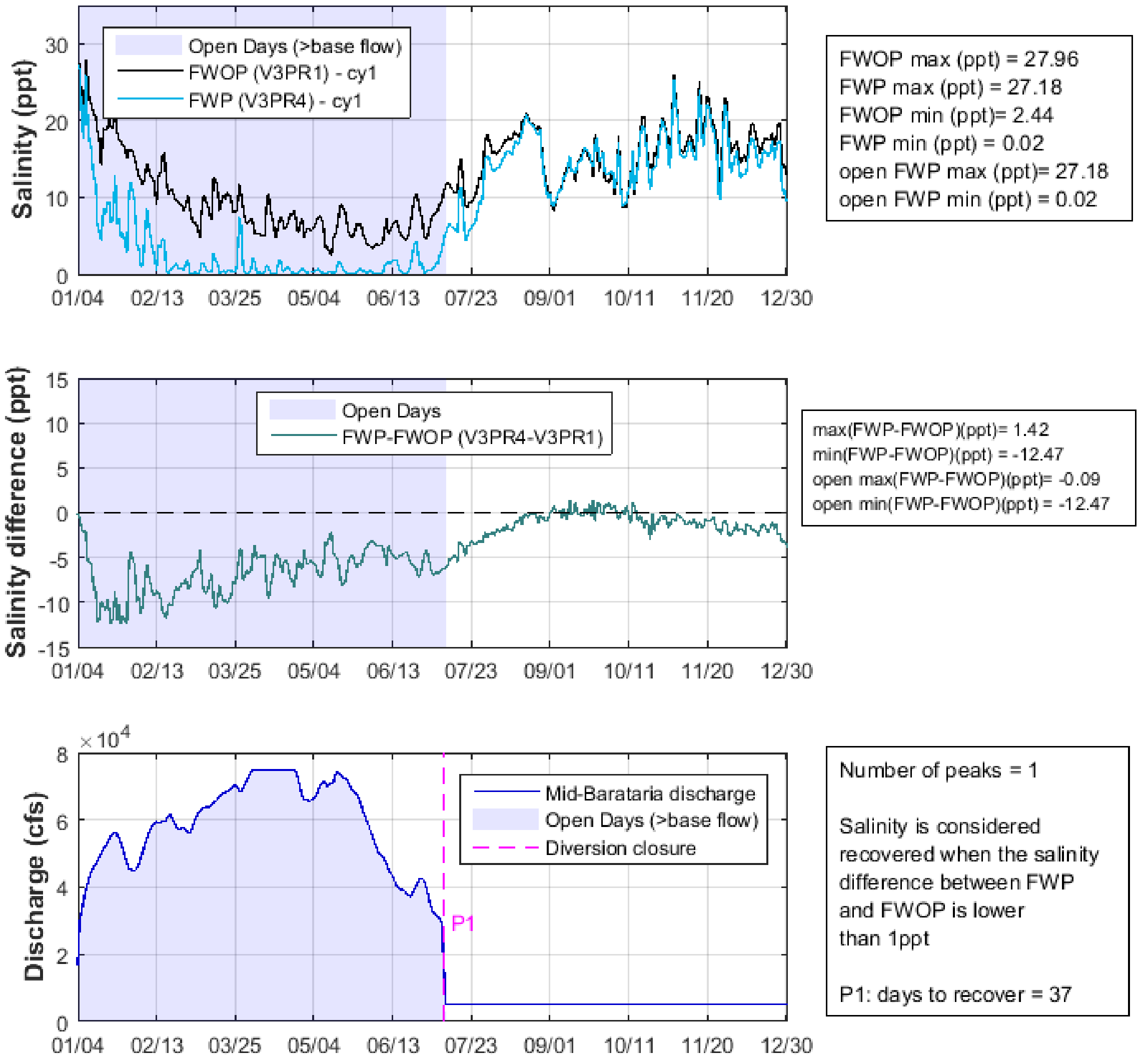


Figure 8b: Barataria Bay near Grand Terre Island

Applicant's Preferred Alternative – Years 2030-2039

*Diversion Scenario V3PR4, cycle 1 – FWP 75,000 cfs

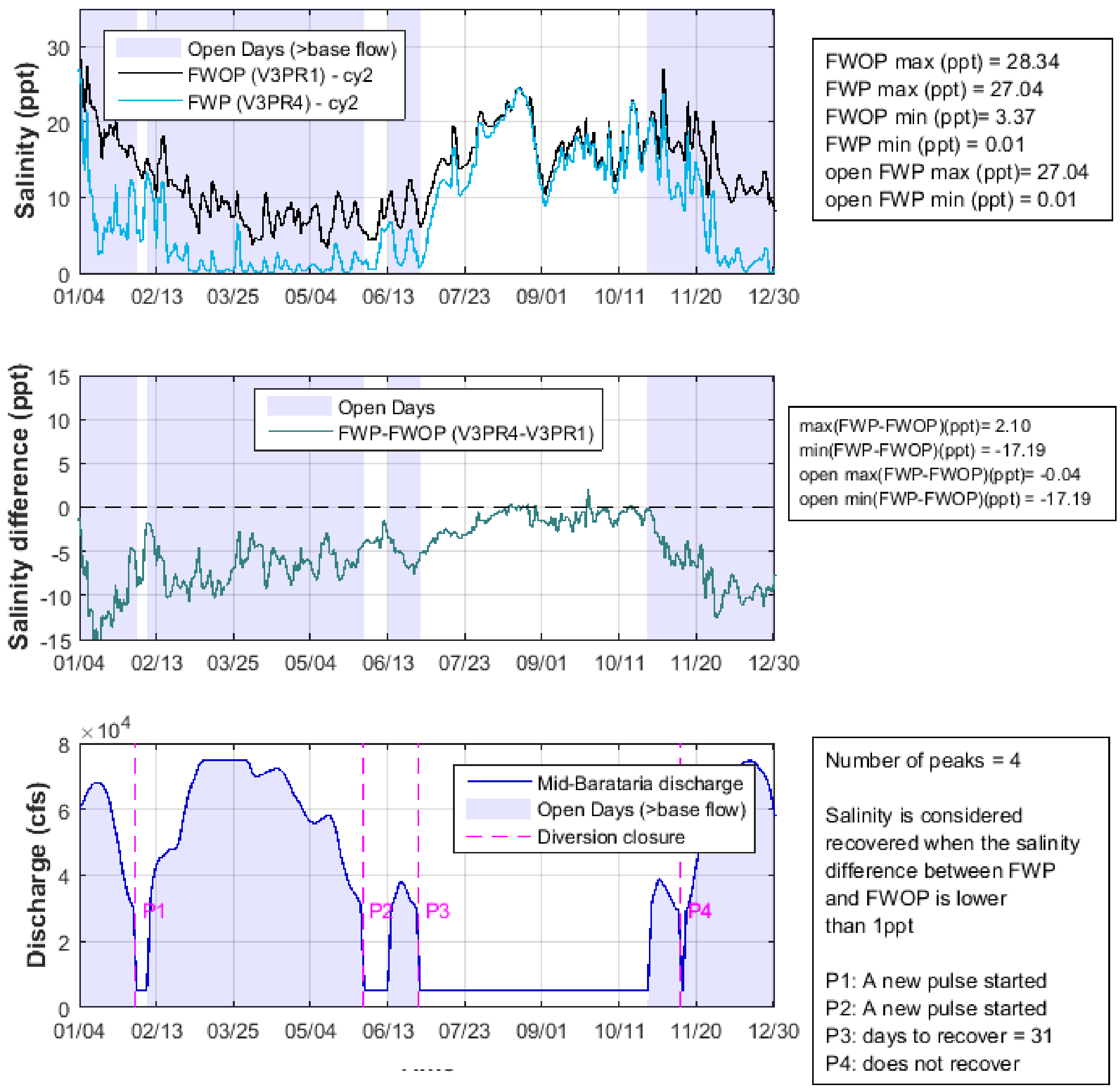


Figure 8c: Barataria Bay near Grand Terre Island

Applicant's Preferred Alternative – Years 2040-2049

*Diversion Scenario V3PR4, cycle 2 – FWP 75,000 cfs

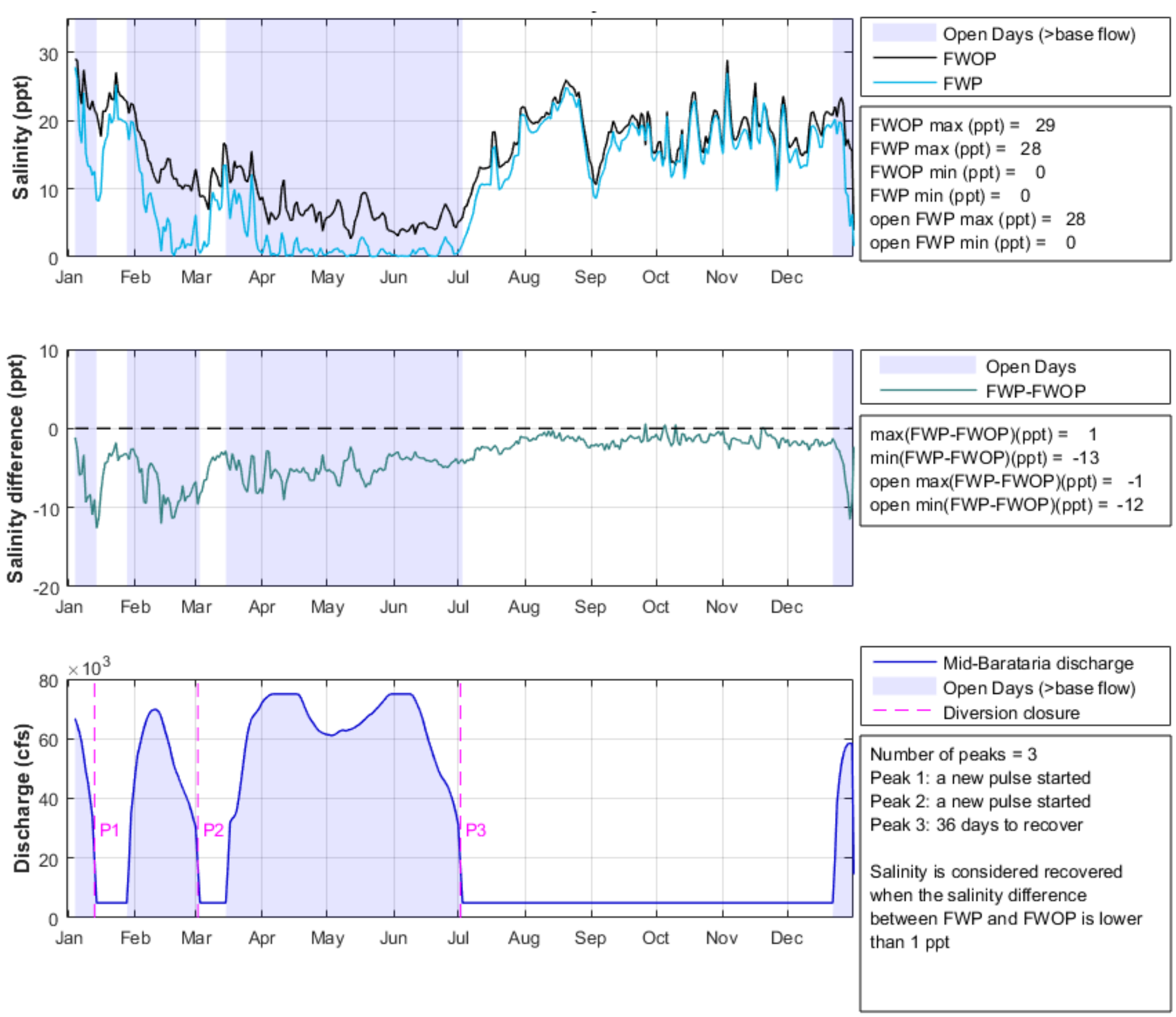


Figure 8d: Barataria Bay near Grand Terre Island

Applicant's Preferred Alternative – Years 2050-2059

*Diversion Scenario V3PR4, cycle 3 – FWP 75,000 cfs

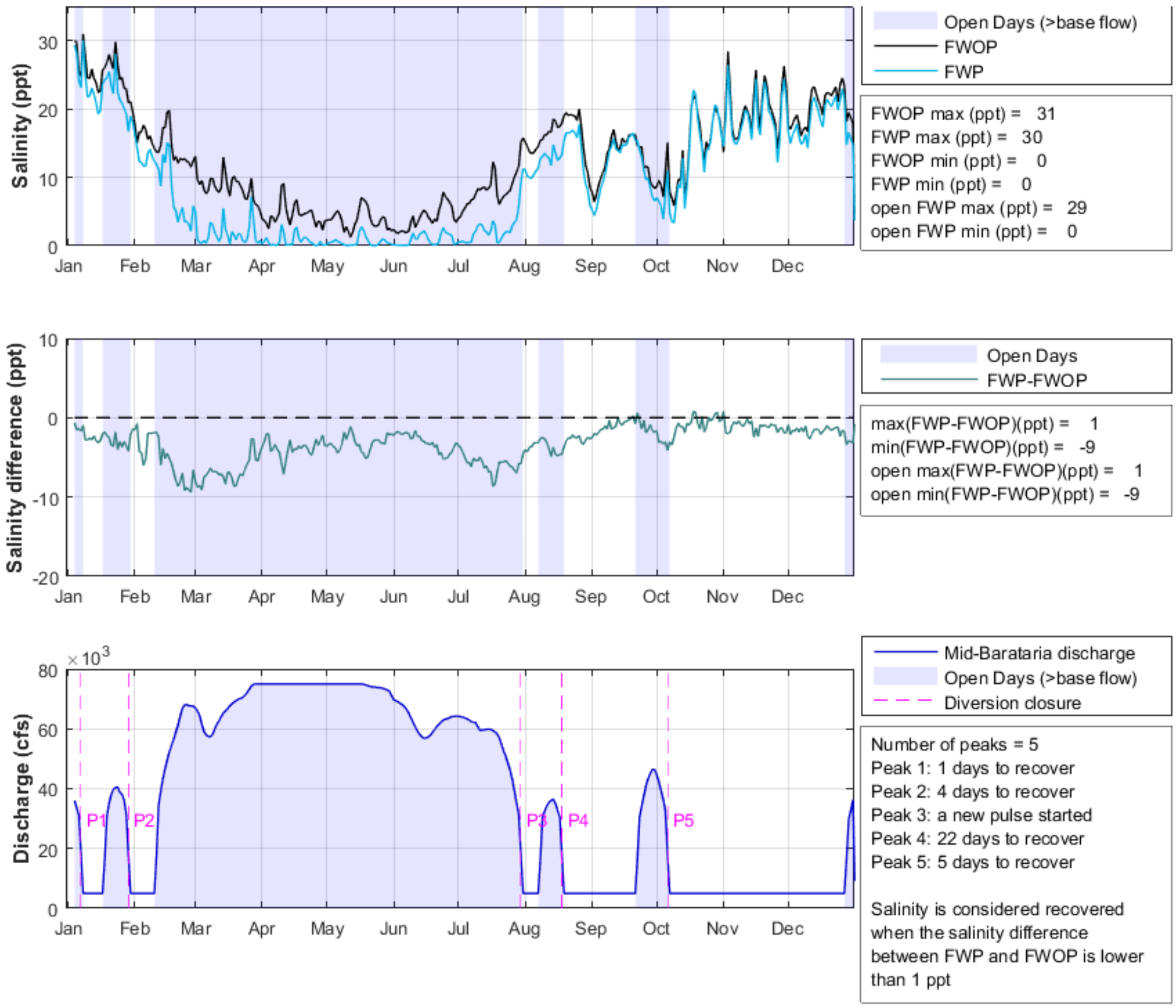


Figure 8e: Barataria Bay near Grand Terre Island

Applicant's Preferred Alternative – Years 2060-2069

*Diversion Scenario V3PR4, cycle 4 – FWP 75,000 cfs

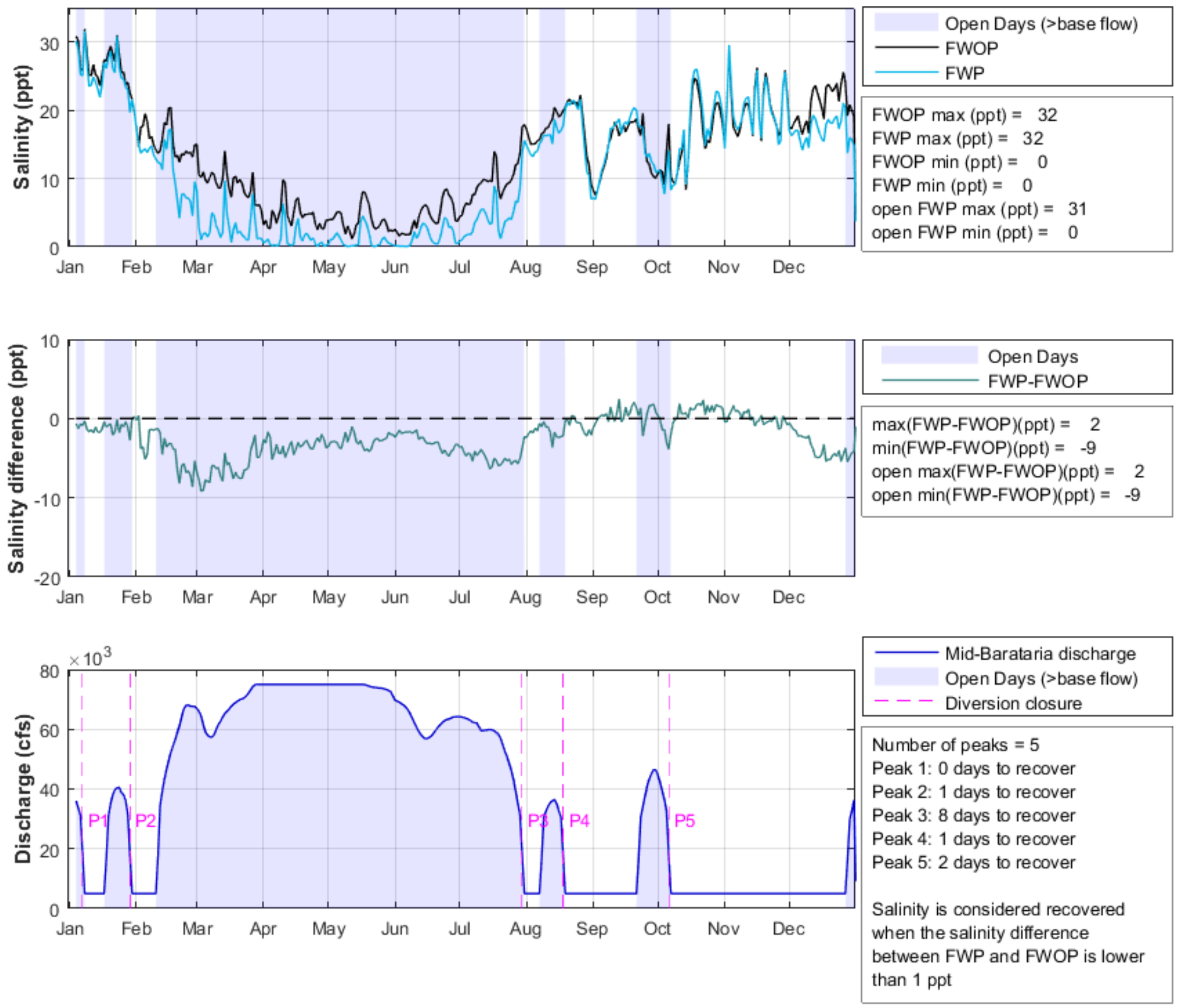


Figure 8f: Barataria Bay near Grand Terre Island

Applicant's Preferred Alternative – Year 2070

*Diversion Scenario V3PR4, cycle 5 – FWP 75,000 cfs

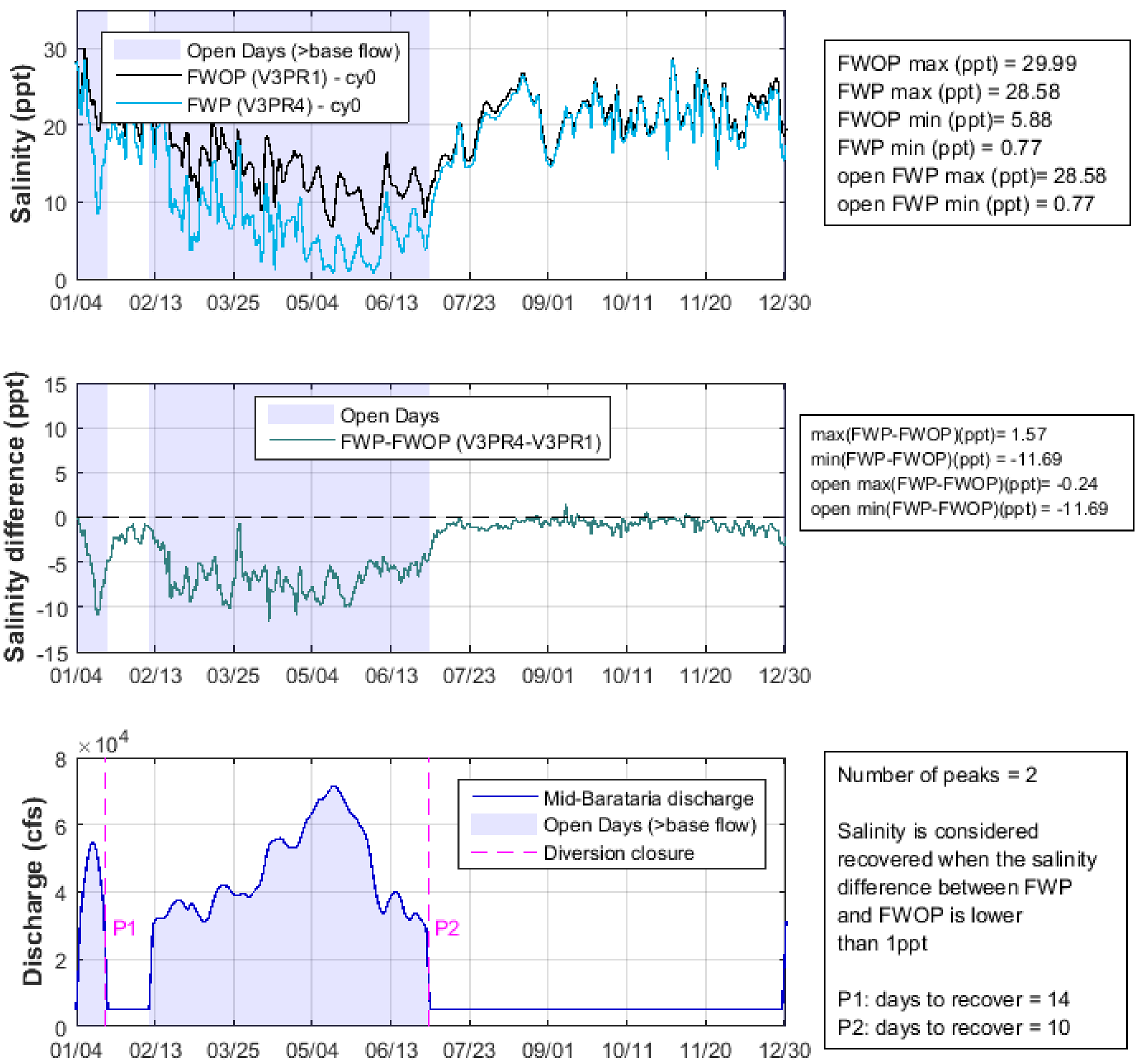


Figure 9a: Barataria Pass at Grand Isle

Applicant's Preferred Alternative – Years 2020-2029

*Diversion Scenario V3PR4, cycle 0 – FWP 75,000 cfs

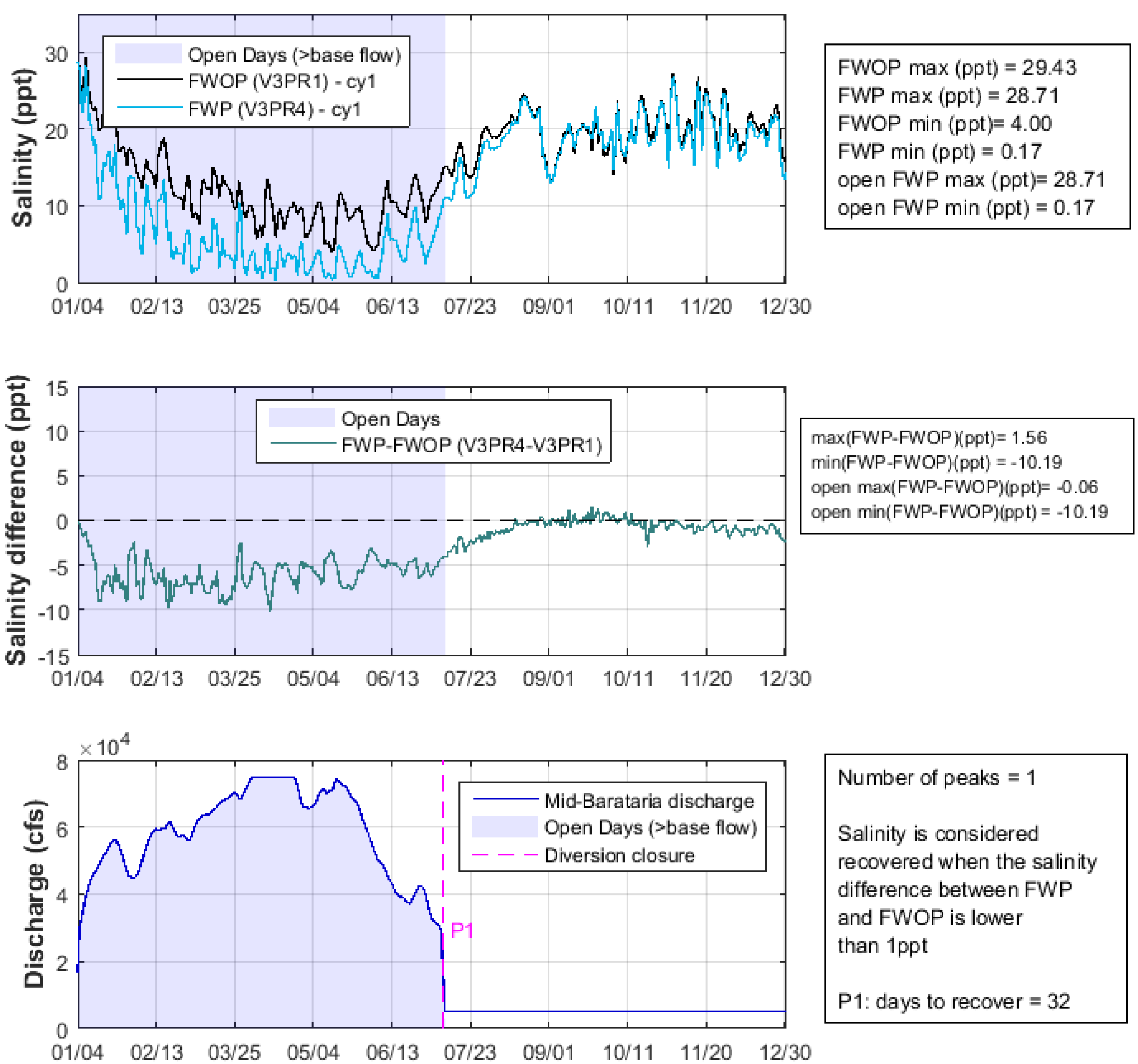


Figure 9b: Barataria Pass at Grand Isle

Applicant's Preferred Alternative – Years 2030-2039

*Diversion Scenario V3PR4, cycle 1 – FWP 75,000 cfs

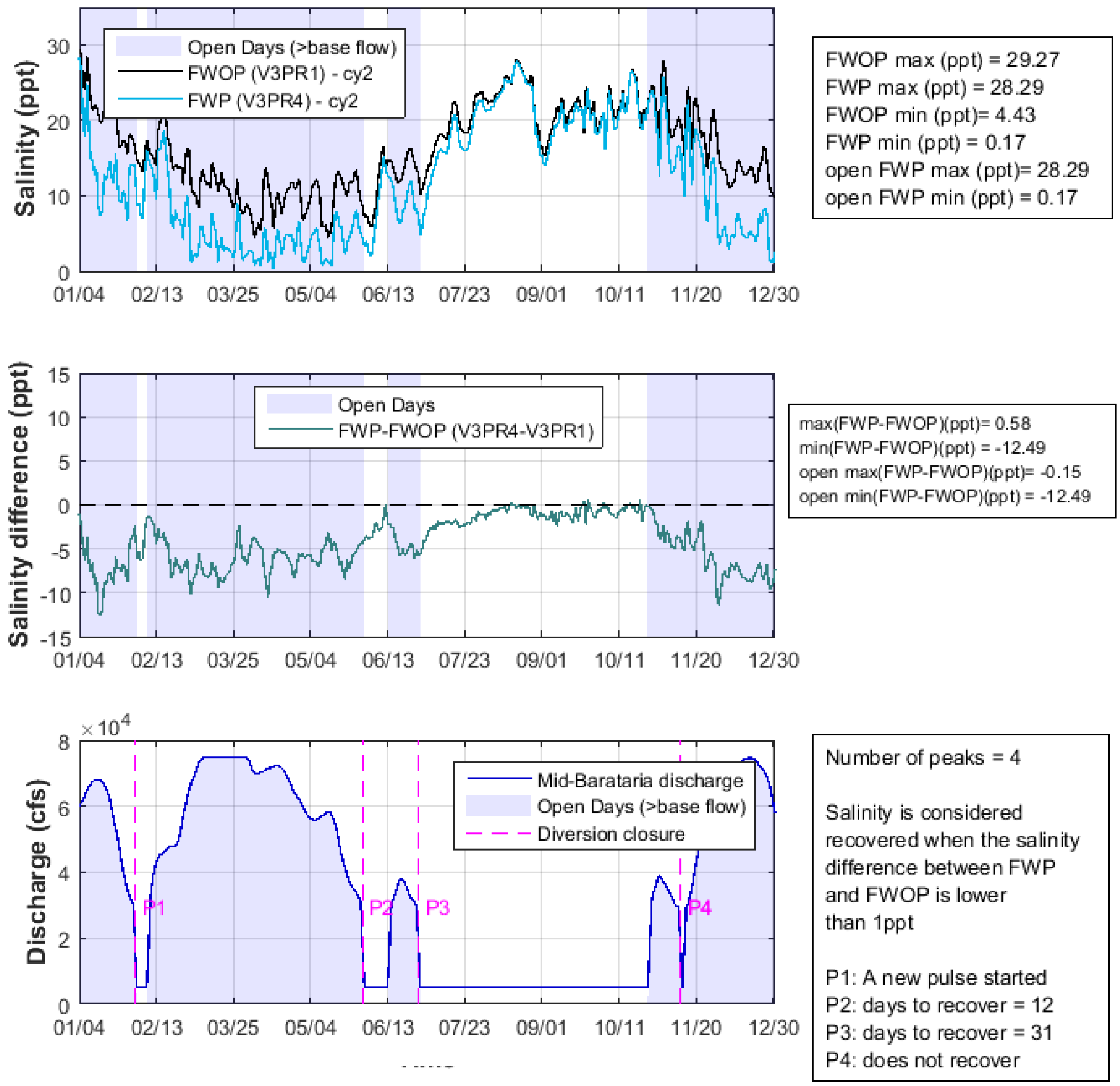


Figure 9c: Barataria Pass at Grand Isle

Applicant's Preferred Alternative – Years 2040-2049

*Diversion Scenario V3PR4, cycle 2 – FWP 75,000 cfs

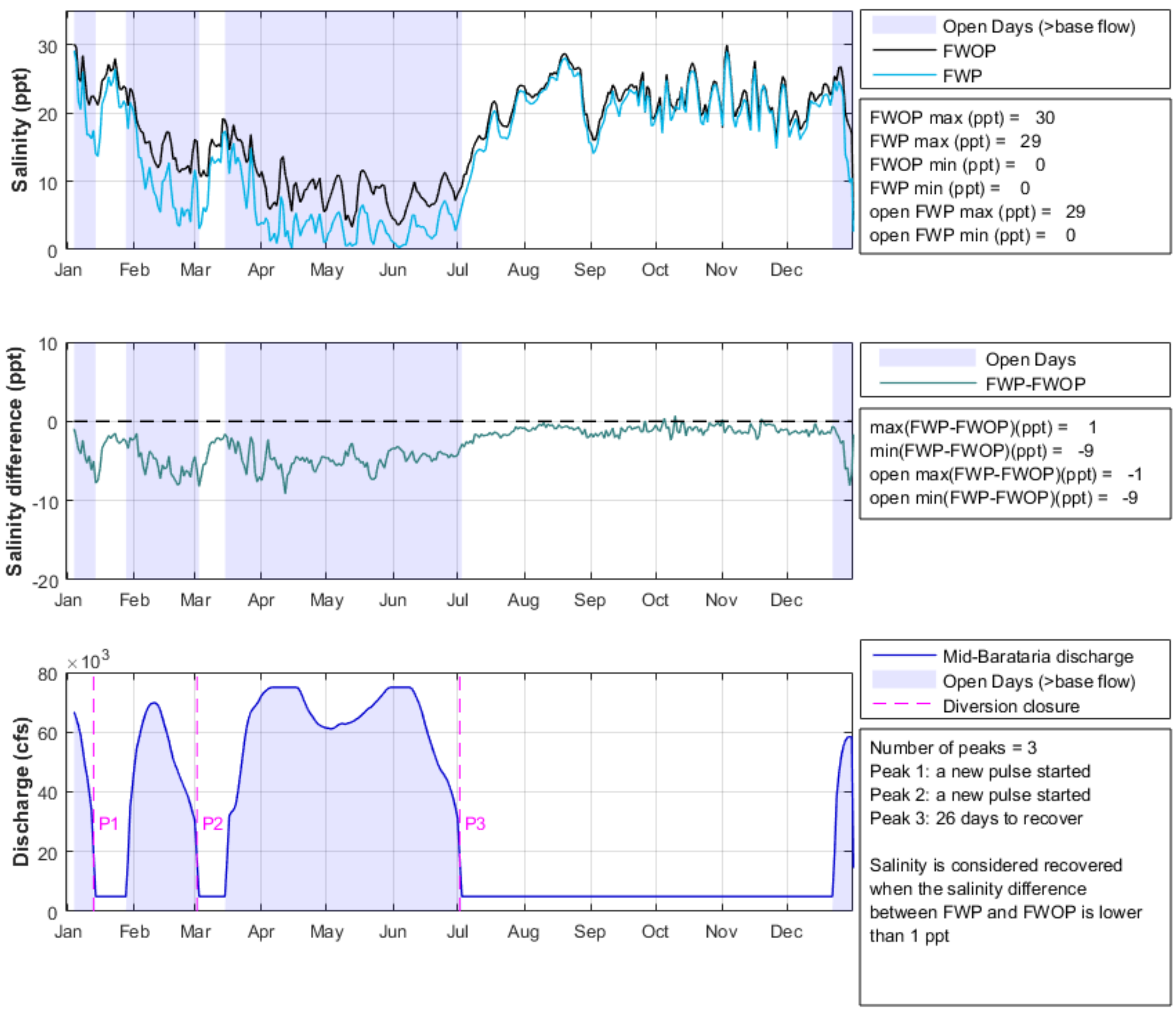


Figure 9d: Barataria Pass at Grand Isle

Applicant's Preferred Alternative – Years 2050-2059

*Diversion Scenario V3PR4, cycle 3 – FWP 75,000 cfs

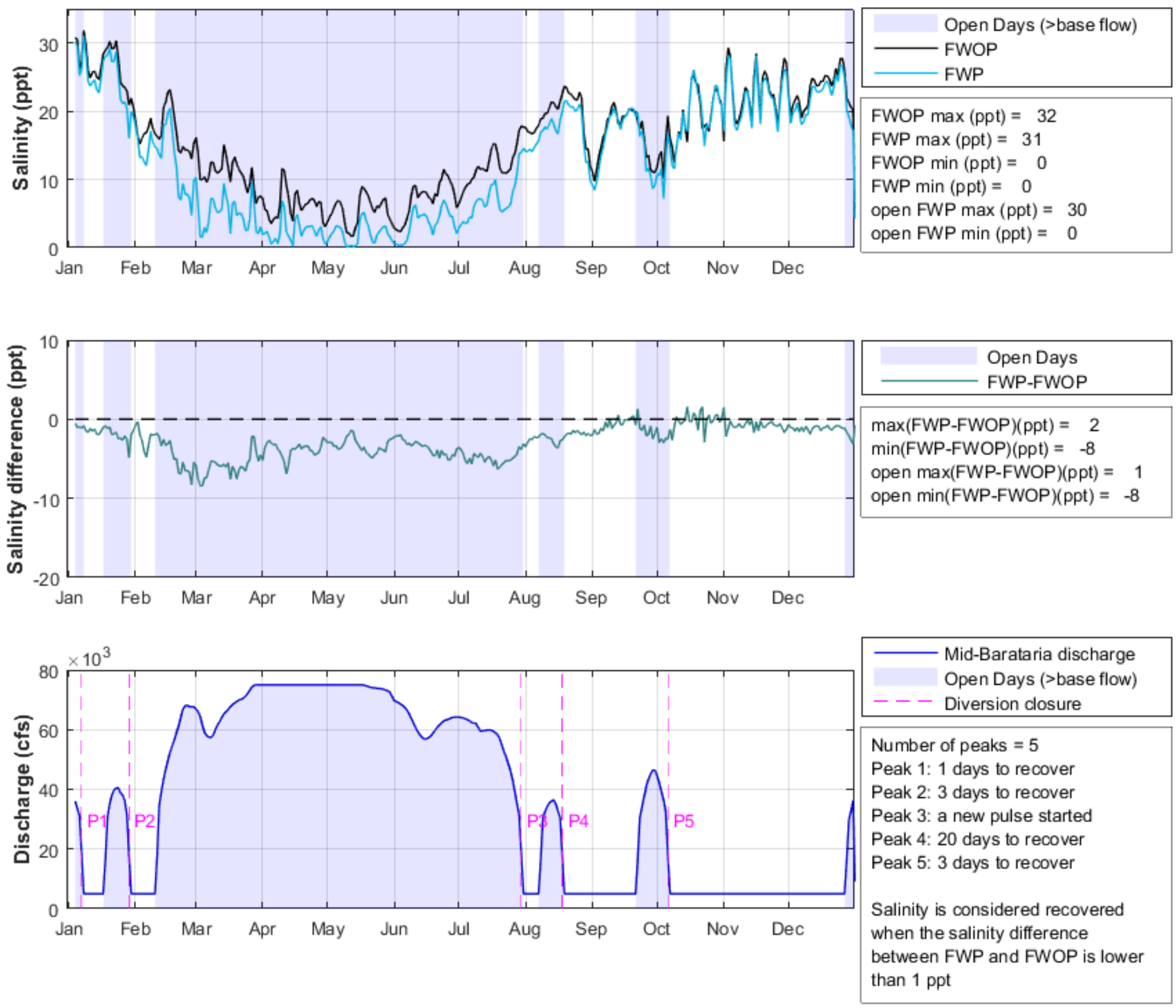


Figure 9e: Barataria Pass at Grand Isle

Applicant's Preferred Alternative – Years 2060-2069

*Diversion Scenario V3PR4, cycle 4 – FWP 75,000 cfs

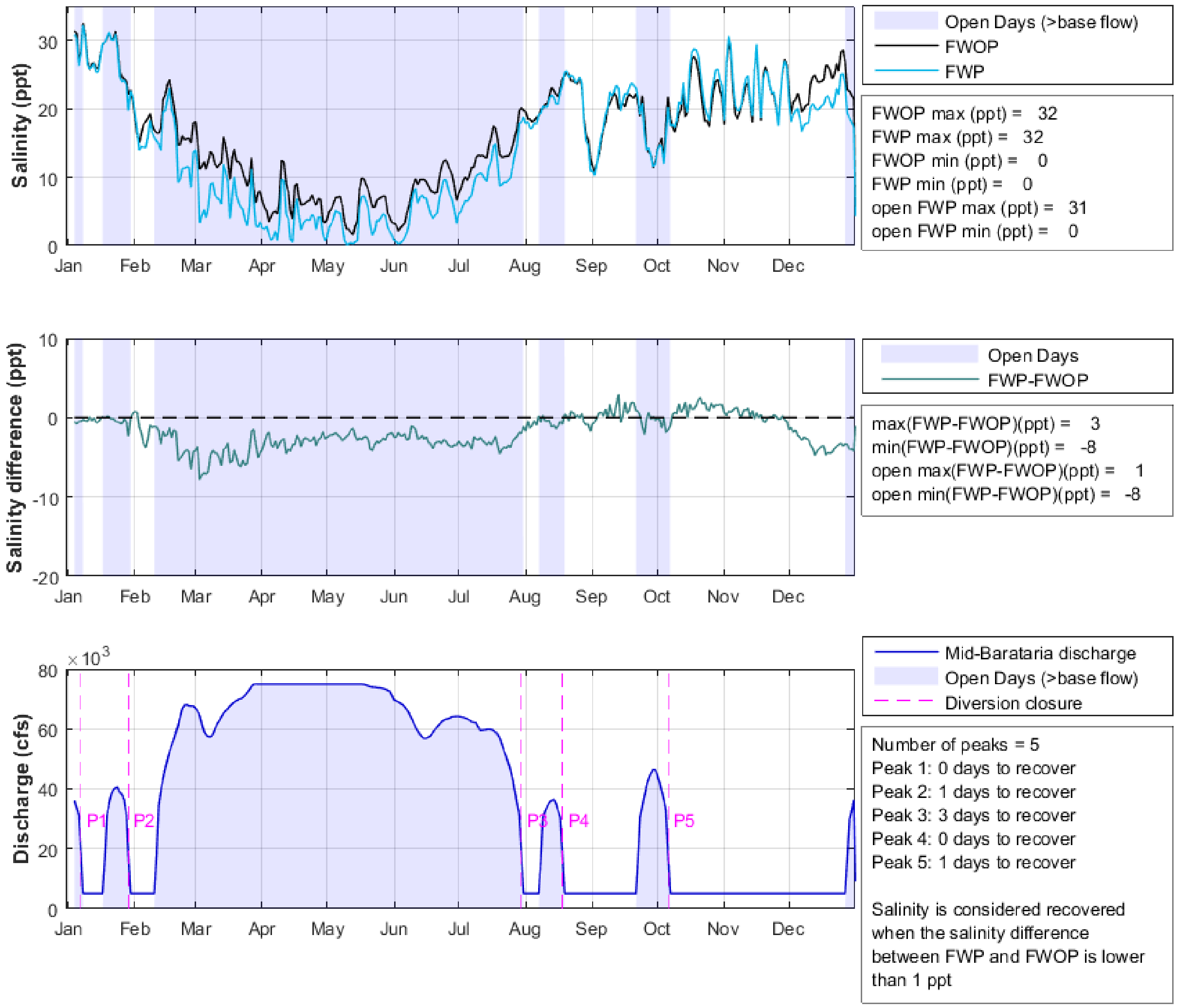


Figure 9f: Barataria Pass at Grand Isle

Applicant's Preferred Alternative – Year 2070

*Diversion Scenario V3PR4, cycle 5 – FWP 75,000 cfs

N2: Essential Fish Habitat Assessment

CONFLUENCE
ENVIRONMENTAL COMPANY

Mid-Barataria Sediment Diversion
ESSENTIAL FISH HABITAT ASSESSMENT

Prepared for:

Louisiana Trustee Implementation Group and the Coastal Protection and Restoration Authority

January 2021

146 N Canal St, Suite 111 • Seattle, WA 98103 • www.confenv.com

Mid-Barataria Sediment Diversion
ESSENTIAL FISH HABITAT ASSESSMENT

Prepared for:

Louisiana Trustee Implementation Group and the
Coastal Protection and Restoration Authority
Baton Rouge, Louisiana

Authored by:

Confluence Environmental Company
Seattle, Washington

January 2021

This report should be cited as:

LA TIG (Louisiana Trustee Implementation Group). 2021. Mid Barataria Sediment Diversion: Essential Fish Habitat Assessment. Prepared for CPRA and LA TIG, Baton Rouge, Louisiana, by Confluence Environmental Company, Seattle, Washington.

1.0 EXECUTIVE SUMMARY

The Coastal Protection and Restoration Authority of Louisiana is proposing to construct, operate, and maintain the proposed Mid-Barataria Sediment Diversion Project. The proposed Project consists of a multi-component river diversion system intended to convey sediment, fresh water, and nutrients from the Mississippi River at approximate River Mile (RM) 60.7 in the vicinity of the town of Ironton, Plaquemines Parish, Louisiana to the mid-Barataria Basin. After passing through a proposed intake structure complex at the confluence of the Mississippi River and proposed intake channel, the sediment-laden water would be transported through a conveyance channel to an outfall area in the mid-Barataria Basin located in Plaquemines and Jefferson Parishes.

Following construction of the Project it would be operated for 50-years based on the flows measured at the Mississippi River gage at Belle Chase. When Mississippi River flows exceed 450,000 cubic feet per second (cfs), flows through the diversion will increase from a base flow target of 5,000 to a maximum of 75,000 cfs. The maximum diversion flow will occur when the Mississippi River at the Belle Chase reaches 1,000,000 cfs.

The Louisiana Trustee Implementation Group has evaluated the Mid-Barataria Sediment Diversion Project to determine how the proposed action will affect Essential Fish Habitat (EFH) as managed under the Magnuson-Stevens Fisheries Conservation and Management Act. Essential Fish Habitat and managed species are shown in Tables ES-1 and ES-2

Table ES-1: Essential Fish Habitat in the Action Area with the Proposed Project

Essential Fish Habitat	Summary
Emergent marshes (tidal wetlands, salt marshes, tidal creeks, rivers/streams)	- Emergent mudflats and marsh acreage predicted to increase by approximately 13,400 acres in Barataria Basin by 2070. - Emergent mudflats and marsh acreage predicted to decrease by approximately 3,000 acres in the Birdfoot Delta by 2070. - Total aquatic vegetation (excluding SAV) acreage predicted to increase in Barataria Basin by 9,790 acres by 2070. - Marsh type shifts towards intermediate to fresh salinity.
Submerged Aquatic Vegetation (SAV)	- Net predicted increase of 2% (1,500 acres) of fresh/intermediate SAV by 2070 - SAV species shift towards fresh/intermediate salinity.
Soft bottom (mud, clay, silt)	- Dredging impacts approximately 700 acres of soft bottom habitat during construction. - Approximately 19,545 acres of habitat that would otherwise be soft bottom habitat converted to emergent marsh, aquatic vegetation, or SAV habitat. - Salinity decreases as a result of the project as described in section 6.5.1 may cause changes in habitat use.
Sand/shell bottom (sand, shell)	- Some existing sand/shell habitat may receive sediment and become soft bottom habitat or emergent marsh habitat.

Essential Fish Habitat	Summary
Oyster reefs	- Freshwater conditions may reduce oyster survival, reproduction and/or growth rates. - Oyster growing conditions predicted to decline in portion of Barataria Bay as described in section 6.6.4. - Future habitat improvements in lower Barataria Bay may create new habitat for oysters.
Water Column Associated (WCA; pelagic, planktonic, coastal pelagic)	- As described in section 6.6.1, conditions in the water column and associated species may shift as water conditions shift towards fresher, cooler, higher nutrient conditions associated with water from the diversion.

Table ES-1: Managed Fisheries

Managed Fisheries	Effect to Managed Species	Summary
Coastal Migratory Pelagic Fish		
King Mackerel (*Scomberomorus cavalla*	Neutral	Primary habitat is along front between estuarine and marine habitats. This front may shift, however will continue to exist.
Cobia (*Rachycentron canadum*)	Neutral	
Red Drum		
Red Drum (*Sciaenops ocellatus*)	Moderate Positive	Increased prey items from marsh and SAV habitat created by the Project.
Reef Fish		
Gray Snapper (*Lutjanus griseus*)	Minor Negative	Distribution may be limited to more saline portions of Barataria Basin. Some preferred prey items expected to decrease.
Lane Snapper (*Lutjanus synagris*)	Minor Negative	
Shrimp		
Brown Shrimp (*Farfantepenaeus aztecus*)	Negative	Reduced habitat quality for brown shrimp during diversion operations due to salinity reductions
White Shrimp (*Litopenaeus setiferus*)	Neutral to Minor Positive	Increased habitat quality due to wetland created by the Project
Highly Migratory Species		
Blacktip Shark	Neutral	Distribution not expected to be affected by changes in salinity. Prey resources are expected to be available throughout Barataria basin
Bull Shark	Neutral	
Finetooth Shark	Neutral	
Scalloped Hammerhead Shark	Neutral	
Atlantic Sharpnose Shark	Neutral	
Spinner Shark	Neutral	
Sailfish (*Istiophorus platypterus*)	Neutral	Associated with Mississippi River plume where no effects are expected
Atlantic Yellowfin Tuna (*Thunnus albacares*)	Neutral	Associated with Mississippi River plume where no effects are expected

During construction, dredging activities are expected to temporarily affect EFH by disturbing bottom sediments and increasing turbidity in the water column near the dredging activity. These activities can have adverse effects on federally managed species. Effects from dredging in the sediment removal area are expected to be temporary; however, habitats affected by beneficial use placement of dredged sediments are expected to transition from aquatic to wetland habitat for many years or permanently.

Operation of the Project is expected to have direct impacts on EFH due to the introduction of freshwater flow and sediment laden water from the Mississippi River into Barataria Basin. As a result, much of the action area will experience reduced salinities and changes in other metrics of water quality including nutrient levels and minor changes to dissolved oxygen. These water quality parameters will affect the suitability of habitat in Barataria Basin to support fishery species, with the effects varying from species to species.

Indirect impacts of the Project include beneficial effects to acreage of submerged aquatic vegetation and emergent marshes. Over the 50-year project time horizon, the resulting distribution of submerged aquatic vegetation and emergent marshes will be higher in the Future With the Project compared to the Future Without Project. Negative indirect impacts of the Project include conversion of oyster reef and sand/shell habitat to soft bottom habitat.

This assessment found that federal managed species use estuarine and Gulf habitats in and adjacent to the action area. The Project will have direct and indirect negative impacts to some components of EFH in the action area. The Project will also convert certain types of EFH from one category to another (e.g., water column to emergent marsh; oyster reef to soft bottom; brackish marsh to intermediate marsh, etc.). The Project will also result in beneficial impacts to some components of EFH through the restoration and maintenance of riverine deltaic processes, including sediment delivery and marsh creation, that have been absent due to major anthropogenic modifications of the system over the last century.

TABLE OF CONTENTS

TABLES

FIGURES

APPENDICES

ACRONYMS AND ABBREVIATIONS

°C	degrees Celsius
°F	degrees Fahrenheit
BA	biological assessment
BMP	best management practices
BUP	beneficial use placement
CASM	Comprehensive Aquatic Systems Model
CEC	Confluence Environmental Company
CFR	Code of Federal Regulations
cfs	cubic feet per second
CPRA	Coastal Protection and Restoration Authority of Louisiana
CPUE	catch per unit effort
CRMS	Coastwide Reference Monitoring System
CSAs	coastal study areas
CW	carapace width
cy	cubic yard
DDT	dichlorodiphenyltrichloroethane
DO	dissolved oxygen
DOI	U.S. Department of the Interior
DWH	Deepwater Horizon
DWH PDARP	The Deepwater Horizon Oil Spill Final Programmatic Damage Assessment and Restoration Plan
EEZ	Exclusive Economic Zone
EFH	essential fish habitat
EIS	Environmental Impact Statement
EPP	Environmental Protection Plan
ESA	Endangered Species Act
EwE	Ecopath with Ecosim (model)
FHA	Federal Highway Administration
FL	fork length
FMC	Fishery Management Council
FMP	Fishery Management Plan
FR	Federal Register
FWOP	Future Without Project
FWP	Future With Project
GMFMC	Gulf of Mexico Fishery Management Plan
HAPC	habitat areas of particular concern
HIS	Habitat Suitability Index
LA	Louisiana
LA TIG	Louisiana Trustee Implementation Group
LADOTD	Louisiana Department of Transportation & Development
LCA	Louisiana Coastal Area
LDWF	Louisiana Department of Wildlife and Fisheries
LJFL	lower jaw fork length
MAMP	Monitoring and Adaptive Management Plan

MBSD	Mid-Barataria Sediment Diversion
mg/L	milligrams per liter
MLLW	mean lower low water
MR&T	Mississippi River & Tributaries
MRL	Mississippi River Levee
NAVD88	North American Vertical Datum 1988
NEPA	National Environmental Policy Act
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOGC	New Orleans Gulf Coast Railway
NOV-NFL	New Orleans to Venice Non-Federal Levees
NPDES	National Pollutant Discharge Elimination System
NRDA	Natural Resource Damage Assessment
NTU	nephelometric turbidity unit
OPA	Oil Pollution Act
OTF	outfall transition feature
PAHs	polycyclic aromatic hydrocarbons
PBFs	physical or biological features
PCBs	polychlorinated biphenyls
PCEs	primary constituent elements
Phase I RP	Final Strategic Restoration Plan and Environmental Assessment #3: Restoration of Wetlands, Coastal, and Nearshore Habitats in the Barataria Basin, Louisiana
POSG	Public Oyster Seed Grounds
ppt	parts per thousand
psu	practical salinity unit
PVC	polyvinyl chloride
RM	river mile
RP	Restoration Plan
SAV	submerged aquatic vegetation
Services	U.S. Fish and Wildlife Service and National Marine Fisheries Service
SL	standard length
SLR	sea level rise
SPCC	spill prevention, control, and countermeasures
SR	State Route
SWPPP	stormwater pollution prevention plan
TESC	temporary erosion and sediment control
TSS	total suspended solids
TWI	The Water Institute of the Gulf
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USDOT	U.S. Department of Transportation
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
WCA	Water Column Associated
YOY	young-of-the-year

2.0 BACKGROUND AND HISTORY

The Coastal Protection and Restoration Authority of Louisiana (CPRA) is proposing to construct, operate, and maintain the proposed Mid-Barataria Sediment Diversion (MBSD) Project. This Project is proposed to maintain and rebuild eroding upland, and freshwater and coastal marsh habitat within the Barataria Basin. The Project is also intended to restore injuries to natural resources caused by the Deepwater Horizon oil spill. The Deepwater Horizon Oil Spill Final Programmatic Damage Assessment and Restoration Plan (DWH PDARP) was developed collaboratively under the Oil Pollution Act (OPA) by federal and Gulf Coast state natural resource trustee agencies (DHNRDAT 2016). The DWH PDARP includes a suite of coastal restoration objectives, including the use of sediment diversions to help maintain and rebuild coastal habitats. Furthermore, the Louisiana Trustee Implementation Group (LA TIG) published the *Final Strategic Restoration Plan and Environmental Assessment #3: Restoration of Wetlands, Coastal, and Nearshore Habitats in the Barataria Basin, Louisiana* (Phase I RP), consistent with OPA and the DWH PDARP. The proposed Project is a preferred alternative for restoring DWH Oil Spill injuries through restoration in the Barataria Basin. This Project is being evaluated for funding under the DWH PDARP restoration planning process by the LA TIG, who will make the final funding decision.

The LA TIG funding decision and the U.S. Army Corps of Engineers (USACE) permitting review process are collectively referred to as the proposed MBSD Project, proposed Project, or Project for the purpose of this this Essential Fish Habitat (EFH) Assessment. The Project constitutes a major federal action with the potential to significantly affect the quality of the human environment. The Project is, therefore, being evaluated under the National Environmental Policy Act (NEPA) through a detailed, interdisciplinary Environmental Impact Statement (EIS) supporting both the USACE and LA TIG decision processes. The Project is also being evaluated under the OPA and DWH PDARP through the development of the Phase II Restoration Plan (RP). This EFH analyzes the Project's potential effects to essential fish habitat. The EIS and RP contain additional details and background on the Project description, Project history, and direct, indirect and cumulative environmental impacts. The information presented here is consistent with the EIS, RP, and supporting reports provided by CPRA. Where appropriate, this document will refer to sections of the EIS or RP for additional information and incorporate that information by reference.

USACE and the LA TIG will use this EFH Assessment to inform consultation under the Magnuson-Stevens Fisheries Conservation and Management Act (MSA), Section 305(b)(2), for assessment of effects to EFH for both agency actions. This EFH Assessment therefore contains the information necessary to satisfy the requirements of 50 CFR 600.920(e)(1). The USACE and the LA TIG anticipate that the National Marine Fisheries Service (NMFS) will consolidate the EFH consultations for both actions and issue a single set of conservation recommendations.

2.1 Project Background

Sediment diversion projects have been included as a critical component of the state's Coastal Master Plans since 2007 (CPRA 2007, 2012, 2017). Previous studies examining sediment diversions from the Mississippi River, which informed the development of the proposed Project, can be found in EIS Section 1.2.2.1. Louisiana's 2017 Master Plan objectives applicable to the proposed Project include harnessing the natural processes that built Louisiana's coastal landscape, sustaining Louisiana's unique cultural heritage, and ensuring that Louisiana's coast continues to be both a sportsman's paradise and a hub for commerce and industry (CPRA 2017). The DHW PDARP also features sediment diversion projects as the primary approach to restore and preserve Mississippi-Atchafalaya River processes by increasing the long-term resilience and sustainability of deltaic wetlands by reducing widespread loss of existing wetland area (DHNRDAT 2016).

2.2 Barataria Basin History

The Barataria Basin was formed over 1,000 years ago as part of the Lafourche delta complex. The area forms a sub-estuary within the Mississippi River deltaic plain (U.S. Fish and Wildlife Service [USFWS] 1987). Historically, the Mississippi River deposited sediment, fresh water, and nutrients into the Barataria Basin during annual overbank flooding cycles; these deposits nourished and sustained wetland habitats. Levees and channelization of the Mississippi River altered natural sediment transport from the river into the basin, eliminating the source of sediment and fresh water that built and maintained wetlands and marshes. As a result, the basin is suffering from significant coastal habitat loss (Couvillion et al. 2011, CPRA 2012). The Barataria Basin lost approximately 29% of its total land area between 1932 and 2016 (Couvillion et al. 2017).

Land loss occurs due to a complex mix of natural and human causes, and the Barataria Basin has been impacted by multiple events and forces (described further in EIS Chapter 3), including the following:

- Storm and hurricane events
- Erosion, subsidence, and sea-level rise
- Industrial, commercial, and residential development
- Additional flood risk management and drainage efforts
- The Deepwater Horizon (DWH) oil spill

Various agencies and nongovernmental organizations have implemented coastal protection, restoration, and rehabilitation projects within the basin in response. The State of Louisiana has adopted a Coastal Master Plan that includes 124 projects that are expected to build or maintain more than 800 square miles of land over the 50-year planning horizon for the plan (CPRA 2017).

Additional information on past, present and reasonably foreseeable CPRA projects within the Project area can be found in the EIS Chapter 4. Additionally, the LA TIG has singled out the Barataria Basin as a key restoration target and has signaled its restoration intentions in this basin via a Strategic Restoration Plan (LA TIG 2018) that also identifies a large-scale sediment diversion as a critical aspect of holistic ecosystem restoration in this area.

2.3 Project Characteristics

The proposed Project is the construction, operation, and maintenance of a controlled sediment and freshwater inlet diversion structure, conveyance channel, and discharge system that will discharge sediment, fresh water, and nutrients from the Mississippi River into an outfall area within the mid-Barataria Basin. The diversion structure would be located in Plaquemines Parish on the right descending bank of the Mississippi River at river mile (RM) 60.7. The conveyance system will cut west through Plaquemines and Jefferson parishes to discharge into estuarine marsh habitat on the east side of mid-Barataria Bay (Figures 2.4-1 and 2.4-2).

The design elements of the proposed Project are separated into 3 categories:

- Diversion Complex – The diversion complex will comprise features that form the basic structural elements for water inlet and conveyance from the Mississippi River to the basin outfall area.

- Basin Outfall area – This is the basin side of the outfall area within the action area (Section 3.4), where initial delta formation is anticipated. This element includes the construction of features that have been determined to increase the efficiency of water and sediment accumulation.

- Auxiliary Features – These are Project elements that accommodate existing or future services and infrastructure, including road, rail, and utilities and drainage systems. These features are considered to be interrelated and interdependent and will be addressed in Section 3.3.6 below.

The proposed Project will require, at a minimum, 3 years to 5 years of construction, depending on the extent of needed ground modifications and soil stabilization measures. Based on preliminary plans, construction will likely occur in several phases.

The proposed Project includes a diversion operations plan. Operation of the large-scale sediment diversion will be triggered with gates opening for flow when the Mississippi River gage at Belle Chasse reaches 450,000 cubic feet per second (cfs) and reducing to a base flow of 5,000 cfs when flow at the Belle Chasse gage falls below 450,000 cfs. When Mississippi River flows exceed 450,000 cfs, flow through the diversion will vary, with a maximum diversion flow of 75,000 cfs. Flow rates will increase proportionately to flow in the Mississippi River until the Mississippi River gage at Belle Chasse reaches 1,000,000 cfs, at which point flow through the diversion will be capped at 75,000 cfs. Operations will be maintained in a manner to prevent reverse flow from the Barataria Basin to the Mississippi River. Diversion operations may be suspended prior to and during major storm events to prevent flow from moving from Barataria Basin into the Mississippi River.

2.4 Project Location

The structural features of the proposed Project are located in south Louisiana on the west bank of the Mississippi River at RM 60.7, just north of the town of Ironton, and the anticipated outfall area for sediment, fresh water, and nutrients conveyed from the river is located within the mid-Barataria Basin (see Figures 2.4-1). The proposed Project area comprises the area within the hydrologic boundaries of the Barataria Basin and the western portion of the lower Mississippi River Delta Basin. The proposed Project area also includes the Mississippi River itself beginning near RM 60.7 and extending to the mouth of the river. Detailed information regarding the proposed Project features and the MBSD Project area can be found in the EIS Chapter 2 and Section 3.1, respectively.

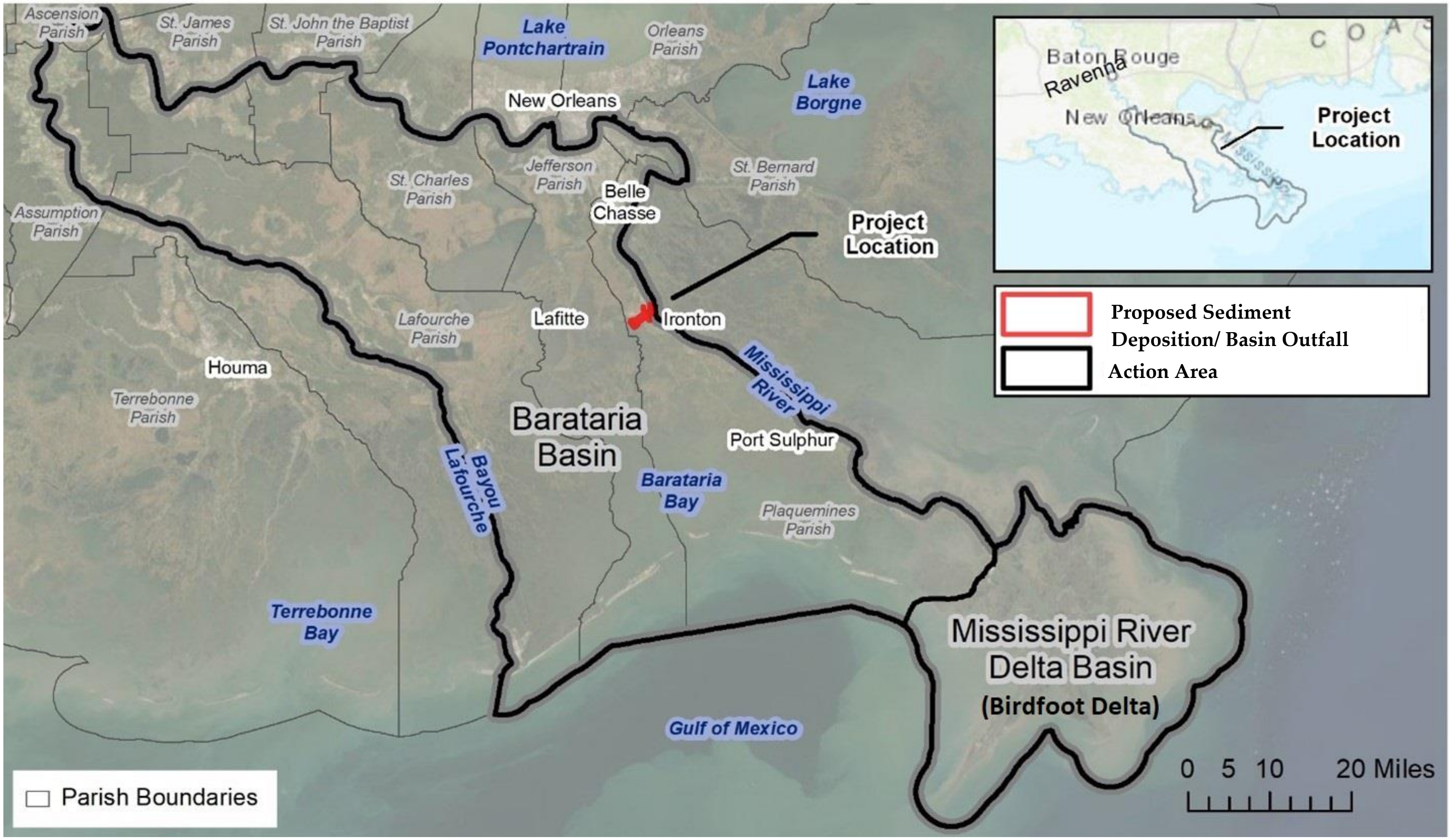


Figure 2.4-1. Location of Project Area (Barataria Basin, western portion of the lower Birdfoot Delta Basin, the Mississippi River from RM 60.7 to the mouth, and a portion of the northern Gulf of Mexico).

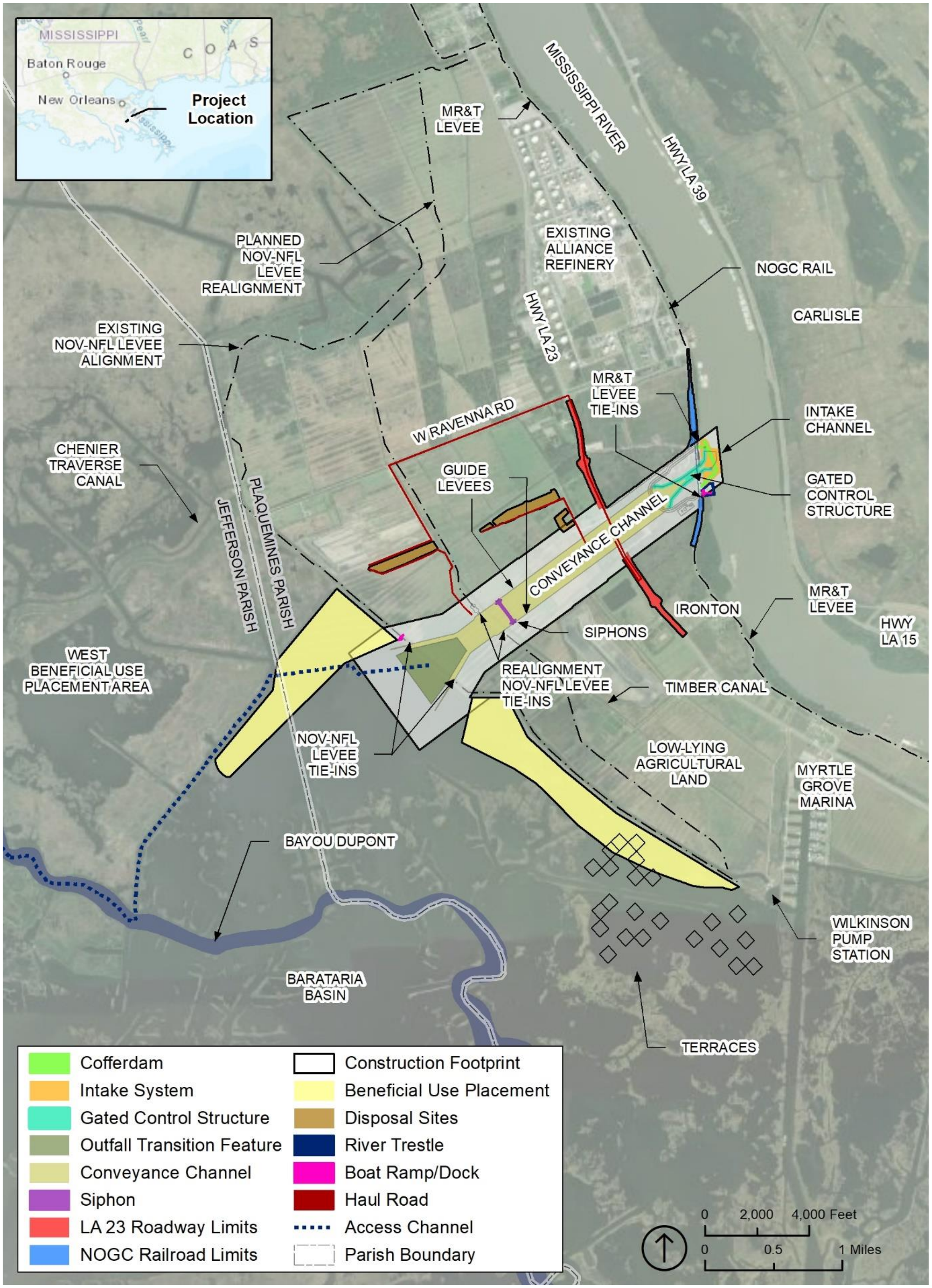


Figure 2.4-2. Project Design Features and Construction Footprint

2.5 Pre-Consultation Technical Assistance

Federal agencies including CPRA, the USACE, and the USFWS and NMFS (the Services) have been participating in a pre-consultation technical assistance process. The goal of this process is to facilitate collaboration between regulatory entities as the Project progresses through NEPA, Endangered Species Act (ESA) and EFH consultation, project design, acquisition of permits, and definition of mitigation. This process has provided a forum for the following:

- Ensuring project consistency with regulations
- Sharing information with regulatory agencies in real time
- Clarifying regulatory agency preferences based on design
- Identifying issues early enough to avoid costly redesigns and schedule delays
- Providing feedback to the project team about how best to comply with anticipated permit requirements
- Testing potential courses of action and airing assumptions in a collaborative environment
- Identifying where regulatory agency requirements differ and developing approaches for reconciling these differences
- Building collaborative relationships

The LA TIG, which is responsible for restoring the natural resources and services within the Louisiana Restoration Area that were injured by the DWH oil spill, has also been involved in this process. The LA TIG has convened numerous working groups to address various aspects of the Project that are relevant to the EFH Assessment. These include the following:

- A MBSD Monitoring and Adaptive Management Plan (MAMP) development working group
- A Modeling Workgroup addressing the various models being used to evaluate Project impacts, including Delft 3D, Ecosystem Models, and ADCIRC
- An ESA and EFH Workgroup

2.6 Recent Consultations and Existing Information

Prior consultations with the Services regarding projects that overlap the geographic area, activities, species, or habitats may provide guidance for many facets of the current EFH Assessment. During the pre-consultation technical assistance process, the Services identified the following consultations and processes that help inform the current EFH assessment:

- Framework Biological Opinion on Deepwater Horizon Oil Spill Final Programmatic Damage Assessment and Restoration Plan and Final Programmatic Environmental Impact Statement (SER-2015-17459) (NMFS 2016)
- USACE Projects
  - Louisiana Coastal Area (LCA) Small Diversion at Convent/Blind River (USFWS 2009)
  - LCA Medium Diversion at White Ditch (USFWS 2010)
  - Bonnet Carré Spillway 2011 and 2016 Emergency Operations (USFWS 2018)

The Biological Opinion listed above analyzes the Project area for restoration actions resulting from the DWH PDARP—a framework for a comprehensive programmatic restoration plan that will guide the development of Project-level actions. While the MBSD Project is a component of the DWH PDARP, it was recognized that sediment diversion projects will require independent evaluations.

The 3 USACE projects listed above represent existing Mississippi River flow diversion activities. Each project contains similarities to the MBSD; however, the MBSD occurs at a different section of the Mississippi River, discharges into different basins, and has different planned operational characteristics.

3.0 DESCRIPTION OF THE PROPOSED PROJECT AND ACTION AREA

The following section describes the proposed Project, which will define the proposed Project and action area for the EFH assessment.

Information in this section is consistent with the EIS, RP, and supporting information provided by CPRA. Where appropriate, this section will refer to sections of the EIS or RP for additional information.

3.1 Discussion of Federal Action and Legal Authority

The regulatory authority of the USACE for this project includes Section 10 of the Rivers and Harbors Act and Section 404 of the Clean Water Act (CWA) (collectively referred to as "Section 10/404"), as well as Section 408 of the Rivers and Harbors Act of 1899. USACE approvals and permissions under these authorities constitute a federal action that may affect EFH.

In addition to the USACE permitting review, Natural Resource Damage Assessment (NRDA) funds arising from the DWH oil spill settlement are being considered as a potential funding source for this project. These funds are managed by the LA TIG, which includes several federal agencies (NOAA, U.S. Department of the Interior [DOI], the U.S. Environmental Protection Agency [USEPA] and U.S. Department of Agriculture [USDA]). NOAA serves as the lead federal natural resource trustee for the DWH PDARP. The federal trustees' approval of funds for this project also constitute a federal action that may affect EFH.

3.2 Project Purpose

The purpose of the proposed Project is to restore for injuries caused by the DWH oil spill by implementing a large-scale sediment diversion in the Barataria Basin that will reconnect and reestablish sustainable deltaic processes between the Mississippi River and the Barataria Basin through the delivery of sediment, fresh water, and nutrients to support the long-term viability of existing and planned coastal restoration efforts (LA TIG 2019, GEC 2019). This project purpose is consistent with LA TIG's Strategic Restoration Plan and Environmental Assessment #3 and the 2017 Louisiana Coastal Master Plan, and as stated by CPRA in their Section 404 permit application. The proposed Project is needed to help restore habitat and ecosystem services injured in the northern Gulf of Mexico as a result of the DWH oil spill.

3.3 Project Description

This section will provide a detailed description of the Project, including the major Project elements from construction through operation and maintenance. Interdependent and interrelated actions will also be described.

Development of the Sediment Diversion will include the following Project elements:

- Diversion Complex
  - Intake System
  - Gated Control Structure
  - Conveyance Channel
  - Guide Levees
- Outfall Area
  - Outfall Transition Feature
- Auxiliary Features
  - Beneficial Use Placement Areas
  - Mitigation

An overview of the Project Description is captured in Table 3.3-1.

Table 3.3-1. Mid-Barataria Sediment Diversion Project Activities with Potential to Affect EFH

Project Element	Project Feature	Project Phase	Project Action	Habitat (Aquatic/ Terrestrial)	Aquatic Interaction (River/Basin)
Diversion Complex	All Features	Diversion Operations	Baseline diversion flow (5,000 cfs diverted)	A	R,B
Diversion Complex	All Features	Diversion Operations	Intermediate diversion flow - river between 450,000 and 1,000,000 cfs (Between 5,000 and 75,000 cfs diverted)	A	R,B
Diversion Complex	All Features	Diversion Operations	High diversion flow River >1,000,000 cfs (75,000 cfs diverted)	A	R,B
Diversion Complex	All Features	Construction Activities: Phase 1 (Site Prep)	Clearing and grubbing the limits of terrestrial construction	T	R, B
			Access: haul road excavation and construction, unloading areas, parking pads, fencing	T	R, B
			Staging: constructing and/or stabilizing staging areas	T	R, B
			Access: Trestle Construction	A	R
			Access: dredging for barge access (basin side)	A	B
		Construction of Foundation Systems: Phase 1-3 (Construction)	Surcharge area with excess fill to consolidate sediments	T	R, B
			Dewatering/rewatering	A	R, B
			Excavation	A	R, B
	Guide Levees	Construction Activities: Phase 2-3	Sediment placement	T	R, B
			Establish vegetation	T	R, B

Project Element	Project Feature	Project Phase	Project Action	Habitat (Aquatic/ Terrestrial)	Aquatic Interaction (River/Basin)
			Install wells	T	R, B
Basin Outfall Area	Outfall Transition Feature	Construction Activities: Phase 1 (Site Prep	Clearing and grubbing the limits of aquatic construction	A	B
			Staging (barge landing)	A	B
			Staging (pier)	A	B
			Staging during construction. Barge delivered materials	A	B
Auxiliary Features	Linear Infrastructure	Railway (NOGC)	Railway bridge construction	A, T	R
		Highway LA 23	Raised and relocated	T	N/A
		Utilities - Power	Relocation of existing power Right-of-Way (ROW)	T	N/A
		Utilities - Fiber Optic	Relocation of existing Fiber Optic ROW	T	N/A
		Utilities - Water	Relocation of 16-inch water main for Plaquemines Parish	T	N/A
		Utilities - Shell Pipeline	Relocation of existing Shell Pipeline	A, T	B
		Drainage System	Siphon drain option	A, T	B
	Beneficial Use Placement Areas	Beneficial Use Placement Areas	Beneficial Use Placement Areas	A	B
	Mitigation	Wetland and aquatic mitigation	Construction of wetland and aquatic mitigation	A	R, B
Diversion Complex	All Features	Maintenance of Sediment Diversion	Debris management	A	R, B
			Channel repairs/modifications	A	R, B

3.3.1 Site Preparation

Construction of the major Project features include clearing and grubbing, stockpiling and placement of material, excavating and constructing of haul roads (including drainage channels, cross-drain structures, and access fencing), hauling of material, grading and paving, dredging, pumping of dredged material to prepared disposal site(s), installation of sediment and erosion control measures and slope protection, permanent and final stabilization, and extension of utilities to serve the proposed Project. A more detailed description of the construction of the proposed Project is provided in Appendix A.

Various types of equipment would be present and operating throughout the construction of the Project, including excavators, trucks, loaders, dozers, rollers, scrapers, pile drivers, cranes, barges, and well point drill rigs for dewatering. The means and methods of the construction contractor will determine what equipment would be on site. A concrete batch plant will be placed in the proposed construction footprint to produce the large volumes of concrete needed for the large structures. A temporary offloading facility may be constructed by the contractor to accommodate safe materials transfer.

Staging Areas

Areas associated with Project construction activities will be located within the overall footprint of the construction limits. Staging areas and construction yards will be about 8 acres. A concrete batch plant will be about 4 acres. The contractor will select the final size and locations of these areas. Staging areas will include the following:

- Haul and access roads
- A concrete batch plant
- Barge offloading facilities located on the Mississippi River and in the Barataria Basin
- A staging area for barge-delivered materials
- Construction yards
- A laydown area for drying and processing clay borrow from excavations

Transport/Access Routes

Access routes will be used to transport construction equipment, deliver equipment, and to dredge the outfall transition feature. There is 1 planned access routes from the north to proposed outfall area, as shown in Figure 3.3.1-1. This route follows a route used for previous restoration projects that had similar required draft for vessels. The route can be accessed from the Gulf Intracoastal Waterway via the Barataria Bay Waterway. The Project will also utilize the Mississippi River, which is navigable by ocean-going vessels up to Baton Rouge and by barge traffic all the way to the Port of Minneapolis, Minnesota.

The Basin-side routes may be adjusted based on survey of bathymetry and presence of underwater obstructions, or oil and gas infrastructure. The route avoids most pipelines in the area, however, pipelines parallel to the existing New Orleans to Venice Non-Federal Levees (NOV-NFL) may be unavoidable and these pipelines may need to be lowered to facilitate dredge access for the Project. Approximately 303,000 cubic yards are projected to be excavated for the channel. The barge and equipment access route includes dredging a bottom width of approximately 50 feet and bottom elevation of -9.00 feet North American Vertical Datum 1988 (NAVD88) to provide flotation clearance during the construction phase. The current channel has an average depth of approximately -4 ft NAVD88. Excavated materials will be deposited adjacent to the channel and deposition areas are projected to create a crest that would be exposed to approximately +2 ft (NAVD88) above the mean tide line.

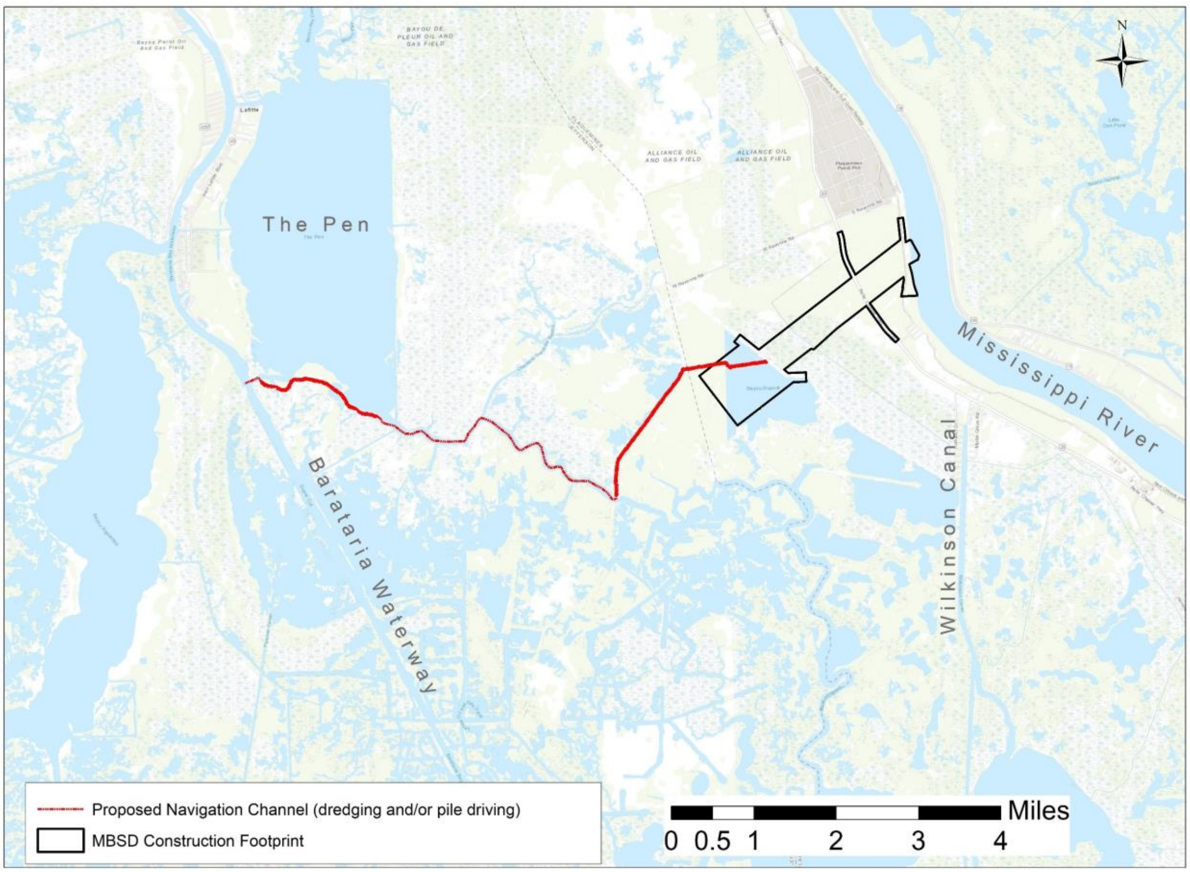


Figure 3.3.1-1. Potential Access Routes that May be Dredged for Barge Access

3.3.2 Sediment Diversion Construction

The proposed Project would require, at a minimum, 3 years to 5 years of construction, depending on the extent of needed ground modifications and soil stabilization measures. Construction would likely occur in several phases.

The design elements of the proposed Project are separated into 3 categories: (1) diversion complex, (2) basin outfall area, and (3) auxiliary features (Figures 3.3.2-1, 3.3.2-2, 3.3.2-3, 3.3.2-4 and 3.3.2-5). Design elements of the diversion complex and basin outfall area are described below. Auxiliary Features are described as interdependent and interrelated actions and are described in Section 3.3.6.

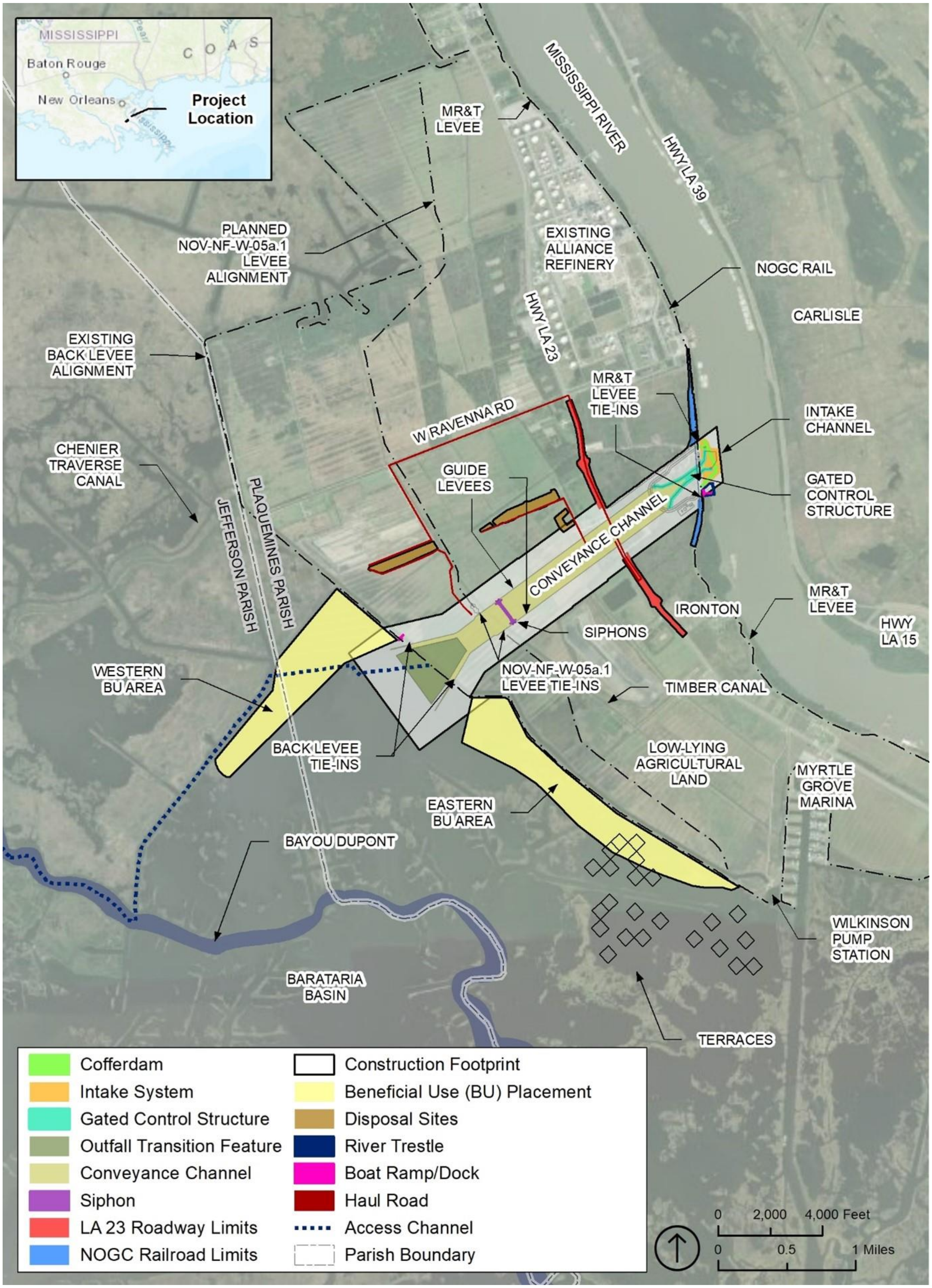


Figure 3.3.2-1. Project Construction Footprint

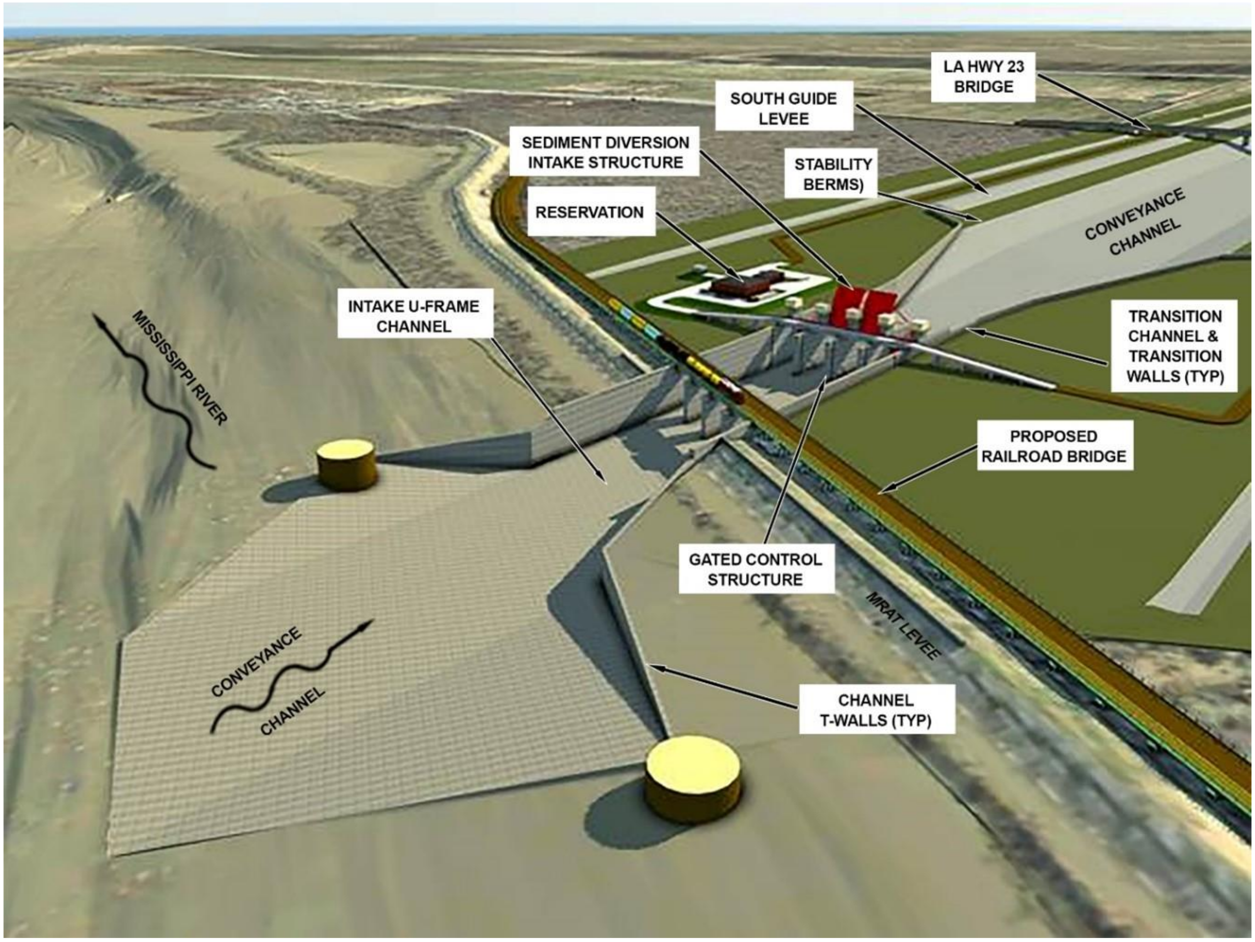


Figure 3.3.2-2. Proposed Project Design Features as Viewed from the Mississippi

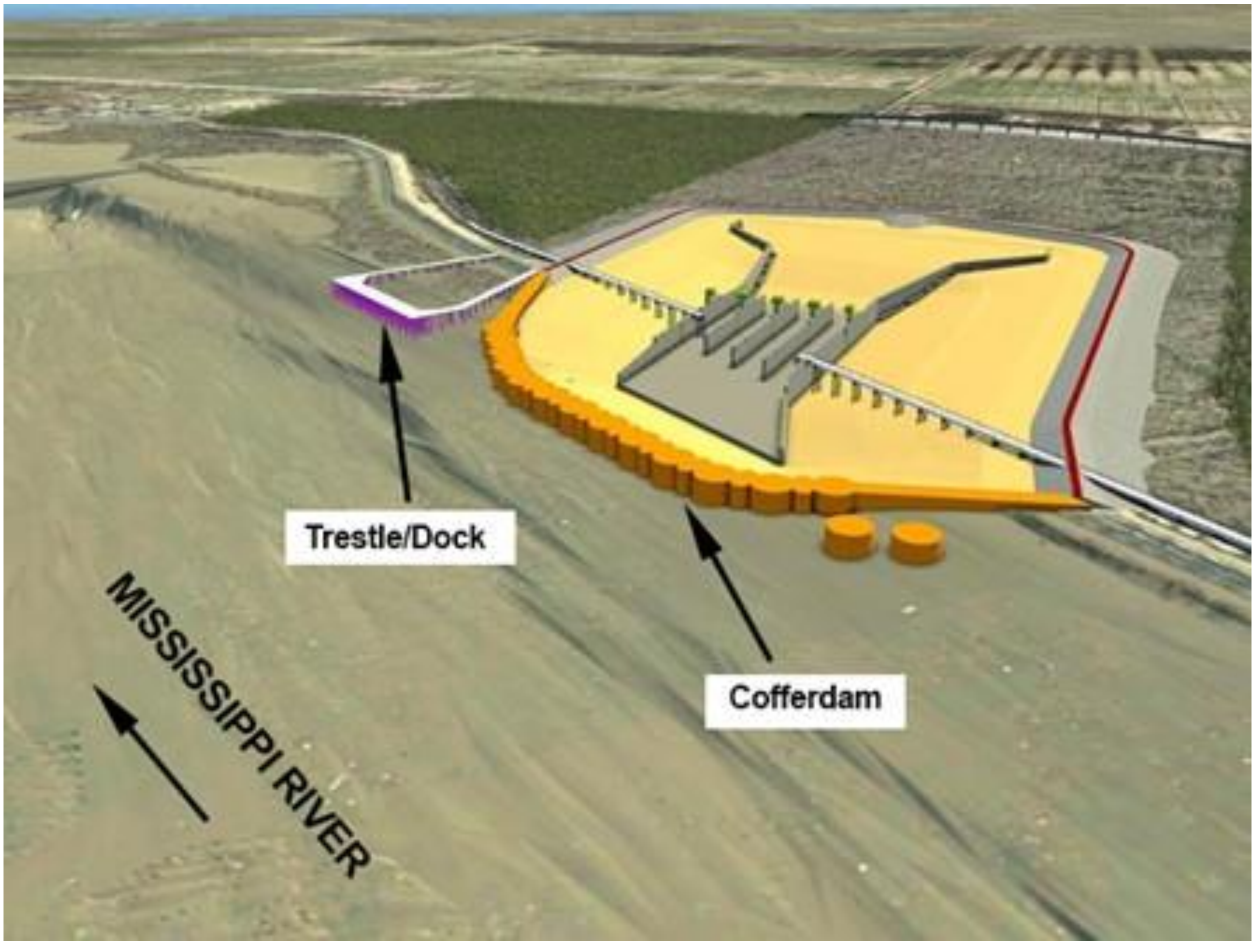


Figure 3.3.2-3. Proposed Trestle and Construction Cofferdam Overview

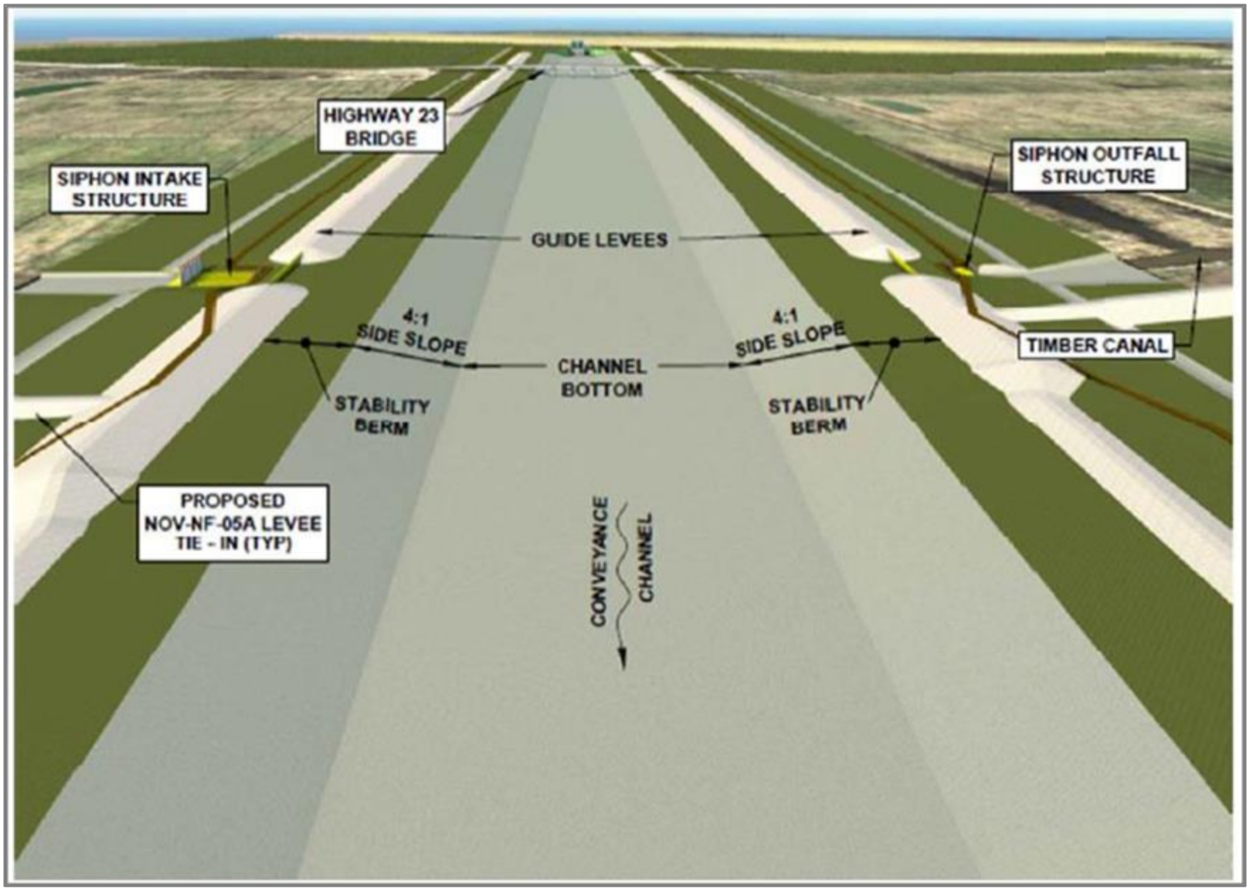


Figure 3.3.2-4. Proposed Conveyance Channel, Guide Levees, Stability Berms, and Siphon

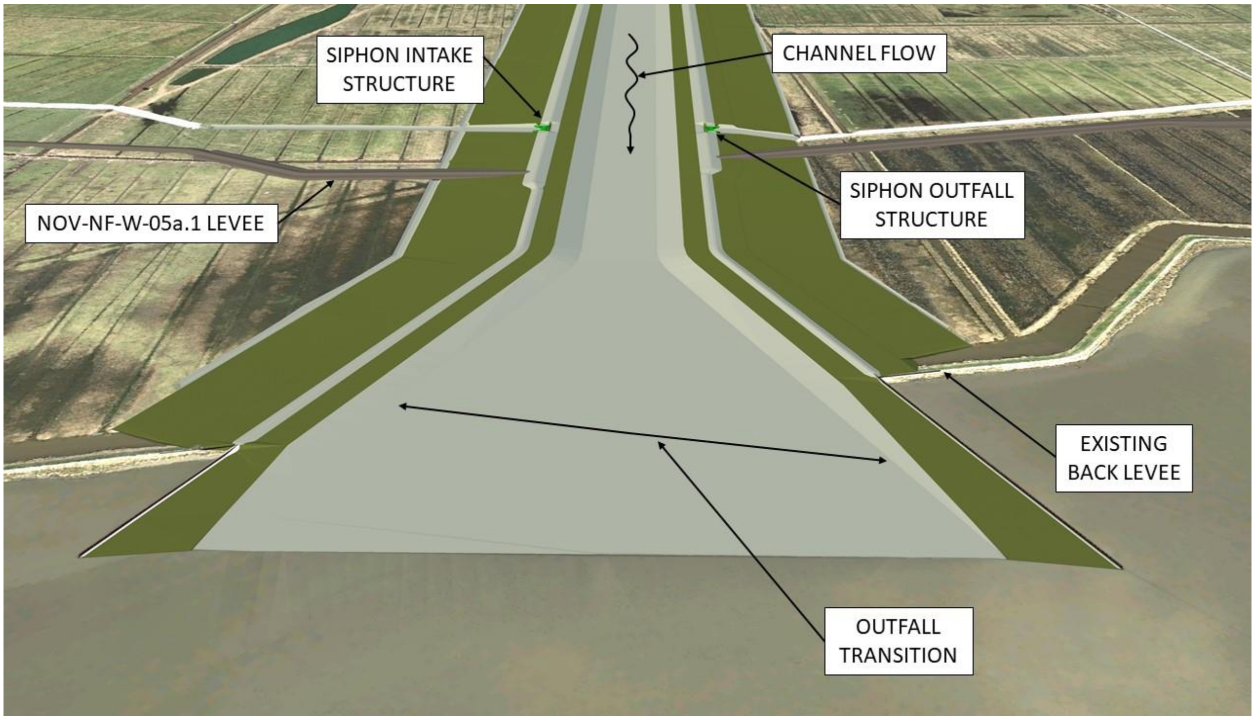


Figure 3.3.2-5. Proposed Outfall Transition Feature

Diversion Complex

The diversion complex would consist of the following features: intake system structure, gated control structure, conveyance channel guide levees, and stability berms. These features would be designed to convey sediment, fresh water, and nutrients from the Mississippi River to the Barataria Basin by way of a control structure confined by guide levees and with enough velocity to prevent buildup of siltation in the channel and to protect against scour. During construction a pile supported trestle with a total surface area of approximately 36,000 s.f. would be installed just downstream of the intake along the Mississippi River for material transfer (Figure 3.3.2-2). The proposed construction limits for the diversion complex would be approximately 1,015.4 acres.

Intake System

The intake system consists of an intake structure (with two flared training walls and an intake channel), a gated control structure, and a transition channel that would connect to the larger conveyance channel (Figures 2.3.2-1 and 2.3.2-2). The training walls and intake channel would be located on the Mississippi River bed slope and adjacent to the sand bar, which occurs at an approximate depth elevation of -50 feet to -70 feet. The training walls would extend into the Mississippi River about 950 feet shoreward (west) of the Mississippi River navigation channel limits.

The training walls would direct the flow of sediment from the river into the intake and restrict riverbank soils from filling in the channel. The walls would be inverted pile-founded T-walls that would gradually increase in elevation from 0.0 and -13.0 feet, respectively, in the river to approximately 16.4 feet where they would connect to the intake channel walls. A temporary cofferdam system would be built around the proposed training walls to dewater the area during construction. It is estimated the cofferdam will be in place for up to 3.5 years. After construction, the cofferdam system would be removed.

Gated Control Structure

The gated control structure would consist of 4, 45-foot-wide steel tainter gates with an invert elevation of -40 feet and a top-of-wall elevation of 16.4 feet. Water flow would be regulated by raising or lowering the gates. The river side of the structure would tie into the current Mississippi River & Tributaries (MR&T) Project Levee alignment, with 4 machine rooms and a maintenance bridge across the top. The gates would be operated with commercial power; diesel generators would be used as back-up. For seepage control, subsurface cutoff walls and drainage systems would be incorporated.

From the gated control structure, water would be funneled through a U-shaped transition channel with widths increasing from the gated control structure to the trapezoidal conveyance channel. The transition wall system under consideration would be pile-supported inverted T-walls.

Construction methods for the gated control structure are provided in EIS Section 2.8 and include the following: construction of subsurface seepage cutoff walls and drainage systems; construction of a temporary setback levee to reduce the risk of flooding until the gated control structure is completed; and construction "in-the-dry" behind the existing MR&T Levee.

Conveyance Channel

The conveyance channel, lined with bedding stone and riprap, would convey sediment-laden river water from the gated control structure and transition channel to the Barataria Basin. From the gated control structure, water would be funneled through transitional widths. The conveyance channel would have a 300-foot bottom width with an invert elevation of –25 feet, setback berms between the top of channel and toe of the guide levees, and guide levees (see Figure 3.3.2-3). The total width of the conveyance channel, stability berms, and guide levees would measure 734 feet and would occupy approximately 563 acres, including the guide levees. The channel would cut through a complex geologic environment that includes point bar deposits, marsh deposits, and abandoned distributary channels.

Construction of the conveyance channel would include clearing and grubbing of the site. The wooded area east of LA 23 would be cleared of trees, since these are not permitted near levees or stability berms. Mechanical and hydraulic excavation methods would be used to excavate the channel. Two USACE-approved and environmentally cleared levee clay borrow sites located contiguous to the proposed conveyance channel would be used for fill material for embankments/levee construction if needed, in addition to material generated from channel excavation. Construction methods are detailed in the EIS Section 2.8.

Guide Levees

Earthen guide levees would be constructed along both sides of the conveyance channel as a linear feature designed to constrain project flows (Figure 3.3.2-3). Drain systems would be incorporated into the levees to expedite soil consolidation and settlement. It is anticipated that multiple lifts and construction sequences would be needed to bring the guide levees to their final design height. The guide levees would also serve as hurricane flood protection against storm surges and would be built to an elevation of 15.6 feet, which is the USACE Design Grade for the proposed upgraded NOV-NFL levee. The levees would include a 10-foot-wide levee crown topped with a gravel access road. The levees would be constructed from soil material excavated for construction of the intake channel and conveyance channel.

Basin Outfall Area

The outfall area is defined as the area on the basin side of the outfall channel that will receive the sediment, fresh water, and nutrients from the Mississippi River via the conveyance channel. This area is delineated by Cheniere Traverse Bayou to the north, Wilkinson Canal to the south, and the Barataria Bay Waterway to the west, and is approximately 676 acres (Figure 3.3.2-1). The area largely consists of degraded wetland, shallow open water, and oil and gas canals. It is anticipated that a delta will form in the outfall area. Details about project-induced land building in the basin are provided in the EIS Section 4.2.

Modeling efforts indicate that, upon proposed project initiation, sand and coarse-grained sediments would be deposited within the outfall area in an initial delta formation with deposition of finer-grained sediment extending further gulfward in the basin, forming a subaqueous delta just below the low-tide water level. Over time, the subaqueous delta will evolve into a subaerial delta above the low-tide water level as vegetation becomes established and encourages additional deposits of sediment. This would in turn extend the formation of new subaqueous delta farther gulfward into the basin. Fine-grained sediments transported by the diversion will travel farther from the outfall area and be dispersed throughout the proposed Project area.

Outfall Transition Feature

The Project design includes the creation of an outfall transition feature (OTF) to increase the efficiency of water and sediment delivery. To create the OTF, the receiving basin surrounding the outlet will be dredged to create a gradual gradient from the diversion channel invert elevation of -25 feet (the bottom grade elevation of the channel) to the existing bed elevation of the receiving basin (-4 feet). The OTF is designed to provide sufficient bed topography for the diversion to flow at maximum capacity, expediting initial delta formation. The OTF will be created by dredging bottom sediment from the open water area within about 640 acres (1 square mile) of the outfall transition walls of the diversion structure. These sediments will be placed at designated beneficial use locations in the receiving basin shown in Figure 3.3.2-1. The bottom of the OTF will be armored with riprap.

Pile Driving

Temporary cofferdams would be used during Project construction for dewatering in-water work areas, controlling groundwater, and to provide structural support. Installation methods may include impact, auguring, vibrating, or other methods. In general, upland pile driving may use either impact or vibratory pile drivers without noise attenuation. Sheet and H piles will be installed using vibratory methods to the extent practicable. In-water pilings may be driven with impact or vibratory pile drivers. Timber piles (12-inch diameter) associated with a boat pier near the outfall will be installed using an impact pile driver in Barataria Basin. In water pile driving associated with the cofferdam and other features on the Mississippi River side of the project are not evaluated in this document because there is no EFH designated in the freshwater areas associated with that work. Estimated quantities, pile types, and duration of pile driving by location (Barataria Basin side) are shown in Table 3.3.2-1.

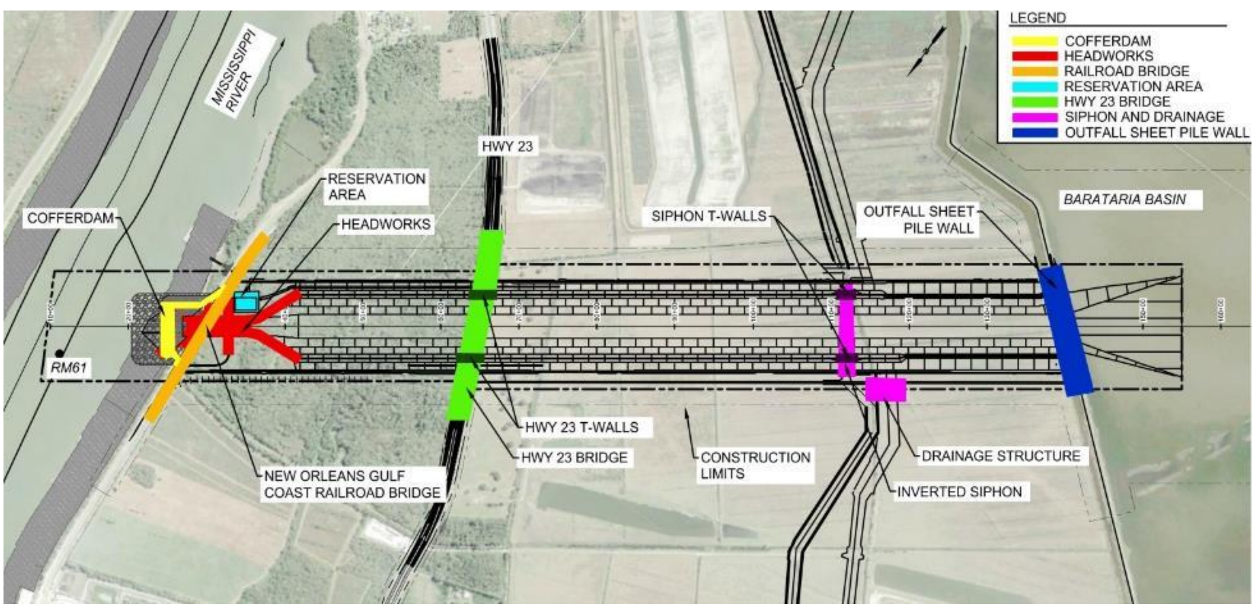


Figure 3.3.2-6. General Locations where Pile Driving is Planned

Table 3.3.2-1. Preliminary Design Pile Installation Information for Barataria Bay Portion of Mid-Barataria Sediment Diversion

Project Area	In Water?	Pile Type	Installation Method	Pile Depth (ft)	Pile Count (# or footage)	Blows/ Pile (#)	Installation Duration (months)	Hours/Day
Cofferdam (cofferdam cells, protection cells, and combi wall)	Yes	Sheet (Steel)	Vibratory Hammer	85-100	420,000 square feet (SF) for Mississippi River cofferdam cells (Steel)	NA	5-10	8-12
		Sheet (Steel)	Vibratory Hammer	85-100	105,000 SF for permanent protection cells (Steel)	NA	3-6	8-12
		Steel Piling	Impact, Cushioned	85-100	15,000 linear feet (LF) of pipe or H/I-shaped king piles for combi-wall	500+	2-6	8-12
Headworks (intake, gate, and transition monoliths)	Yes*	Sheet (Steel)	Vibratory Hammer	40-85	120,000 SF of sheet piles	NA	4-8	8-12
		Concrete or Steel H Piling	Impact, Cushioned	100-200	175,000 LF of square, pipe, and/or H-piles	500+	12-15	8-12
New Orleans & Gulf Coast (NOGC) Railroad Bridge	No	Concrete or Steel Piling	Impact, Cushioned	50-100	50,000 LF of square, pipe, and/or H-pile	500+	6-10	8-12
Highway 23 Bridge and T-wall	No	Concrete or Steel Piling	Impact, Cushioned	50-100	50,000 LF of piles	500+	4-6	8-12
		Steel H Piling	Impact, Cushioned	50-100	20,000 LF of H-piles (T-wall)	500+	1-3	8-12
River Trestle	Yes	Steel Pipe Piling	Impact, Cushioned	75-100	132 piles 36-inch	500	2-3	8-12
Inverted Siphon, Sluice Gate, and T-walls	No	Timber, Concrete, or Steel Piling	Impact, Cushioned	60-100	40,000 LF of piles (siphon headworks – Timber, Concrete, or Steel)	250-500	1-3	8-12
		Steel H Piling	Impact, Cushioned	50-100	20,000 LF of H-piles (T-wall – Steel)	500+	1-3	8-12
		Sheet (Steel)	Vibratory Hammer	40-85	40,000 SF of sheet pile (Temporary Retaining Structure & cutoff wall)	NA	1-3	8-12

Project Area	In Water?	Pile Type	Installation Method	Pile Depth (ft)	Pile Count (# or footage)	Blows/ Pile (#)	Installation Duration (months)	Hours/Day
Canal Cut-Off	Yes (Timber Canal)	Sheet (Steel)	Vibratory Hammer	25-80	20,000 SF of sheet pile	NA	1-3	8-12
Outfall	Yes (Basin)	Sheet (Steel)	Vibratory Hammer	50-100	30,000 SF of sheet pile	NA	2	8-12
Boat Pier	Yes (Basin)	Timber piling	Impact	20	30 timber piling (12-inch diameter)	20	5 days	8-12
Navigation Markers	Yes (Basin)	Timber (piling)	Press Installation	20	TBD timber piling (12-inch diameter)	NA	1-2	8-12
Secondary Site Features	No	Timber, Concrete or Steel Piling	Impact, Cushioned	25-100	40,000 LF of pile	250-500	1-3	8-12
*This will be behind the cofferdam during construction. Note: *Information contained in Table 1 is based on information available from the Basis of Design Report and engineering judgement.*								

3.3.3 *Operation of Sediment Diversion*

Lower Mississippi River Conditions & Historic Flows

The Mississippi River carries sediment-rich flows south to the Gulf of Mexico. At the Project location, the depth of the river is approximately 120 feet and a sand bar exists at a depth of about 50 feet. The top width of the river is approximately 2,000 feet. Near the Project inlet, the Mississippi carries a flow ranging from 425,000 cfs to 1,250,000 cfs during typical annual peak flow events. Transported sediment consists of clay, silt, and sand particles. The dominant hydraulic processes in the vicinity of the diversion are longitudinal, transverse, and vertical velocities due to the upstream river bend, suspended sediment transport through the water column, and bed load transport along the sand bar present at the proposed diversion.

Planned Operations Summary

The proposed Project includes a diversion operations plan based on initial sediment transport and deposition modeling. A monitoring and adaptive management plan will be implemented concurrently to observe and evaluate system performance and environmental response. The plan may prescribe operational changes where necessary to improve system performance or if certain threshold environmental conditions are reached.

The diversion operation plan currently calls for initial opening of the sediment diversion gates when the Mississippi River gage in Belle Chasse reaches 450,000 cfs. Once operational, the gates will be operated to maintain controlled diversion rates ranging from a target minimum of 5,000 to a maximum of 75,000 cfs, scaled to flow conditions in the main river. The maximum diversion flow of 75,000 cfs will occur when the Mississippi River gage in Belle Chase exceeds 1,000,000 cfs. The target baseflow diversion rate of 5,000 cfs would occur when Mississippi River flows drop below 450,000 cfs at the Belle Chase gage. The diversion rate between these threshold flows will be controlled by the difference in water surface elevation between the Mississippi River and the Barataria Basin (the “head differential”). When the Mississippi River flow and stage are high, the increased head differential will push a higher volume of water and sediment through the diversion into the Barataria Basin. When the Mississippi River flow and stage are low, there will be less energy to push water and sediment through the diversion. Figure 3.3.3-1 illustrates this variable flow rate for a representative Mississippi River hydrograph from 2011 (data derived from The Water Institute of the Gulf 2014).

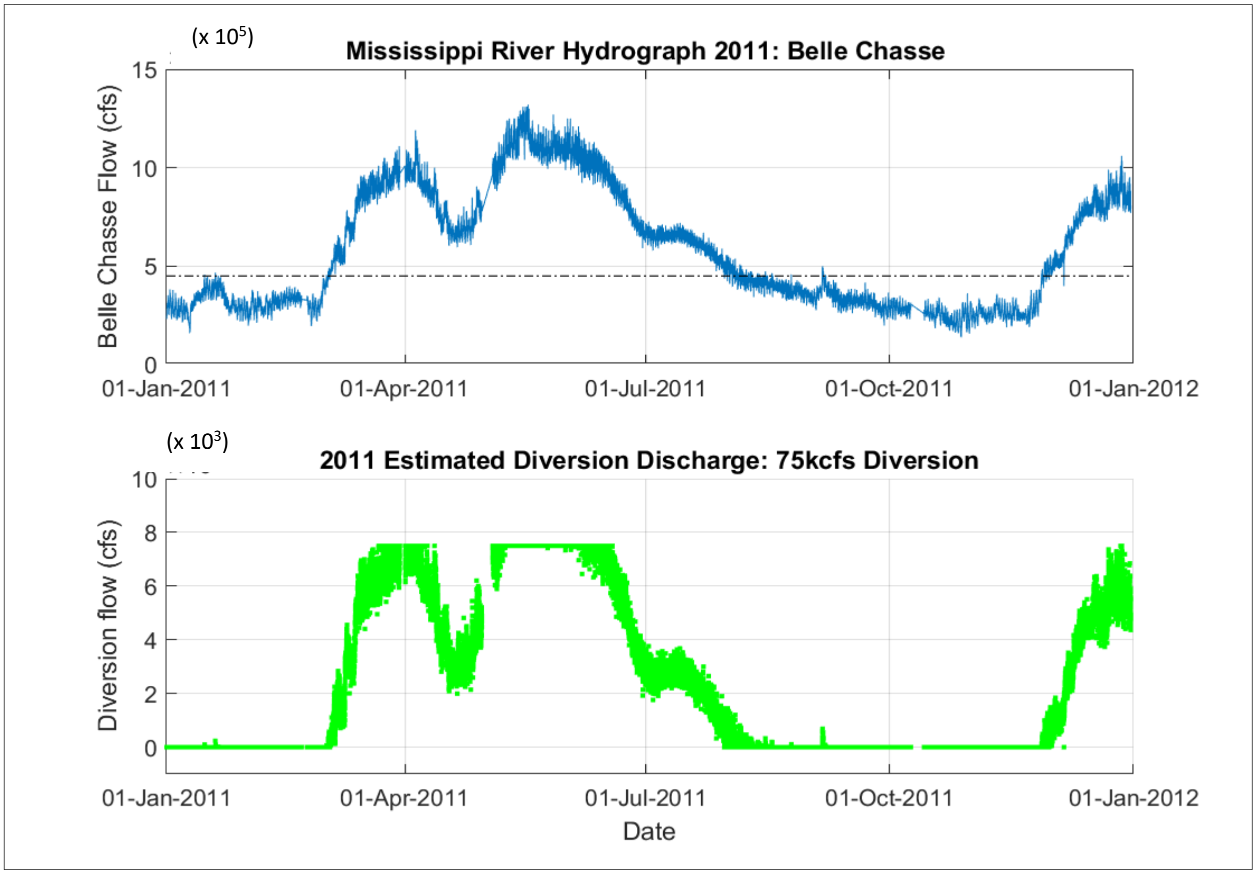


Figure 3.3.3-1. Variable Flow for 75k Diversions (bottom plot) Driven by 2011 Mississippi River Discharge (top plot) with a 450,000 cfs Operational Trigger in the Mississippi River
Source: Water Institute of the Gulf 2015

The diversion would be operated to maintain the target diversion rate of 5,000 cfs when river flows drop below 450,000 cfs. The Project proposes to use diversion gates or other alternative methods to provide maintain sufficient baseflow in the Mississippi River to meet the diversion target, but this may not be possible under all conditions. The diversion rate could theoretically fall to zero when high tides coincide with low baseflows in the main river. The diversion will be operated to prevent backflow from the Barataria Basin towards the Mississippi River.

3.3.4 Maintenance of Sediment Diversion

The sediment diversion may require periodic maintenance activities. These may include the following:

- Periodic inspections of diversion components
- Periodic maintenance of diversion components
- Clearing of vegetation

- Dredging in the outfall area to maintain flows or provide site access/beneficial reuse of sediment

Post-construction operations monitoring, and maintenance will be addressed within the following plans:

- Operations and Maintenance Plan
- Monitoring and Adaptive Management Plan

3.3.5 Description of Proposed Conservation Measures

Proposed conservation measures include environmental protection measures and best management practices (BMPs) that would be implemented during the construction of the Project to avoid or minimize potential environmental effects.

CPRA will develop an Environmental Protection Plan (EPP) that details the procedures for the prevention and/or control of pollution and habitat disruption that may occur during construction. As part of the EPP, the Plan shall detail the action which the contractor shall take to comply with all applicable federal, state and local laws and regulation concerning environmental protection and pollution control and abatement, as well as any additional specific requirements. The EPP will include an approved Spill Control Plan, Waste Management Plan, Contaminant Prevention Plan, and Environmental Monitoring Plan.

Many of these BMPs are standard approaches that will apply universally to many Project construction or operation activities. This section discusses provisional BMPs that CPRA anticipates will be included as construction or operation commitments for the Project.

Environmental protective measures presented below include those protecting land and water resources.

Inwater Work – Best Management Practice

Timing Restrictions

The Project will coordinate with natural resource agencies to identify construction activities and timing restrictions applicable to this Project. Given the large amount of in-water construction associated with the Project, it may not be feasible to avoid construction when fish, turtles, or marine mammals are potentially present.

Pile Driving Noise Attenuation

The Project will develop a pile-driving plan to guide pile-driving operations. This plan will identify locations, approximate timing and installation methods including any noise attenuation methods.

Upland Work – Best Management Practices Strategy for Temporary Stormwater Management

Stormwater Pollution Prevention Plan

The stormwater pollution prevention plan (SWPPP) is prepared to meet National Pollutant Discharge Elimination System (NPDES) permit requirements for stormwater discharges from construction sites. The SWPPP will address the following:

- Planning and organization
- Site assessment
- BMP identification
- Implementation
- Evaluation and monitoring

Temporary Erosion and Sediment Control Plan

A temporary erosion and sediment control (TESC) plan is required to prevent erosive forces from damaging project sites, adjacent properties and the environment. A TESC plan will be prepared and implemented to minimize and control pollution and erosion due to stormwater runoff.

Spill Prevention, Control and Countermeasure Plan

A spill prevention, control and countermeasure (SPCC) plan is prepared by the contractor to prevent and minimize spills that may contaminate soil or nearby waters.

Operations Plan

CPRA will develop an operation plan to guide overall operations of the MBSD. This will include standard and emergency procedures guiding operation of the diversion structure.

Monitoring and Adaptive Management Plan

CPRA is developing a monitoring and adaptive management plan (MAMP) in association with the Project that will guide field monitoring of species, habitats and water quality considerations during operation of the MBSD. This plan will include monitoring efforts and management actions that may affect operations based on identified thresholds and planning processes.

Mitigation Measures

The Project is a component of the DWH PDARP and a priority of Louisiana's Comprehensive Master Plan for a Sustainable Coast (CPRA 2017a). Project components including the Beneficial Use Placement of dredged materials to support and maintain wetlands are examples of mitigation measures incorporated into Project design. Mitigation measures identified as conservation recommendations from the EFH consultation will be combined with mitigation measures resulting from the MAMP and other regulatory reviews into the Mitigation Plan for the Project.

3.3.6 Interdependent and Interrelated Actions

This section will discuss interdependent or interrelated actions or activities associated with the proposed Project, if any. These are actions that would not occur "but for" the proposed Project.

Installation of the MBSD will cross existing linear transportation infrastructure, utility, and drainage systems that serve the adjacent communities. These systems will need to be modified to accommodate the Project. In addition, Project construction will generate a large amount of excavated soil and sediment. This material will be repurposed for beneficial use placement at selected locations in Barataria Bay. The required infrastructure modifications and planned beneficial use of overburden and dredged material are referred to as "Auxiliary Activities and Structures" and are described below. See EIS Section 2.8 for additional details.

Specifically, the segments of state highway LA 23 and the New Orleans and Gulf Coast (NOGC) Railway crossing the proposed conveyance channel would need to be raised and relocated. In addition, linear public and private utilities located along the LA 23 corridor, including electric, water, communications, and cable lines will need to be relocated. These features will be temporarily relocated during Project construction and permanently replaced once the conveyance channel is complete.

Auxiliary Activities and Structure development will adhere to the same construction BMPs described above for the MBSD.

Linear Infrastructure

New Orleans Gulf Coast Railway

The NOGC, a subsidiary of the Rio Grande Pacific Corporation, operates a 32-mile-long railroad that traverses the west bank of the Mississippi River immediately adjacent to the Project. The NOGC currently serves more than 20 switching and industrial customers who produce a variety of fishing, agricultural, petroleum, chemical, and steel products. The railroad line terminates approximately 1,500 feet south of the centerline of the proposed conveyance channel. NOGC plans to extend the rail line further south pending future service agreements. Construction of the conveyance channel would require that a portion of the NOGC Railroad right-of-way be raised and relocated over the conveyance channel (Figure 3.3.2-2). The proposed railroad modifications include maintaining the existing railroad alignment, constructing a bridge over the proposed conveyance channel with a bottom elevation of

16.4 feet, and extending the track by 600 feet to comply with bridge approach design standards. Further details on railroad modifications may be found in the EIS Chapter 2.

The preliminary construction sequence for the railroad modification includes the following:

- Construct temporary marshalling track along the north conveyance channel levee.
- Remove portion of existing track crossing the conveyance channel.
- Install turnout at intersection and lockout mechanism to prevent trains from accessing removed track segment.
- Place embankment approaches on each side of the conveyance channel.
- Construct bridge spans following construction of the concrete conveyance channel.
- Install replacement bridge and approaches including ballast, track, and train bumping post or hill.
- Remove temporary track and turnout.

Railroad bridge and track construction will adhere to the BMPs for upland and inwater work described in Section 3.3.6. Preventative maintenance and inspection measures will follow typical intervals for similar railroad bridges.

The Project will coordinate with NOGC to ensure appropriate emergency response plan is in place for any incidents along the portion of the rail line crossing the conveyance channel to protect the Barataria Basin and Mississippi River from potential spills.

Highway Louisiana 23

State highway LA 23 is the principal transportation corridor for the parish and a designated hurricane evacuation route. Project construction will require raising and relocating the affected segment of LA 23 to a new bridge crossing the conveyance channel. The proposed construction footprint for the LA 23 Bridge is about 153 acres. The proposed bridge structure would have a length of 2,176 feet with at least 7 feet of clearance over the top of the conveyance channel floodwalls of 15.6 feet.

The LA 23 Bridge will be constructed using standard bridge construction techniques. The pilings supporting intermediate piers/bents within the conveyance channel may be installed prior to or after channel excavation, as determined by the contractor's preferred construction methods. Girders will be standard AASHTO-type precast and the deck will be cast in place. Pile-supported bridge approach segments will likely be precast concrete or steel.

The proposed preliminary construction sequence includes the following:

- Install the construction detour crossovers.

- Reduce and shift southbound traffic to shoulder; shift northbound traffic to southbound lanes.
- Place surcharge fill for ramps, levee road crossings, and relocated roadways.
- Construct flood walls on Louisiana Department of Transportation & Development (LADOTD) right-of-way.
- Construct LA 23 Bridge, 24-inch waterline relocation on bridge, and relocated highway with median barrier.
- Construct northbound ramps on both sides on the conveyance channel.
- Construct remaining segments of median barrier north and south of the conveyance channel.
- Shift LA 23 traffic to the bridge.
- Remove southbound LA 23 pavement.
- Construct remaining flood wall across LADOTD right-of-way.
- Complete southbound roadway tie-ins and southbound ramp connections and tie-ins to the haul roads.
- Place southbound roadway.

Highway and bridge construction will adhere to the BMPs for upland and inwater work described in Section 3.3.6. Preventative maintenance and inspection measures will follow typical intervals for similar highways and highway bridges as regulated by the Federal Highway Administration (FHA).

The Project will coordinate with LADOTD and FHA to ensure an appropriate emergency response plan is in place for any incidents along the portion of the highway crossing the conveyance channel to protect the Barataria Basin and Mississippi River from potential spills.

Mississippi River and New Orleans to Venice Levees

The MBSD Project will require tie-ins to the Mississippi River Levee (MRL). The U-frame intake structure is enclosed on both the north and south sides with inverted T-wall monoliths that will provide the tie-ins. Since the T-walls are within the open excavation for the U-frame and gated diversion structure, the nearest MRL T-walls will match their bottom elevations and step upward as they embed further into the levee. The design of this feature is currently being finalized.

A segment of the New Orleans to Venice (NOV) levee will be moved landward by the Project, the existing back levee will remain on the current alignment.

The final configuration of the MBSD Project's conveyance channel levee will require closures of Timber Canal at approximate Station 113+50 and the NOV Back-Levee Canal at approximate Station 140+00.

Utilities

Several public and private facilities and utilities will be relocated as part of the Project. Currently linear power, communication, and water utilities run along the LA 23 corridor. These utilities will need to be modified to cross the MBSD. Water, fiber optic, and other utility improvements will be incorporated into the new LA 23 Bridge. In addition to utilities, several commercial pipelines cross the proposed conveyance channel corridor.

Specific utility improvements required for the Project are described in the following sections.

Power

Energy power transmission and distribution lines are currently located along the LA 23 corridor. The high-voltage transmission line is mounted on steel poles located on the west side of LA 23. The distribution lines are mounted on wooden poles along each side of the highway. Power transmission lines will be relocated to support the transmission tower improvements required to span the diversion channel. The distribution lines will be integrated into the new bridge structure.

The Project will coordinate with the power line owners to provide temporary service during construction.

Fiber Optic

AT&T Communications maintains fiber optic and copper telephone cables along the LA 23 right-of-way. CMA Communications maintains fiber optic and coaxial cables along the pipeline.

The Project will coordinate with the fiber optic line owners to provide temporary service during construction and restore service after Project is complete.

Water

Plaquemines Parish maintains 20-inch polyvinyl chloride (PVC) water line running along the west side of LA 23, a 16-inch water line running on the west side of LA 23, and an existing windmill/water well within the construction limits. Inframark Services owns a 16-inch line in the Project construction limits.

The Project will coordinate with the water owners to provide temporary service during construction and restore service after Project is complete.

Pipelines

Several pipelines cross the proposed conveyance channel. These include a 20-inch-diameter crude oil pipeline owned by Shell Pipeline Company, currently located on the flood side of the NOV Levee; a 12-inch-diameter natural gas line owned by High Point Gas Transmission; a 16-inch-diameter propylene line owned by Chalmette LA Liquids and Sulphur River Exploration; and a 12-inch-diameter gas pipeline owned by American Midstream Assets. The Shell pipeline will remain in its current alignment but will be lowered to a suitable depth to travel beneath the proposed conveyance channel. The remaining pipelines will be incorporated into the LA 23 bridge structure. The Project will coordinate with pipeline owners to create temporary bypasses to maintain service during construction.

Pipeline relocation activities will adhere to Project construction BMPs described in Section 3.3.6. The Project will also coordinate with US Department of Transportation (USDOT), LADOTD, and pipeline owners to ensure that an appropriate emergency response plan is in place for any incidents involving the conveyance channel in order to protect the Barataria Basin and Mississippi River from potential spills.

Drainage System

Project construction will bisect the existing drainage system; thus, to address interior drainage management needs in the area north of the diversion, construction of an inverted siphon/drop structure will occur. CPRA is considering using an inverted siphon or drop structure (located below the conveyance channel) to convey drainage from the northern drainage area to Wilkinson Pump Station. The 1,200-foot-long siphon will extend beyond the limits of the guide bank levees. The proposed construction limit for the inverted siphon/drop structure and other structural accommodations is about 215 acres and is within the existing construction footprint of the conveyance channel. The design and location of a siphon/drop structure is partially driven by the final location for the NOV levee and drainage design.

Beneficial Use Placement Areas

The proposed Project also includes beneficial use placement areas (BU areas) (Figure 3.3.2-1). These BU areas are intended to be used for placement of material excavated during Project construction on an as-needed basis. Material will be used at appropriate locations within 1 or both of the BU areas to create features that will allow excess sediments excavated during construction to be disposed of in a way to promote habitat improvements (such as wetland creation, wetland nourishment, shallow aquatic habitat, or other beneficial features such as ridges or terraces). The west BU area is approximately 442 acres and the east BU area is 1,729 acres.

These areas were chosen, in part, due to the general lack of existing oil and gas infrastructure in the vicinity and to minimize risk of interfering with the initial delta formation. Material excavated for construction of the conveyance channel and the OTF will, if suitable, first be used for construction of Project components. Any remaining dredged material would be used beneficially within a portion of one or both of the 2 identified proposed beneficial use areas. Because the exact type of material and quantities needed for construction are not yet known, the precise use of the material is unknown and cannot be quantified at this time.

3.4 Project Action Area

The action area for this Project is defined as: all areas to be affected directly or indirectly by the federal action and not merely the immediate area directly adjacent to the action. The action area includes the proposed Project location and all surrounding areas where effects due to the sediment diversion may reasonably be expected to occur. The action area is contained within the Project Area described in Section 3.1.1 of the EIS.

The action area was developed by reviewing the direct and indirect impact mechanisms associated with the Project. These include construction activities associated with the Project as well as areas in Barataria Basin, Birdfoot Delta, and the Mississippi River Delta Basin potentially affected by Project operations. The extent of the action area in the Barataria Basin and Birdfoot Delta incorporates the limits of construction for the Project, areas where dredging for site access may occur, and areas potentially affected by operations of the Project. The action area has been identified as the Barataria Basin and Birdfoot Delta as well as nearshore areas by the barrier island (Figure 3.4-1).

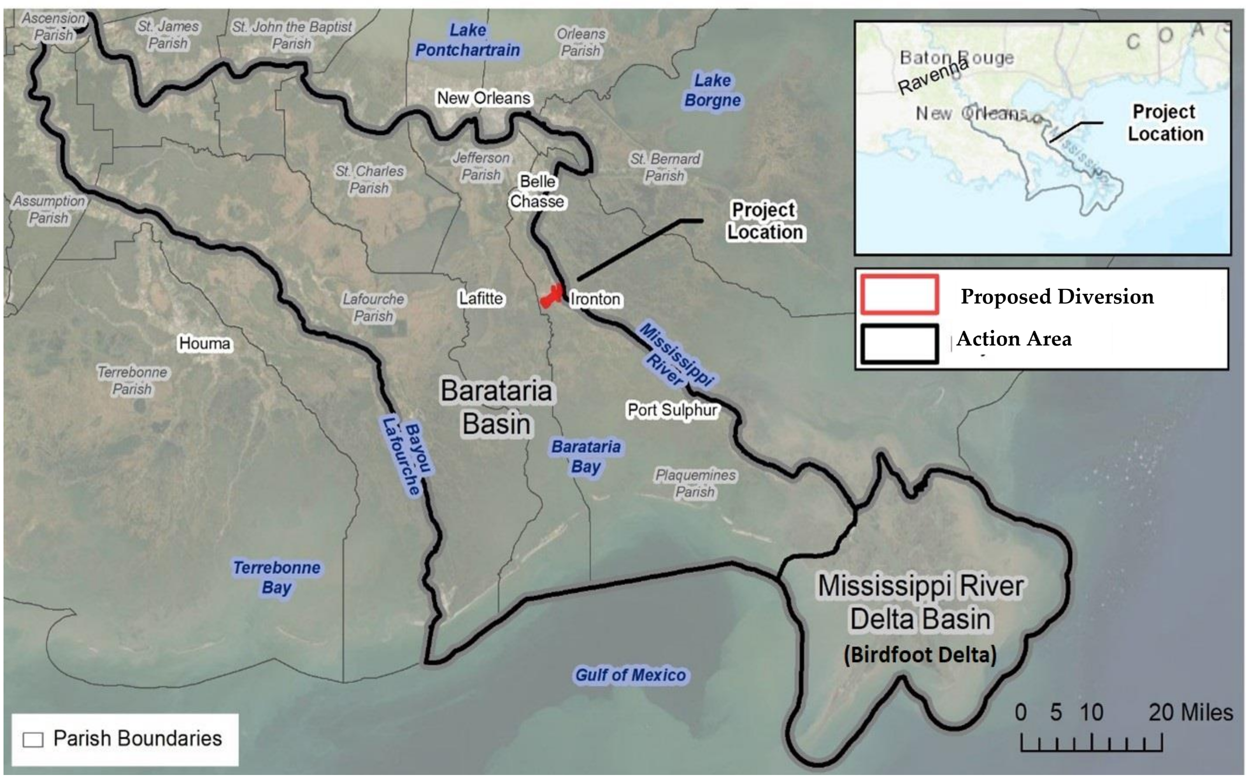


Figure 3.4-1. Project Action Area – Barataria Basin, Birdfoot Delta Basin and Proposed Diversion Structure

4.0 ESSENTIAL FISH HABITAT IN ACTION AREA

This section will describe important elements of Essential Fish Habitat (EFH) in the areas potentially influenced by the proposed Project. EFH associated with this Project includes the Barataria Basin and Lower Mississippi River Delta Basin which is also referred to as the Birdfoot Delta.

A provision of the Magnuson-Stevens Act requires that Fishery Management Councils (FMCs) identify and protect EFH for every species managed by a Fishery Management Plan (FMP) (U.S.C. 1853(a)(7)). The Gulf of Mexico FMC (GMFMC) defines 6 FMPs for the Gulf of Mexico: shrimp, red drum, reef fish, coastal migratory pelagics, corals, and spiny lobster. In addition, NMFS's Highly Migratory Species Division manages an FMP for highly migratory species (HMS; sharks, tuna, and sailfish) as they cross domestic and international boundaries. Managed species in and around the action area are included under the following FMPs, each of which includes one or more species:

- Shrimp Fishery of the Gulf of Mexico, U.S. Waters
- Red Drum Fishery of the Gulf of Mexico
- Reef Fish of the Gulf of Mexico
- Coastal Migratory Pelagic Resources in the Gulf of Mexico and South Atlantic
- Atlantic HMS

The Magnuson Stevens Act defines EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity." EFH includes habitats necessary for various life stages of fish species and provides a regulatory mechanism linking estuarine and marine habitats. Coastal wetlands provide important habitat for numerous fish species along the northern Gulf of Mexico, and access to these areas is a function of hydrology (Minello 1999, Beck et al. 2001, Baker et al. 2013). Six of the 12 EFH classified habitats (those habitats identified as important to life stages of fish) within the Gulf of Mexico occur within the proposed action area:

- Emergent marshes (tidal wetlands, salt marshes, tidal creeks, rivers/streams)
- Submerged Aquatic Vegetation (SAV; seagrasses, benthic algae)
- Soft bottom (mud, clay, silt)
- Sand/shell bottom (sand, shell)
- Oyster reefs
- Water Column Associated (WCA; pelagic, planktonic, coastal pelagic)

EFH is separated into nearshore, estuarine, and offshore components. Only estuarine and nearshore habitats occur in the proposed action area. The following EFH habitats do not occur in the proposed action area and will not be discussed further: mangroves, reefs, banks/shoals, hard bottoms, drift algae, and shelf edge/slope.

Habitat areas of particular concern (HAPC) are localized areas of EFH that are ecologically important, sensitive, stressed, and/or rare areas. Although designated HAPCs have no regulatory protections above all other EFH, projects impacting HAPCs may be more scrutinized and may be subject to additional conservation measures (NOAA 2016). No HAPCs are located in the action area.

Information in this section is consistent with the EIS, RP, and supporting information provided by CPRA. Where appropriate, this section will refer to sections of the EIS or RP for additional information.

4.1 Emergent Marshes (Estuarine)

Wetlands provide a diverse set of functions and provide ecological, economic, and social benefits. The ability to perform a function is influenced by the characteristics of the wetland and the physical, chemical, and biological processes in it (USACE 2017). Louisiana's coastal wetlands provide habitat for wildlife, finfish, shellfish, and other aquatic organisms, including threatened or endangered species. Further, they support, by volume, the largest commercial fishery in the contiguous United States (NOAA 2019; see Section 3.14). Wetlands improve water quality by removing organic and inorganic toxic materials, suspended sediments, and nutrients via plant uptake and sedimentation. Primary productivity, decomposition, and other chemical processes also contribute to the removal of certain chemicals from the water (Mitsch and Gosselink 2000). Wetlands also provide a level of flood control. Wetland vegetation can attenuate waves and storm surges, and communities sheltered by wetlands may sustain less damage from storm surges (Day et al. 2007). Further, due to their anoxic, wet conditions, wetlands provide a natural environment for sequestration and storage of carbon from the atmosphere. Most wetlands are net carbon sinks when methane emissions and carbon sequestration are balanced (Mitsch et al. 2012).

Wetland types that overlap with EFH within the action area include emergent wetlands, which are further classified by their salinity regimes and tidal influence (Figure 4.1-1). Wetlands in the Barataria Basin are typically classified as freshwater, intermediate, brackish, or saline based on salinities and the corresponding plant communities present (Chabreck 1972, CPRA 2017). Table 4.1-1 summarizes the acreage and percentage of the action area covered by estuarine wetland types, based on vegetation data from CPRA's 2017 Coastal Master Plan (CPRA 2017).

Estuarine emergent wetlands provide important wintering habitat for a variety of waterfowl as well as foraging and nesting habitat for many other avian species. Many larval and juvenile marine species utilize intermediate marsh as their nursery habitat (Hillmann 2017). Plant diversity within the intermediate or oligohaline marsh (0 to 5 ppt) is the highest of the 3 estuarine marshes, and is dominated by narrow-leaved persistent species such as marsh hay or saltmeadow cordgrass (also known as wiregrass; *Spartina patens*), bulltongue arrowhead (*Sagittaria lancifolia*), and Roseau cane (*Phragmites australis*).

Seaward of the intermediate marsh, brackish marsh exhibits salinity ranges from 5.0 to 18.0 parts per thousand (ppt) but can fluctuate from fresh to saline conditions depending on tidal movements and freshwater runoff from the upper basin (Conner and Day 1987). Similar to intermediate marsh, brackish marsh provides valuable nursery habitat for larval and juvenile forms of many estuarine and marine species as well as wintering habitat for large numbers of waterfowl. Plant diversity within this marsh type is not as high as the intermediate marsh but is higher than that found in saline marsh. Dominant species in brackish marsh include marsh hay saltmeadow cordgrass (*Spartina patens*), salt grass (*Distichlis spicata*), 3-cornered grass (*Schoenoplectus americanus*), and saltmarsh bulrush (*Bolboschoenus robustus*).

In Barataria Basin, the saline marsh exhibits the highest salinity levels of the 3 estuarine marshes, ranging from 18.0 to 30.0 ppt (FGDC 2013). This marsh type can experience salinity shifts on a seasonal basis and sometimes daily, depending on weather conditions, tides, and rainfall (Conner and Day 1987). As with the intermediate and brackish marsh, saline marsh also provides important nursery habitat for an abundance of estuarine species, and wintering habitat for numerous waterfowl species. Saline marsh has the lowest plant diversity of any of the marsh types and is dominated by 2 species: smooth cordgrass (*Spartina alterniflora*) and black needlerush (*Juncus roemerianus*) (Lin et al. 2016). Black mangroves (*Avicennia germinans*) are expanding into the salt marshes of Louisiana (Alleman and Hester 2011).

Table 4.1-1. Estuarine Wetland Habitat Types Occurring within the Action Area

Wetland Type	Total Acres within the Action Area	Percent of the Action Area
Estuarine Wetlands*		
Intermediate Marsh	216,950	10
Brackish Marsh	144,015	6
Saltmarsh	141,235	6

*freshwater marsh also present
Source: CPRA 2017

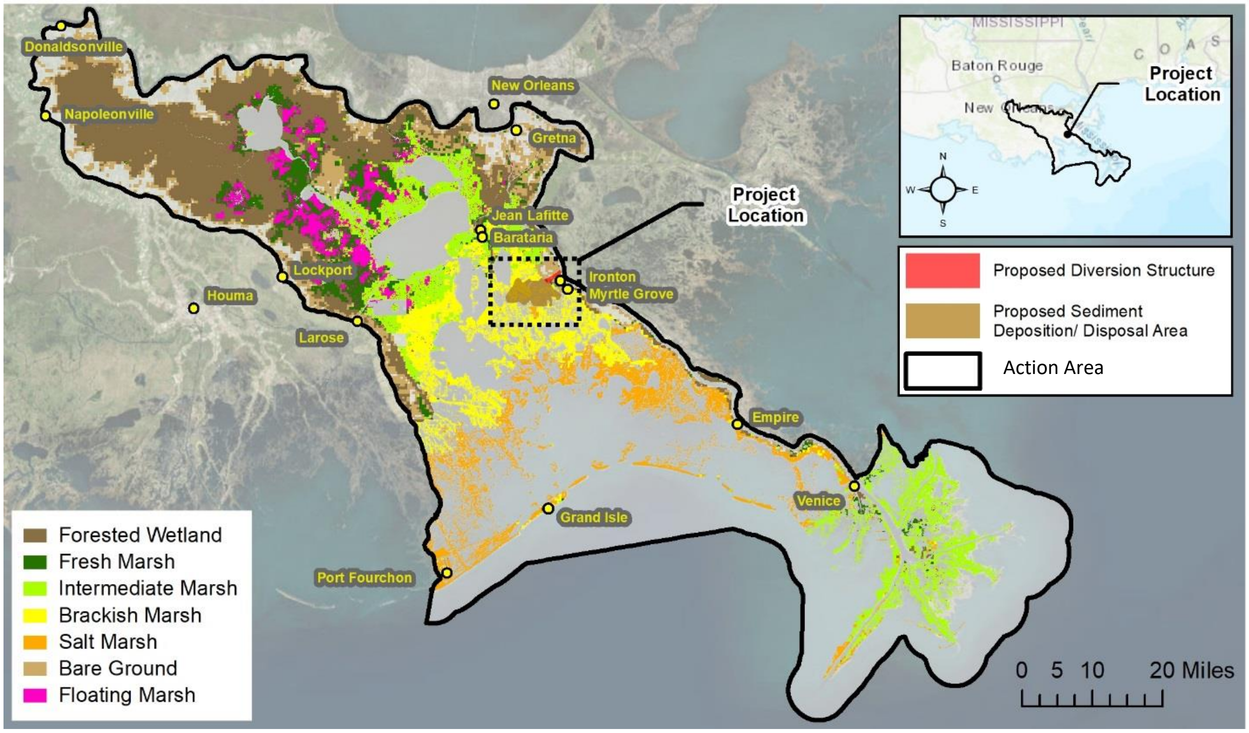


Figure 4.1-1. Wetland Types in the Action Area
(Source: CPRA 2017)

4.2 SAV (Estuarine and Nearshore)

Habitats in the Barataria Basin exhibit a salinity gradient, ranging from freshwater swamps in the uppermost basin, followed by intermediate habitats, brackish habitats, and then extensive salt marshes at the coast, with estuarine and marine SAV becoming more prevalent in the open water. SAV supports a diverse epiphytic biota, exports organic matter and nutrients into the water column, oxygenates the water column, and stabilizes bottom sediments by reducing current velocity and wave energy. In turn, these processes affect species composition, biomass, and distribution of the SAV as well as the fauna that rely on SAV for habitat (Koch 2001).

SAV species distributions and biomass are influenced by salinity, water depth, turbidity, as well as other variables. Hillmann et al. (2017) documented 14 SAV species in the coastal portion of the Barataria Basin, 4 of which—coontail (*Ceratophyllum demersum*), Eurasian water milfoil (*Myriophyllum spicatum*), widgeon grass (*Ruppia spp*.), and hydrilla (*Hydrilla verticillata*)—accounted for 73% of the above-ground biomass collected. Coontail, widgeon grass, and lesser pondweed (*Potamageton pusillus*) were collected across freshwater, intermediate, brackish, and saline zones. Hydrilla was collected only in freshwater habitat, common water nymph (*Najas guadalupensis*), and wild celery (*Vallisneria americana*) in all but saline habitat, and Eurasian water milfoil in all but freshwater habitat. Turtle grass (*Thalassia testudinum*), star grass (*Halophila engelmannii*), shoal grass (*Halodule wrightii*), and manatee grass (*Syringodium filiforme*) corresponded strongly with salinity, as anticipated. Other relationships among SAV and environmental variables found by Hillmann et al. (2016a) included the following:

- SAV species distribution corresponded significantly to environmental variables (salinity, water depth, and turbidity).
- Vegetation biomass was significantly lower in the saline zone when compared with other zones, when all samples were combined (including those without SAV).

The factors controlling SAV distribution across salinity regimes in the northern Gulf Coast are not well documented; this makes predictions of resource availability difficult (Hillmann et al. 2017). Consequently, SAV coverage is predicted as a group rather than by species (Visser et al. 2013, 2017). Changes in salinity, water depth, and light transmission can result in changes in biomass, productivity, species composition, and distribution of SAV (Hillmann et al. 2017). SAV declines in the middle and upper Barataria Basin have been attributed to saltwater intrusion associated with hurricanes and flood control activities. SAV increased in the upper and middle basin coincident with the Davis Pond Freshwater Diversion Project (operational in 2002), but declined following salinity increases and scouring associated with Hurricanes Gustav in 2002 and Ike in 2008.

SAV has been described as “the most significant form of complex cover for aquatic animals in the Barataria Basin” (LDWF 2015a). Diverse SAV communities are often scattered throughout the marshes and provide important food and cover to a wide variety of fish and wildlife species, including juvenile and overwintering shrimp and crabs; coastal fishes such as drum, croaker, seatrout, and flounder; and habitat and foraging areas for invertebrates and fish (Hillmann et al. 2017, LDWF 2005, Fonseca and Bell 1998). SAV in intermediate and brackish areas provide nursery grounds and shelter for many species of fish and shellfish (Rozas and Odum 1988, LWDF 2005). Rozas et al. (2012) found that the density and biomass of the most abundant faunal taxa were higher within seagrass areas than within Spartina marsh.

4.3 Soft Bottoms (Estuarine and Nearshore)

Soft bottoms consist of unconsolidated sediment and unvegetated areas. They include mud, clay, and silt substrates, and are the most extensive habitat in the action area. Soft bottoms provide essential habitat throughout many life stages of fish and shellfish. They may also be important nursery areas for some species. Many species utilize soft bottom habitats in early life stages, then move to deeper habitats or emigrate to shelf habitats in adulthood. Species use and abundance may be affected by characteristics including substrate grain size, salinity, turbidity, dissolved oxygen levels, and water circulation.

4.4 Sand/Shell (Estuarine and Nearshore)

Sand and shell substrates include sandy material, shell, and a mix of shell hash or rubble.

4.5 Oyster Reefs (Estuarine and Nearshore)

Oyster reefs filter large volumes of water and can affect water quality and plankton abundance (La Peyre et al. 2014, zu Ermuggason et al. 2012). Oyster filtration affects energy cycling and carbon transfer within the estuarine food web (Newell et al. 2005, La Peyre et al. 2013). Oyster reefs and bars also provide hard-structure habitat that estuarine fish and invertebrates can use for feeding and as predation refuge (see Section 5.6; for example, La Peyre et al. 2014, Stunz et al. 2012, Humphries et al. 2011, Grabowski et al. 2005). Oyster reefs and bars can also help reduce wave stress and stabilize shorelines to reduce marsh erosion and shoreline retreat rates within Barataria Bay (La Peyre et al. 2014, La Peyre et al. 2015, Piazza et al. 2005).

4.6 Water Column Associated (WCA) (Estuarine and Nearshore)

Open water in the action area includes natural and dredged/excavated channels and open water ponds, or bays that are designated as deepwater habitats by Cowardin et al. (1979). These open-water habitats are further classified as either lacustrine or riverine for freshwater systems and estuarine or marine for saltwater systems. Open water in the action area may be characterized as having unconsolidated bottom, aquatic bed, or unconsolidated shore substrates (FGDC 2013).

5.0 FISHERIES SPECIES

NMFS and the GMFMC (2013, 2015, 2017, NOAA Mapper, GMFMC EFH Portal) identify EFH along the estuarine and nearshore coastal zones in the proposed action area for 5 of the 14 species managed under the GMFMC FMPs (Table 5.0-1): white shrimp (*Litopenaeus setiferus*), brown shrimp (*Farfantepenaeus aztecus*), red drum (*Sciaenops ocellatus*), lane snapper (*Lutjanus synagris*), and gray snapper (*Lutjanus griseus*). Although EFH for the dog snapper (*Lutjanus jocu*) was also identified within the proposed action area, it was removed from the reef fish FMP in June 2016 and no longer has designated EFH (81 FR 32249). The remaining species using habitats in the shelf waters off Louisiana within the action area (Table 5.0-1) are king mackerel (*Scomberomorus cavalla*) and cobia (*Rachycentron canadum*). HMS EFH is established for 6 shark species, yellowfin tuna (*Thunnus albacares*), and the sailfish (*Istiophorus platypterus*) in the estuarine and nearshore waters of the proposed action area (Table 5.0-1). Habitat zones in the Gulf of Mexico are shown in Figure 5.0-1.

Information in this section is consistent with the EIS, RP, and supporting information provided by CPRA. Where appropriate, this section will refer to sections of the EIS or RP for additional information.

Table 5.0-1. Potential Species of Estuarine and Nearshore Fishes and Life History Stages with Designated EFH in the Waters of Barataria Basin (Source: GMFMC 2016).

Species and Life Stage	Estuarine							Nearshore					
	WCA	EM	SAV	HB	SB	S/S	OR	WCA	SAV	HB	SB	S/S	OR
Coastal Migratory Pelagic Fish													
King mackerel													
Adult								x					
Juvenile								x					
Cobia													
Adult								x					
Spawning								x					
Juvenile								x					
Larvae	x							x					
Eggs/parturition	x							x					
Red Drum													
Adult		x	x	x	x	x		x		x			
Juvenile		x	x		x					x		x	
Larvae		x	x		x								
Eggs/parturition								x					
Reef Fish													
Gray snapper													
Adult		x			x	x				x	x	x	
Juvenile		x	x		x	x			x		x	x	
Spawning										x			
Lane snapper													
Adult										x		x	
Juvenile			x	x	x	x			x	x	x	x	
Larvae	x		x					x	x				
Shrimp													
Brown shrimp													
Adult					x						x	x	

Species and Life Stage	Estuarine							Nearshore					
	WCA	EM	SAV	HB	SB	S/S	OR	WCA	SAV	HB	SB	S/S	OR
Subadult					x	x					x	x	
Juvenile		x	x		x	x	x						
Larvae								x					
White shrimp													
Adult											x		
Subadult					x	x					x	x	
Spawning					x						x		
Juvenile		x	x		x		x		x		x		x
Larvae	x							x					
Eggs/parturition					x	x					x	x	
Highly Migratory Species													
Blacktip shark (Gulf of Mexico stock)													
Adult								x					
Juvenile								x					
Neonate/YOY	x							x*					
Bull shark													
Adult	x							x					
Juvenile	x							x					
Neonate/YOY	x							x*					
Spinner shark													
Adult								x*					
Juvenile								x*					
Neonate/YOY								x					
Scalloped hammerhead shark													
Adult								x*					
Juvenile								x*					
Finetooth shark													
Adult								x*					
Spawning								x*					
Juvenile								x*					

Species and Life Stage	Estuarine WCA	Estuarine EM	Estuarine SAV	Estuarine HB	Estuarine SB	Estuarine S/S	Estuarine OR	Nearshore WCA	Nearshore SAV	Nearshore HB	Nearshore SB	Nearshore S/S	Nearshore OR
Neonate/YOY								x*					
Sharpnose shark													
Adult								x*					
Juvenile								x*					
Neonate/YOY								x*					
Yellowfin tuna													
Juvenile								x*					
Sailfish													
Adult								x*					

*found in the Coastal Gulf only (not Barataria Bay)
WCA = Water Column Associated
EM = Emergent Marshes
SAV = Submerged Aquatic Vegetation
HB = Hard Bottom
SB = Soft Bottom
S/S = Sand/Shell
OR = Oyster Reefs
DA = Drift Algae
YOY = young-of-the-year

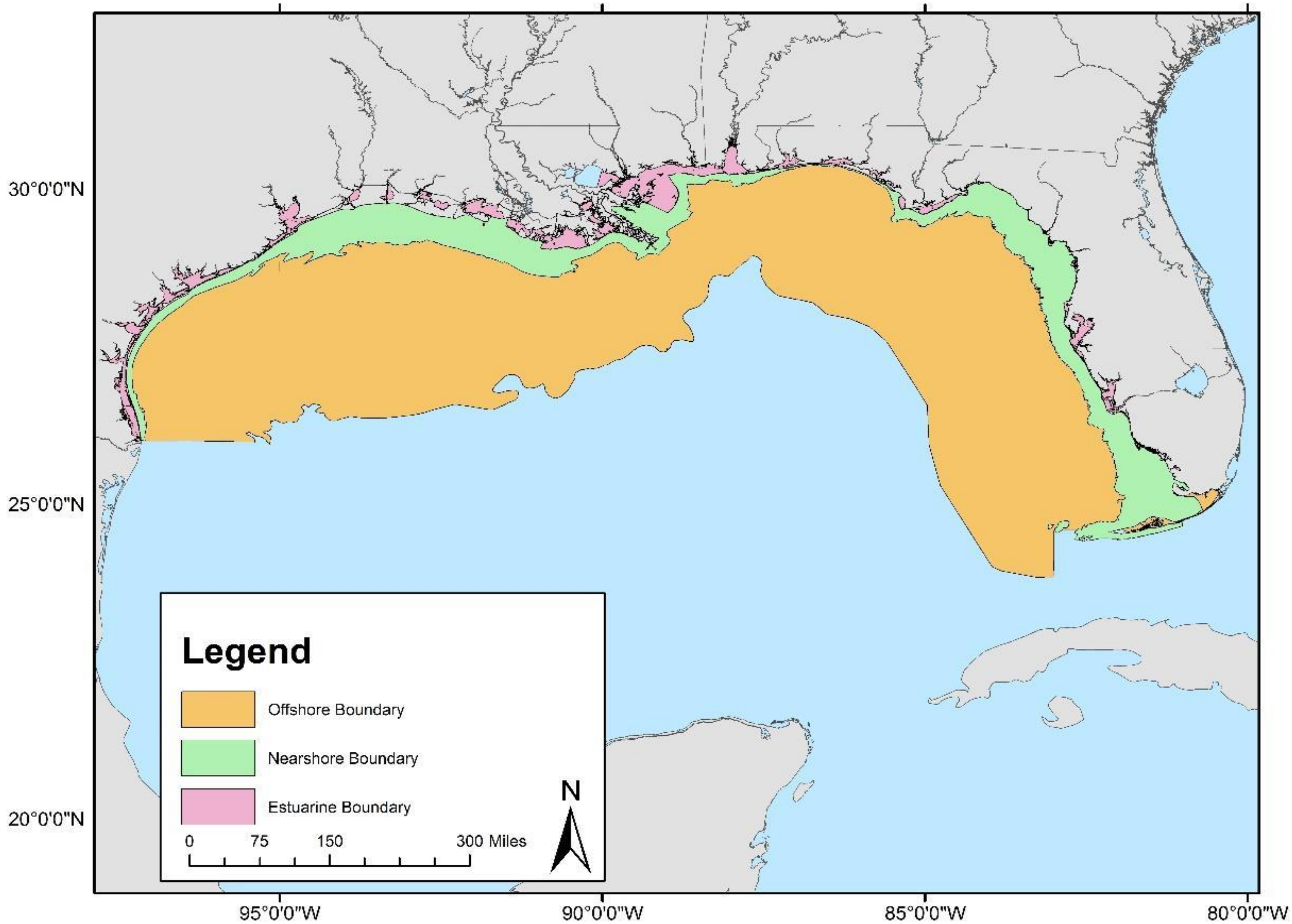


Figure 5.0-1. Spatial Depiction of Habitat Zones: estuarine (inside barrier islands and estuaries), nearshore (18 meters [60 feet] or less in depth) and offshore (greater than 18 meters [60 feet] in depth)
Estuarine and nearshore habitats are considered within the action area. (Source: GMFMC 2016).

5.1 Coastal Migratory Pelagic Fish

EFH for coastal migratory pelagic fish consists of Gulf of Mexico waters and substrates extending from the US/Mexico border to the boundary between the areas covered by the GMFMC and the South Atlantic FMC from estuarine waters out to depths of 183 meters (600 feet) (NOAA 2015). Coastal migratory pelagic fish use the habitats in nearshore and shelf waters off Louisiana.

5.1.1 King Mackerel

King mackerel occur throughout the Gulf of Mexico and Caribbean Sea, and along the western Atlantic from the Gulf of Maine to Brazil. In the Gulf of Mexico, king mackerel densities are centered in south Florida and Louisiana. Early juveniles are found in shallower nearshore waters (less than 9 meters deep) from May to October, while the seasonality and depth of late juveniles in nearshore waters is unknown (GMFMC 2016). Adults associated with the water column can be found over reefs and in coastal waters, generally in depths less than 200 meters, mostly in areas with oceanic salinities (32–36 ppt). Migrations to the northern Gulf in the spring are believed to be temperature dependent, with the species found in highest abundances in temperatures greater than 20 °C (68 °F) (GMFMC 2004, GMFMC 2016).

King mackerel rarely enter the interior Barataria Basin's estuarine habitats, but have been observed in seine and trawl surveys of high salinity marine habitats around the barrier islands of the outer basin, Barataria Bay, and Bastian Bay (GMFMC 2016). Northwestern and northeastern Gulf shelf habitats are considered important spawning areas from May to October. Spawning adults, eggs, and larvae are found offshore and in shelf habitats outside of the action area (GMFMC 2004, 2016). Larvae found in the north central and northwestern Gulf to the west of the delta exhibit enhanced growth associated with the high productivity of the Mississippi River plume (De Vries et al. 1990, GMFMC 2016). Early juvenile king mackerel are commonly found in nearshore waters in the Gulf of Mexico; this suggests that this life stage is likely to occur around the outer boundary of the action area.

5.1.2 Cobia

Cobia are a predatory pelagic species found in coastal nearshore and offshore waters of the Gulf of Mexico, at depths ranging from 1 meter to 70 meters (Figure 5.1.2-1). They are most commonly associated with shoals over hard banks, buoys, shipwrecks, oil rigs, and other hard surfaces (GMFMC 2016). Adults feed on fishes and crustaceans, including crabs and shrimp. Cobia migrate seasonally from March through October between spawning and rearing habitats, determined primarily by suitable temperature conditions.

Cobia spawning occurs in coastal waters with temperatures ranging from 23 °C to 28 °C (73 °F to 82 °F). The species broadcast spawns, releasing positively buoyant eggs that rise to the top meter of the water column where they are dispersed by currents, wind, and tidal action. Larvae are broadly distributed in surface waters of the northern Gulf over depths ranging from 3.1 to 300 meters, where they feed on zooplankton. Individual cobia are capable of spawning multiple times per year and typically demonstrate a broad spawning period with distinct seasonal peaks (Brown-Peterson et al. 2001). The specific location of spawning habitats in the Gulf of Mexico remains unclear. Brown-Peterson et al. (2001) reviewed available research and concluded that spawning in the northern gulf most likely occurs on the shelf 50 to 90 km offshore. More recent studies have documented cobia spawning in high-salinity bays and estuaries and adjacent coastal shelf areas, indicating that these habitats may be important for species management (Ditty 2006, Lefebvre and Denson 2012).

Cobia larvae are commonly found in estuarine and nearshore areas with salinities greater than 18.9 parts per thousand (ppt), indicating that estuaries and nearshore areas provide productive nursery habitat (GMFMC 2016). Notably, larval and juvenile cobia have been observed in research surveys in the northern Gulf, outside of the barrier islands dating back to 1967 (GMFMC 2016). Based on the size distribution of juveniles observed in the lower Barataria Basin and known larval growth rates (Falk et al. 2007), multiple spawning events may be occurring in or near the action area in any given year. This is consistent with the findings of Brown-Peterson et al. (2001), who observed multiple spawning peaks in the north central Gulf of Mexico over a broad period extending from April through September. These findings suggest that cobia may use the saline waters of the action area and adjacent shelf habitats for spawning, larval recruitment, and juvenile rearing. Juvenile cobia are regularly found in coastal and offshore waters feeding on small fishes, squid, and shrimp. Cobia are a favored prey resource for dolphinfish and other piscivorous fish species (GMFMC 2004, 2016).

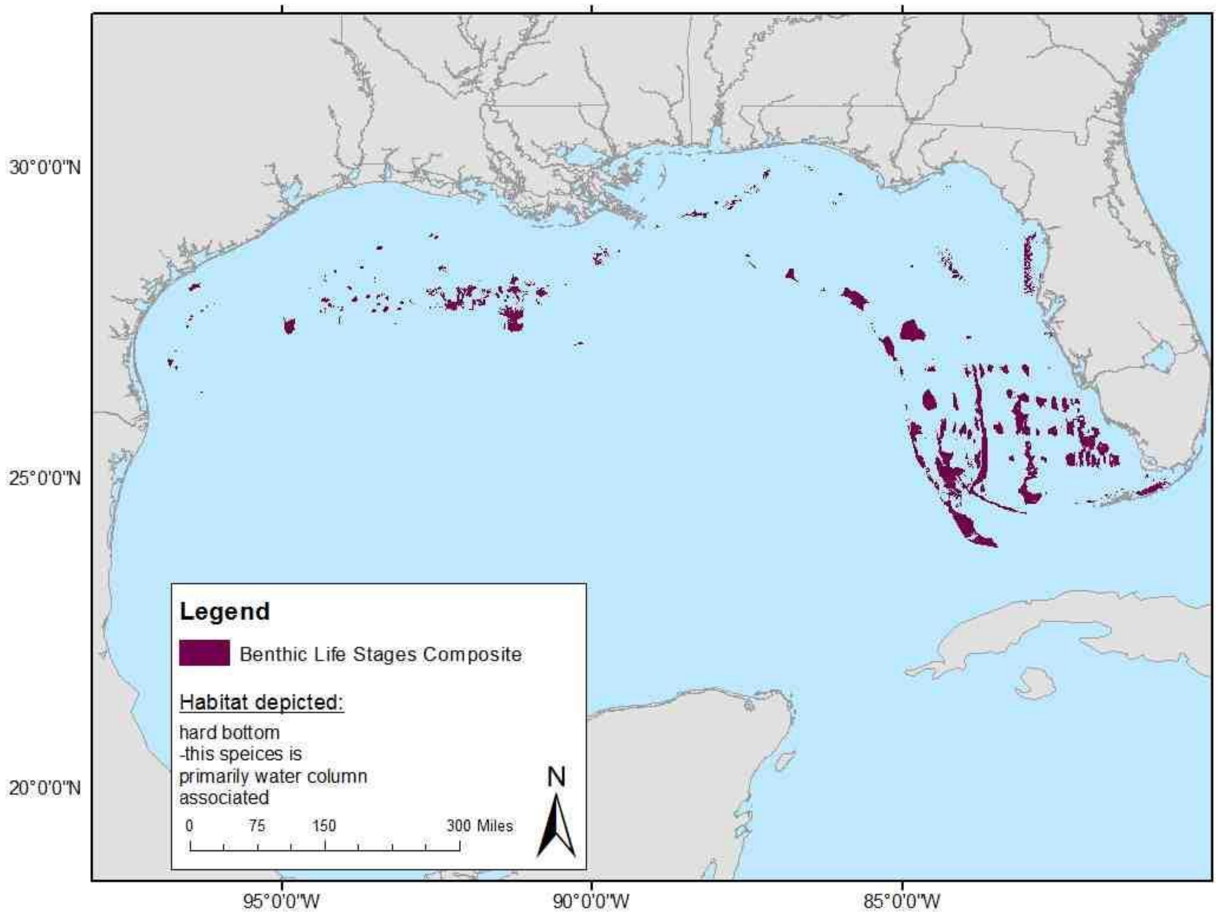
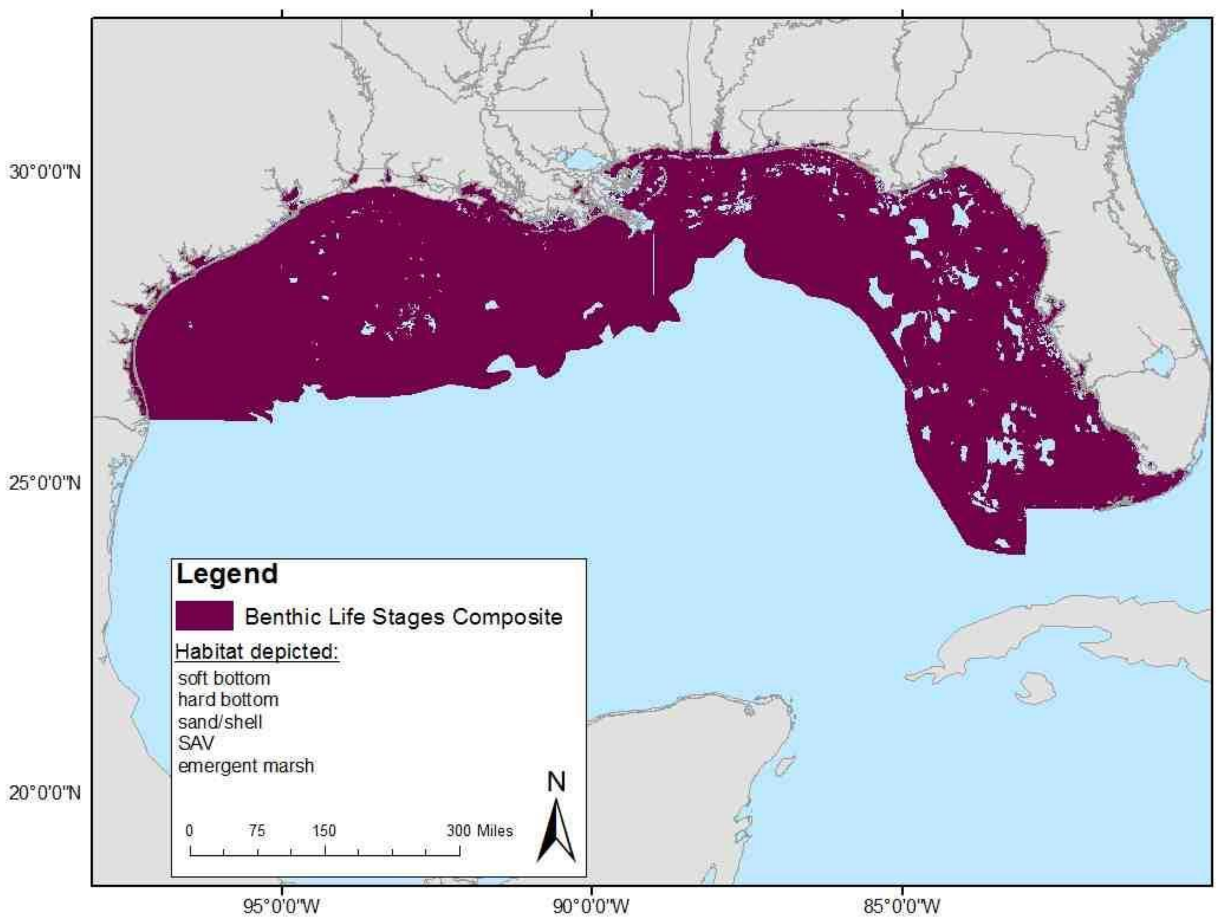


Figure 5.1.2-1. Map of Benthic Habitat Use by All Life Stages of Cobia.
This species is primarily associated with the water column, but also uses hard bottom habitat in nearshore and offshore waters out to 70 meters. (Source: GMFMC 2016).

5.2 Red Drum

Red drum are found in the western Atlantic from Massachusetts to northern Mexico; they are distributed throughout the Gulf of Mexico (Figure 5.2-1). Depending on life stage, they are found from estuarine to offshore waters and occur over a variety of habitat types including SAV, soft bottom, hard bottom, emergent marsh, sand/shell; in early life stages they are associated with the water column (GMFMC 2004, 2016). EFH for red drum includes all Gulf of Mexico estuaries; waters and substrates extending from Vermilion Bay, Louisiana to the eastern edge of Mobile Bay, Alabama, out to depths of 45.7 meters (150 feet); waters and substrates extending from Crystal River, Florida, to Naples, Florida between depths of 9 meters and 18 meters (30 feet and 60 feet); and waters and substrates extending from Cape Sable, Florida to the boundary between the areas covered by the GMFMC and the South Atlantic FMC between depths of 9 meters and 18 meters (30 feet and 60 feet) (NOAA 2015).

Red drum spawn on the northern Gulf of Mexico shelf during a relatively brief period, generally August into October (Wilson and Nieland 1994). The larvae and early juveniles are carried by tides and currents in late fall to the shallow estuaries, with peak ingress occurring in October. Larvae are carried through barrier island passes in the surface waters and juveniles move from the bay up the estuary to quiet backwater nursery areas to grow (Perret et al. 1980, Peters and McMichael 1987). Early juvenile drum leave the shallow nursery habitats when they reach about 40 mm to 120 mm (1.6 inches to 4.7 inches) total length (TL) to move into bays and deeper channel waters. In their first spring, juveniles may remain in deep-water bays or congregate in tidal passes (Simmons and Hoese 1959, Peters and Michael 1987). Large juvenile and adult red drum make long-range movements throughout the estuaries and into backwaters with increasing temperature and foraging opportunities. Subadults appear to remain in the bays throughout the year while older fish (>3 years) move to the shelf in early fall and winter to



spawn (Perret et al. 1980, Hein and Shepard 1986, Wilson and Nieland 1994).

Figure 5.2-1. Map of Benthic Habitat Use by All Life Stages of Red Drum
Benthic habitats used by red drum extend out to 70 meter depths. (Source: GMFMC 2016).

Red drum support an important recreational fishery in the south Atlantic and Gulf state waters, where landings have averaged 14,500,944 pounds annually from 2000 through 2013 (Louisiana has not reported recreational landings since 2013), with the annual proportion of recreational landings from Louisiana constituting more than 70% of the total (NMFS 2018). Recreational fisheries for juvenile and subadult red drum that live within the estuarine waters (ages 1 to 4) are strictly managed within each of the Gulf of Mexico state waters. Red drum were commercially overfished in the Gulf of Mexico during the late 1980s, and a commercial harvest moratorium has been in place since 1987 (Powers et al. 2013).

Although early juvenile red drum use the marsh edge and shallow vegetated habitats of the estuaries extensively, LDWF do not collect high numbers of juveniles during sampling with seine nets, as the juveniles likely outswim the gear (LDWF pers. comm.). Based on total catch of red drum in the LDWF fisheries-independent gillnet samples from the coastal study areas (CSAs) in Watkins et al. (2014), Barataria Basin accounted for approximately 12% of the coast-wide catch. The Barataria Basin trammel net samples accounted for only 5% of total catch from LDWF's coast-wide fisheries-independent monitoring. The catch per unit effort (CPUE) of subadult red drum in the LDWF gillnets, and subadult and adult red drum in the trammel nets (unpubl. data from Watkins et al. 2014) show a generally small increasing trend since 2000 (Figure 5.2-2). Higher mean seasonal CPUEs equal to 3 red drum per sample are evident in 2 to 3 years between the late 1980s and mid 1990s for both LDWF gears.

Red drum production in Louisiana marshes was affected by the DWH oil spill (DWH NRDA Trustees 2016a). Red drum juveniles settled in the fall of 2010 adjacent to the oiled marsh shorelines. Juvenile drum growth was reduced by 47% in 2010 along oiled shorelines when compared to shorelines without oiling (Powers and Scyphers 2015). By 2013, heavier persistently oiled marshes were still sufficiently contaminated to reduce drum growth by an estimated 21%. Juvenile drum exposed to oil gained less weight and were smaller than fish exposed to clean sediment (Powers and Scyphers 2015). The reduction in growth of red drum exposed to heavier persistently oiled marsh sites was assumed to result in fewer adults due to smaller fish suffering higher levels of predation. An estimated 563 metric ton wet weight of red drum was lost due to oiling of salt marsh in Louisiana. This effect was estimated to occur over 62 km (38.5 miles) of oiled shoreline in Louisiana between 2010 and 2012 (DWH NRDA Trustees 2016a).

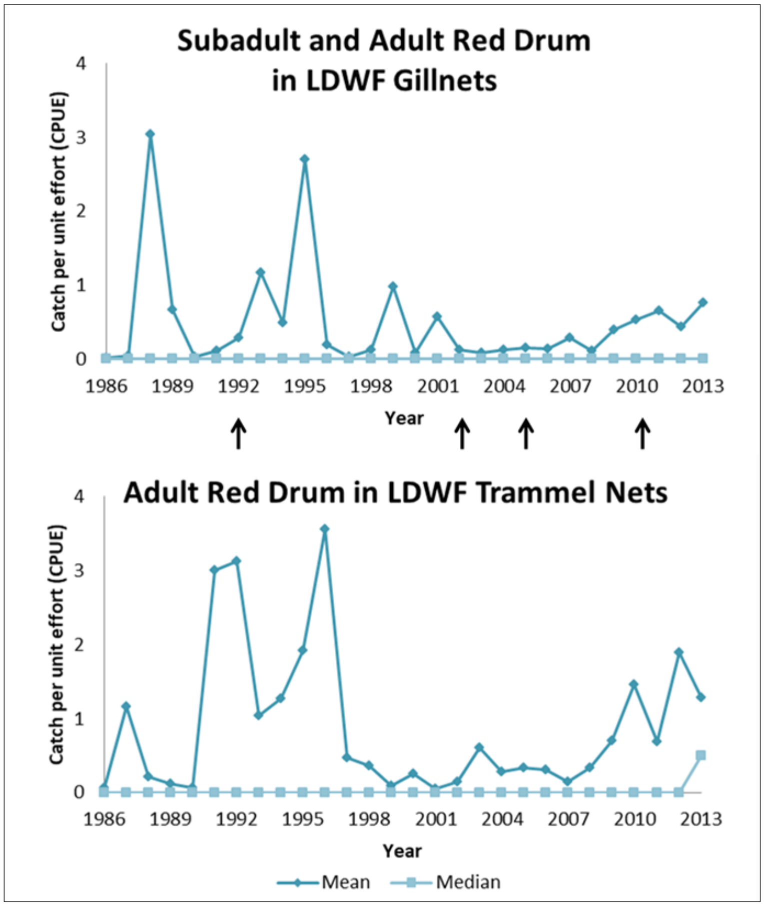


Figure 5.2-2. Mean and Median CPUE of Adult Red Drum in the LDWF Gillnet Samples (top) and in the Trammel Nets (bottom) for Barataria Basin

The arrows indicate some recent natural and anthropogenic events for reference in the time series (Hurricane Andrew in 1992, beginning of Davis Pond Diversion operations in 2002, Hurricane Katrina in 2005, the DWH oil spill in 2010).

5.3 Reef Fish

EFH for reef fish consists of Gulf of Mexico waters and substrates extending from the US/Mexico border to the boundary between the areas covered by the GMFMC and the South Atlantic FMC from estuarine waters out to depths of 183 meters (600 feet) (NOAA 2015). In the proposed action area, EFH for reef fish is included in the estuarine and nearshore coastal zones.

Adult reef fish are often associated with coral reef, limestone, hard bottom, and artificial reef substrates. Adults may also forage over sand near reefs. Adults tend to have relatively small home ranges and do not migrate long distances. Juvenile reef fish species are found in shallow, inshore areas associated with SAV beds and inshore reefs. For many species, older, larger fish are found in deeper water. Reef fish feed on a variety of invertebrates including shrimp, crabs, amphipods, octopus, and squid. Larger reef fish may also eat smaller fish (GMFMC 1981). Reef fish EFH in the Gulf of Mexico is shown in Figure 5.3-1. The following reef fish species may occur in the action area, though there is no reef habitat within the action area.

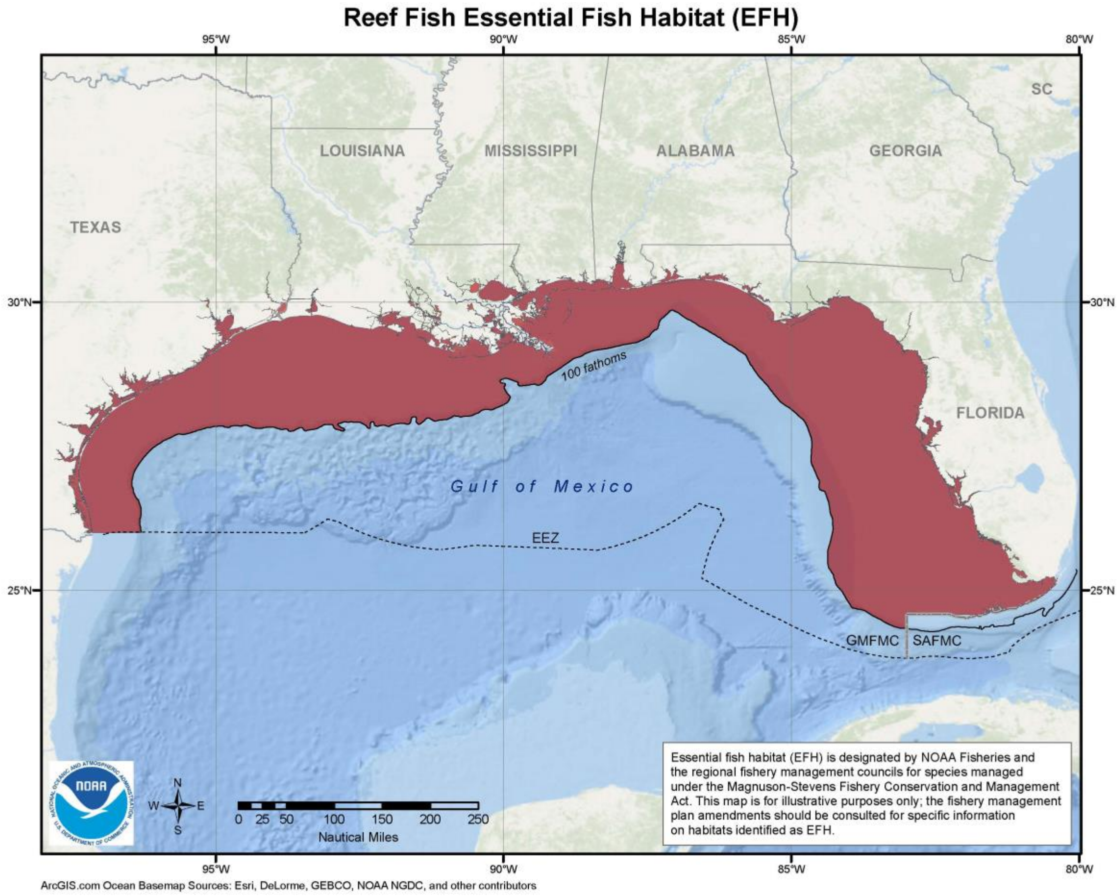


Figure 5.3-1. Reef Fish EFH in the Gulf of Mexico
(Source: GMFMC 2016)

5.3.1 Gray Snapper

Gray snapper (*Lutjanus griseus*, also known as mangrove snapper) occur in estuaries and shelf waters of the Gulf of Mexico and are particularly abundant off south and southwest Florida (Figure 5.3.1-1). Considered to be one of the more abundant snappers inshore, the gray snapper inhabits waters to depths of about 180 meters. Adults are demersal (near the seabed) and mid-water dwellers, occurring in marine, estuarine, and riverine habitats. They occur up to 32 km (19.9 miles) offshore and inshore as far as coastal plain freshwater creeks and rivers. Though the current EFH (GMFMC 2016) only recognizes the presence of adult gray snapper within the action area, recent research has also documented juvenile gray snapper in action area. Gray snapper have been observed from marine nearshore habitats on the seaward side of Barataria Bay barrier islands to low-salinity habitats within upper Barataria Basin (GMFMC 2016). Gray snapper are found among mangroves, sandy grass beds, and coral reefs and over sandy, muddy, and rocky bottoms. Spawning occurs offshore around reefs and shoals from June to August. Eggs are pelagic and are present June through September after the summer spawn, occurring in offshore shelf waters and near coral reefs. Larvae are planktonic, occurring in peak abundance June through August in offshore shelf waters and near coral reefs from Florida through Texas. Postlarvae move into estuarine habitats outside of the Project area and are found especially over dense grass beds of *Halodule* and *Syringodium*. Juveniles are marine, estuarine, and riverine dwellers, often found in estuaries, channels, bayous, ponds, grass beds, marshes,

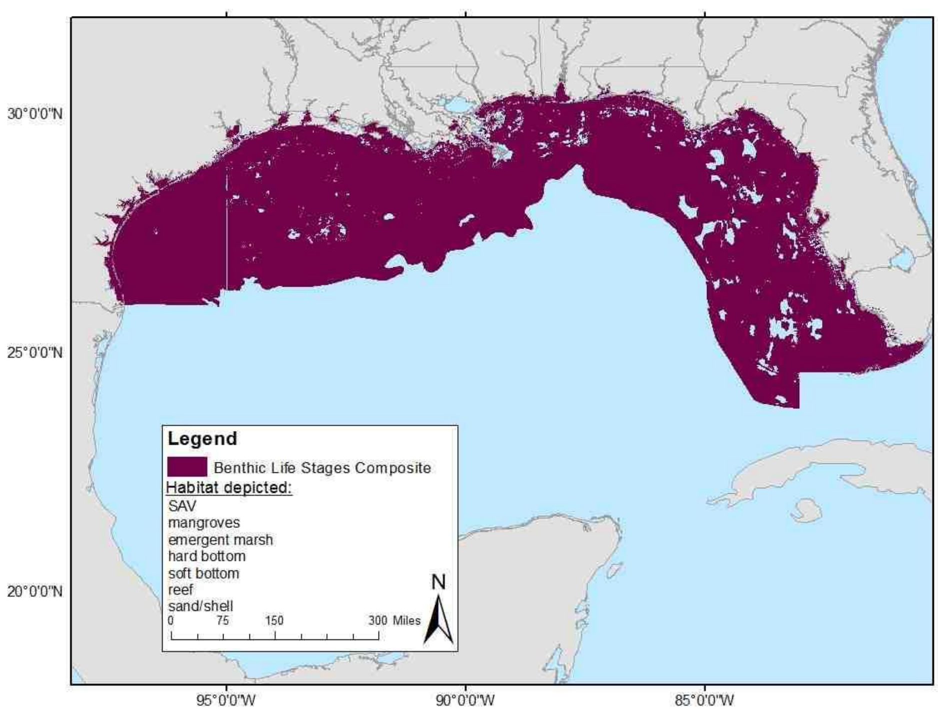


Figure 5.3.1-1. Map of Benthic Habitat Use by All Life Stages of Gray Snapper
Benthic habitats used by gray snapper include depths to 180 meters. (Source GMFMC 2016)

mangrove swamps, and freshwater creeks. They appear to prefer *Thalassia* grass flats, marl bottoms, seagrass meadows, and mangrove roots (GMFMC 2004, GMFMC 2016). More detailed information on habitat associations of gray snapper is provided in Nelson (1992) and Patillo et al. (1997). Adult Gray snapper may be present throughout the action area.

5.3.2 Lane Snapper

Lane snapper (*Lutjanus synagris*) can be found throughout the Gulf of Mexico (Figure 5.3.2-1), and in the western Atlantic from North Carolina to southeastern Brazil. Juveniles and adults are found across most habitat types, including SAV, sand/shell, reefs, soft bottom, banks/shoals, and mangroves. Adults occupy nearshore and offshore waters, at depths from 4 meters to 132 meters and temperatures of 16 °C to 29 °C (61 °F to 84 °F) (GMFMC 2016). Most fishery data and research studies combine reporting of lane and gray snapper because the 2 species commonly co-occur and share similar habitat associations (GMFMC 1981). While lane snapper larvae and juveniles are found in estuaries, they require high salinity levels on the order of 30 to 35.5 ppt; this limits their distribution primarily to marine habitats. Larval and juvenile lane snapper have been regularly observed around barrier islands at the mouth of the Barataria Basin in fishery surveys dating back to 1967, but they have not been observed north of Barataria Bay (GMFMC 2016).

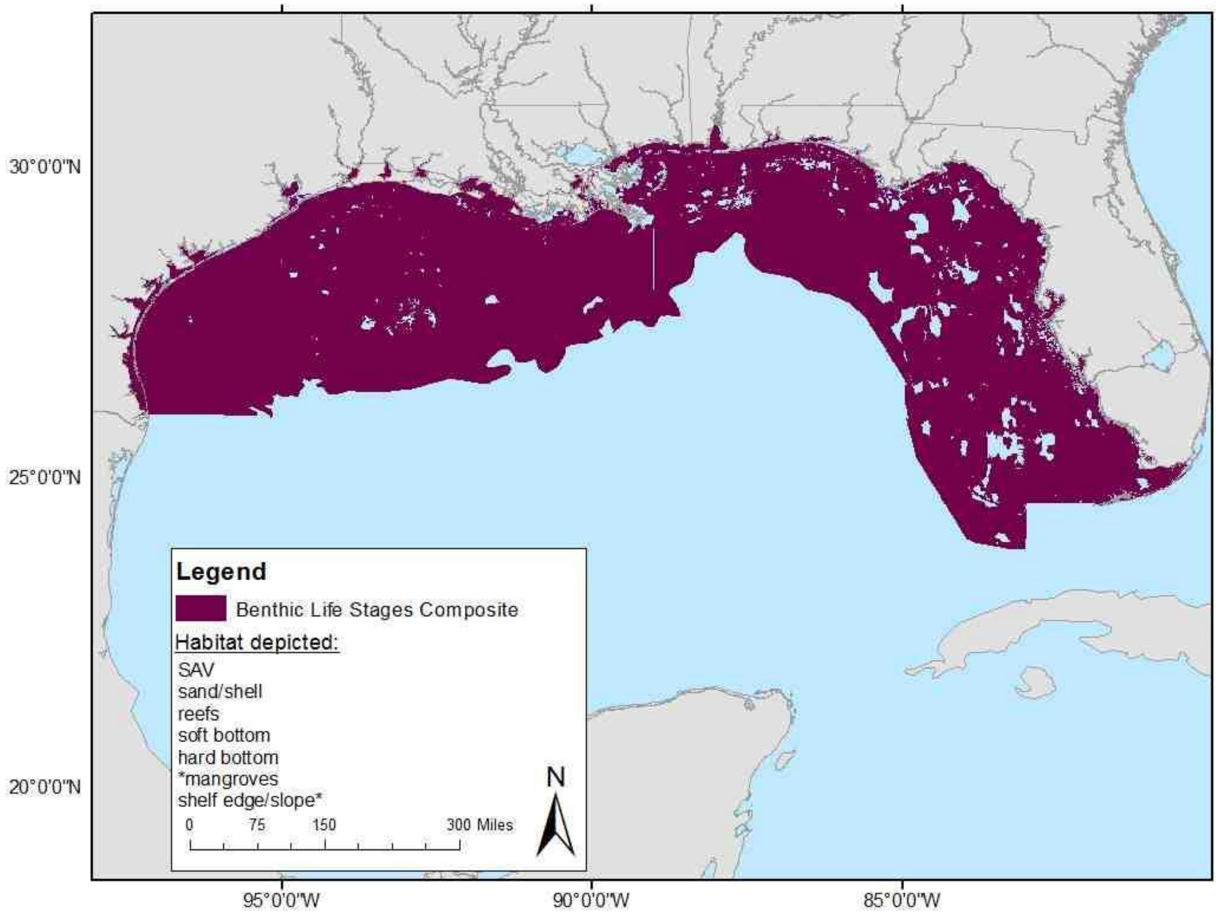


Figure 5.3.2-1. Map of Benthic Habitat Use by All Life Stages of Lane Snapper
Benthic habitats used by lane snapper include depths out to 132 meters. Legend information in asterisks refers to a habitat type identified in a study conducted outside GMFMC jurisdiction. (Source: GMFMC 2016).

5.4 Shrimp

EFH for shrimp consists of Gulf of Mexico waters and substrates extending from the US/Mexico border to Fort Walton Beach, Florida. This includes the following:

- Estuarine waters out to depths of 183 meters (600 feet).
- Waters and substrates extending from Grand Isle, Louisiana, to Pensacola Bay, Florida, between depths of 183 meters (600 feet) and 594 meters (1,950 feet).
- Waters and substrates extending from Pensacola Bay, Florida, to the boundary between the areas covered by the GMFMC and the South Atlantic FMC out to depths of 64 meters (210 feet), with the exception of waters extending from Crystal River, Florida, to Naples, Florida between depths of 18.3 meters (60 feet) and 274 meters (900 feet).
- In Florida Bay between depths of 161.5 meters (530 feet) and 109.7 meters (360 feet) (NOAA 2015).

Brown and white shrimp species are described below.

5.4.1 Brown Shrimp

Brown shrimp (*Farfantepenaeus aztecus*) are benthic omnivores distributed from Massachusetts to southern Florida, and throughout the Gulf Coast to the northwestern Yucatan Peninsula (Patillo et al. 1997). The highest abundance of brown shrimp occurs along the Louisiana, Texas, and Mississippi coasts and the shelf waters in the northern Gulf Coast (Allen et al. 1980, NOAA 1985, Williams 1984). Brown shrimp have an average life span of 24 months to 28 months in the Gulf.

Brown shrimp are an estuarine-dependent species, meaning they spend some or all of their life cycle in the estuary. O'Connell et al. (2017a) present details of the brown shrimp life cycle and the seasonal timing of peak abundances and movement of shrimp life stages on the shelf and in and out of Louisiana estuaries. The information is condensed here for Barataria Basin. At 10 mm to 15 mm (0.4 inch to 0.6 inch) TL, brown shrimp postlarvae are carried into Barataria Basin by shelf currents and tides, with peak migration in Barataria Basin occurring from January through June (Zein-Eldin and Renaud 1986). Metamorphosis to juveniles and settlement occurs around 25 mm (0.98 inch) TL in the estuaries, with peak months of early juveniles in Barataria Basin from mid-March through early June. The early juveniles prefer flooded marsh and edge habitats where they prey on benthic algae, infauna, and epifauna and can avoid larger aquatic predators, including their own species (Zimmerman et al. 1990, Rozas and Reed 1993). Juveniles remain in the shallow vegetated nursery habitats of Barataria Basin for about 3 months until they grow to approximately 60 mm (2.4 inches) TL (Minello et al. 1989). The larger juveniles move into deeper channels and open bays of the estuary in summer. They begin migrating as subadults (80 mm to 100 mm (3.1 inches to 3.9 inches) TL) out of the estuary toward the shelf in late summer and fall (Minello et al. 1989). Brown shrimp habitat distribution in the Gulf of Mexico is shown in figure 5.4.1-1.

Brown shrimp juveniles feed primarily on detritus, benthic algae, and microorganisms (Turner and Brody 1983). Subadult brown shrimp reside in the soft mud bottom and sand/shell bottom habitats in deeper estuarine channels and nearshore habitats before beginning their migration to offshore areas in the summer (GMFMC 2016). Subadult brown shrimp consume detritus, benthic algae, and smaller organisms living in the bottom substrate such as amphipods, polychaetes, and nematodes (Turner and Brody 1983). Research by Turner (1977) reported the production of Penaeid shrimp (which includes brown shrimp and white shrimp) to be directly correlated to the amount of wetlands in the estuary.

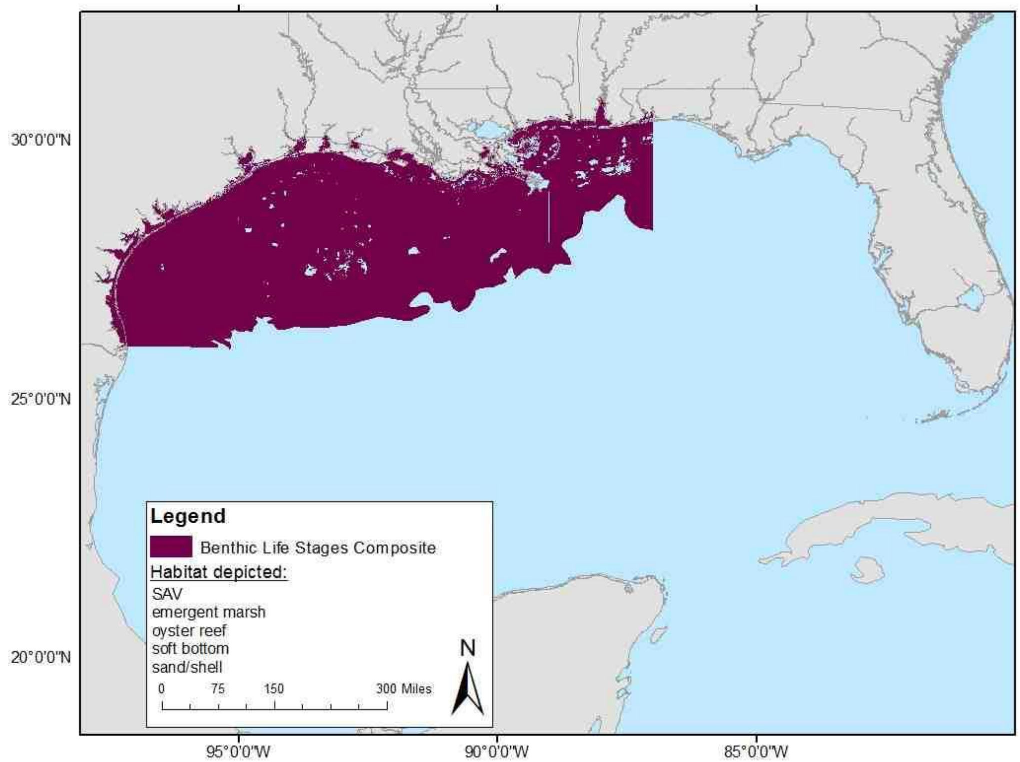


Figure 5.4.1-1. Map of Benthic Habitat Use by All Life Stages of Brown Shrimp
Benthic habitats used by brown shrimp include depths out to 110 meters. (Source: GMFMC 2016).

Brown shrimp juveniles and subadults are highly abundant in Louisiana estuaries, and the migrating subadults support valuable commercial inshore and offshore fisheries in the early spring through late summer. Louisiana has the second highest brown shrimp landings after Texas, with Louisiana accounting for an annual average contribution of 30% of the total U.S. landings by weight (from 2000 to 2016, NMFS 2018). The GMFMC manages the Penaeid shrimp fishery (including brown, white, and pink shrimp) in federal waters (offshore from 5.6 km [3.5 miles] to 370.4 km [230 miles]). LDWF manages the state's inshore fishery (state waters from shore to 5.6 km (3.5 miles]). An annual average of nearly 80% of Louisiana's reported shrimp landings from 2000 to 2013 are from the state waters; the Barataria Basin contributes the largest average annual proportion (44%) of the inshore landings (LDWF Shrimp Management Plan 2015).

Using total number of individual shrimp caught by the LDWF (in 50-foot seines and 16-foot trawls) for the coastal study areas in Watkins et al. (2014), the Barataria Basin has historically accounted for about 15% of the total coast-wide shrimp catch in both gears. The relative abundance (CPUE) of brown shrimp in the basin has been generally stable in more recent years, following the opening of the Davis Pond Freshwater Diversion Project in 2002 and Hurricane

Katrina in 2005 (Figure 5.4.1-2). Higher than usual CPUE estimates for 2011 through 2013 in Barataria are evident but not outside of historical annual values in the basin (Figure 5.4.1-2).

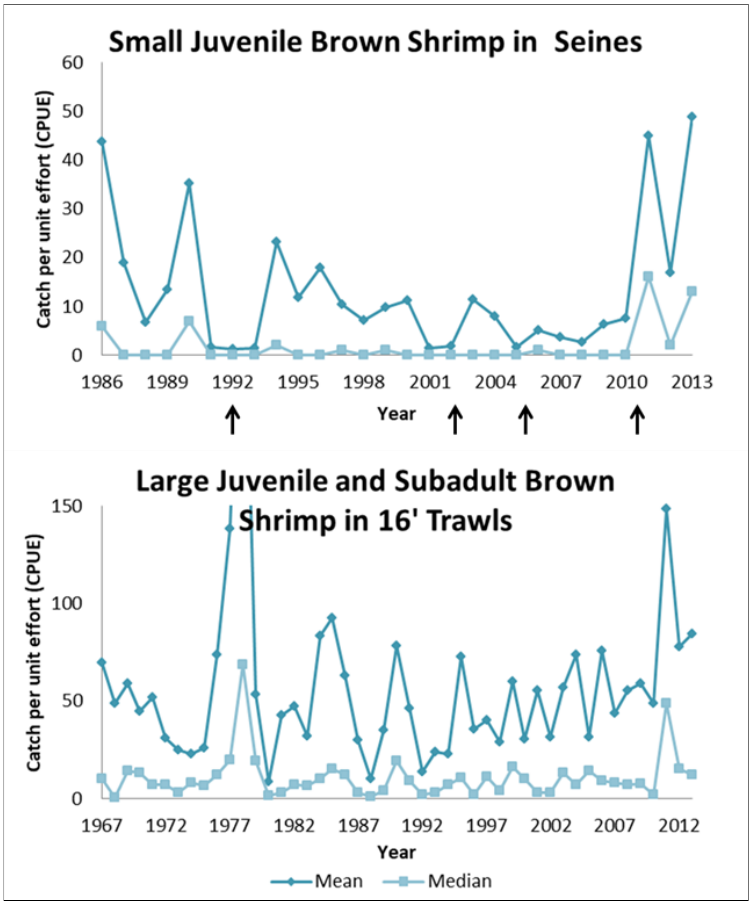


Figure 5.4.1-2. Mean and Median CPUE of Small Juvenile Brown Shrimp (top), and Large Juveniles and Subadults (bottom) in the LDWF Samples for Barataria Basin

The mean CPUE is equal to 311 shrimp per trawl sample for 1978 (bottom). Arrows indicate recent major events for reference. Hurricane Andrew in 1992, Davis Pond Diversion began operations in 2002, Hurricane Katrina in 2005, and the DWH oil spill in 2010.

A study to examine the effects of the DWH oil spill oiling exposure and remediation efforts on brown shrimp juvenile growth for the Barataria Basin (Rozas et al. 2014) showed growth of juvenile brown shrimp was reduced by 27% to 56% in heavier persistently oiled and heavier oiled shorelines compared to sites not oiled. Freshwater releases in response to the spill reduced basin-wide salinity and likely reduced juvenile brown shrimp production by affecting benthic prey abundance or by the stress of adapting to lower salinities (Adamack et al. 2012). The effect of oiling on shrimp growth caused an estimated total loss of 1,176 metric tons of brown shrimp in the marsh over 2010 and 2011. Oiling effects lasted at least into fall of 2011 along the 288 km

(179 miles) of heavier oiled and heavier persistently oiled shoreline in Louisiana and Mississippi (Powers and Scyphers 2015).

5.4.2 White Shrimp

White shrimp (*Litopenaeus setiferus*) are benthic omnivores distributed along the Atlantic Coast from Fire Island, New York, to St. Lucie, Florida, and along the Gulf Coast from Apalachee Bay, Florida, to Campeche Bay, Mexico (Patillo et al. 1997). White shrimp are most abundant along the Louisiana coast (Kilma et al. 1982). In the Gulf, they typically live for a year; some studies have also shown them to live up to 2 years to 4 years in the area (Christmas and Etzold 1977, Kilma et al. 1982).

White shrimp are an estuarine-dependent species with a similar life cycle and estuarine habitat use by juveniles and subadults as the brown shrimp, although the seasonal timing of white shrimp juveniles in the estuaries lags the brown shrimp by a few months. O'Connell et al. (2017b) presents details of the white shrimp life cycle and the seasonal timing of peak abundances and movement of shrimp life stages on the shelf and in and out of Louisiana estuaries. The description from O'Connell et al. (2017b) is condensed here for Barataria Basin. Currents and tides carry postlarval stages of white shrimp from the shelf into the estuaries from May through November (Zein-Eldin and Renaud 1986), with peak numbers in June and September (Baxter and Renfro 1968, Klima et al. 1982). Metamorphosis to juveniles occurs at 25 mm (0.98 inch) TL (Cook and Lindner 1970, Muncy 1984). Juveniles from 25 mm to 120 mm (0.98 inch to 4.72 inches) TL move to less saline waters (salinities usually below 5 ppt and 10 ppt) and farther up into the estuary compared to brown shrimp. After about 3 month juveniles leave the shallow habitats of the estuary for deeper, more saline regions in the lower estuary as they reach maturity and migrate back to the shelf to spawn (Cook and Lindner 1970). White shrimp habitat distribution in the Gulf of Mexico is shown in Figure 5.4.2-1.

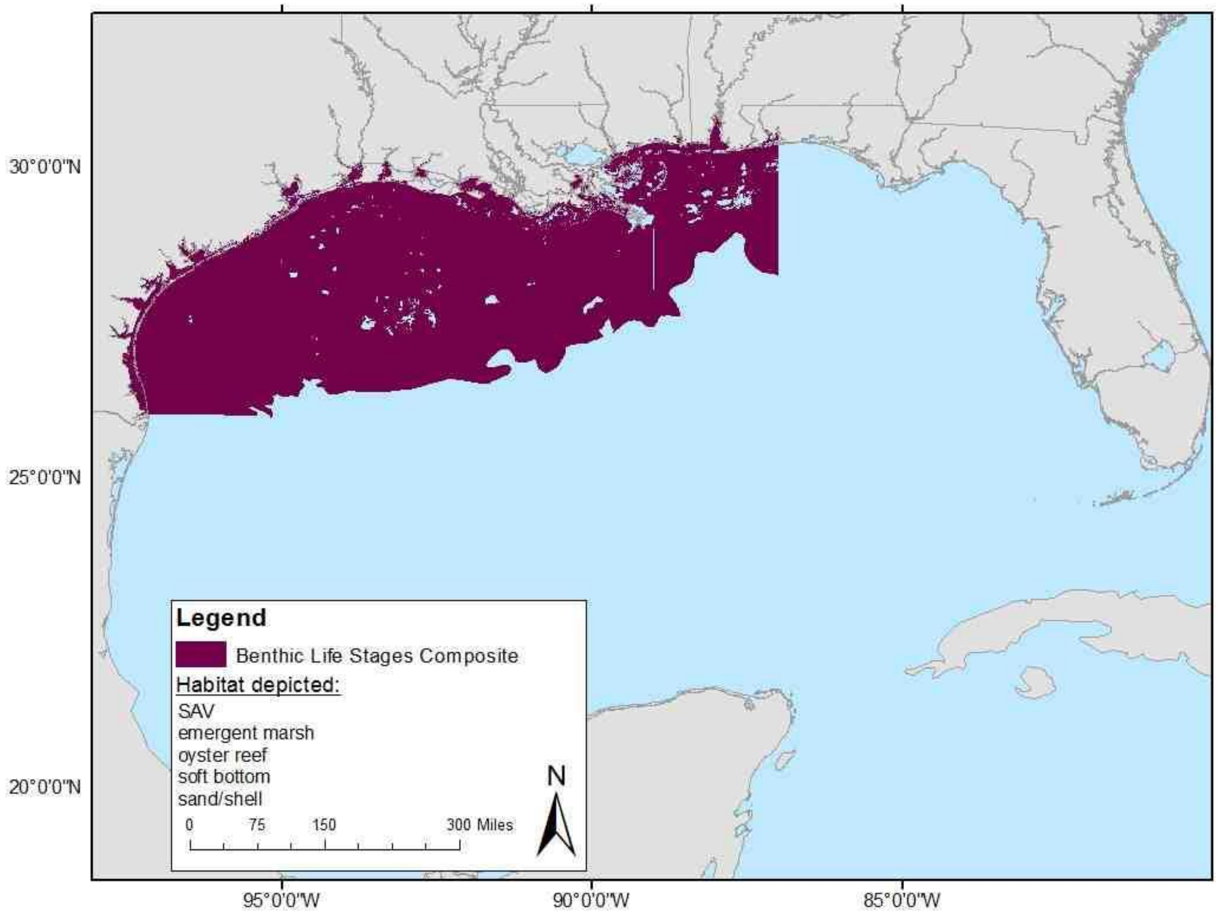


Figure 5.4.2-1. Map of Benthic Habitat Use by All Life Stages of White Shrimp.
Benthic habitats used by white shrimp include emergent marsh, SAV, oyster reefs, soft bottom, mangroves, and sand/shell out to 34 meter depths. (Source: GMFMC 2016).

Subadult and adult white shrimp are abundant in Barataria Basin and support a valuable commercial inshore and offshore fishery in Louisiana. The Louisiana white shrimp fishery has supported more than 60% of the U.S. annual landings of the species from 2000 to 2016 (http://www.st.nmfs.noaa.gov). An annual average of 64% of Louisiana's reported white shrimp landings from 2000 to 2013 are from the state waters (LDWF Shrimp Management Plan 2015x). The Barataria Basin reported an annual average of 13,002,833 pounds of shrimp during this time period, about 31% of the average annual landings for all of coastal Louisiana and second in basin-wide landings to Terrebonne Basin, directly to the west of Barataria Bay (LDWF Shrimp Management Plan 2015).

By comparing total number of individual shrimp caught by the LDWF fisheries-independent surveys (50-foot seine and 16-foot trawls) for the coastal study areas in Watkins et al. (2014), Barataria Basin accounted for only 2% of the total coast-wide white shrimp catch in seines and

6.5% of the catch in the trawls. The relative abundance of white shrimp in the trawl samples has been generally increasing since the late 1990s in Barataria Basin (Figure 5.4.2-2). Higher CPUE estimates for 2010, 2011, and 2012 are evident and similar to what is shown for brown shrimp. The LDWF data were only available through August of 2013 at the time of analysis (Watkins et al. 2014), so the 2013 seine and trawl CPUE estimates are likely low since fall and winter samples are missing from the dataset.

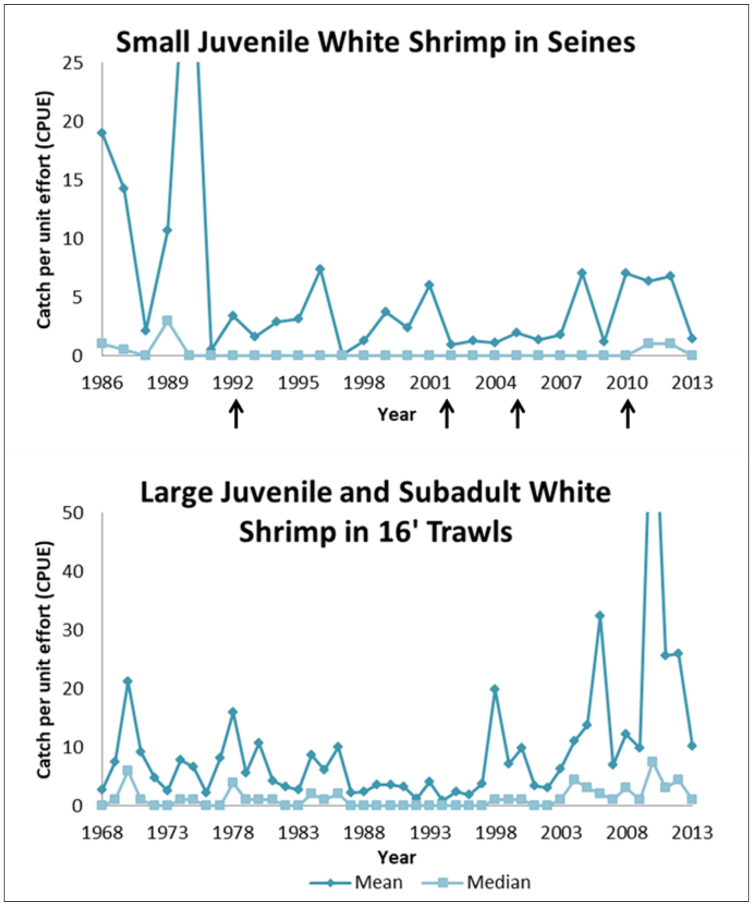


Figure 5.4.2-2. Mean and Median CPUE of Small Juvenile White Shrimp (top), and Large Juveniles and Subadults (bottom) in LDWF Samples from Barataria Basin

Mean CPUE = 45 shrimp per seine sample for 1990 (top) and 78 shrimp per trawl sample for 2010 (bottom). Arrows indicate recent relevant events (Hurricane Andrew in 1992, beginning of Davis Pond Diversion Project operations in 2002, Hurricane Katrina in 2005, the DWH oil spill in 2010).

DWH effects on white shrimp juvenile growth were estimated in the Barataria Basin by Rozas et al. (2014), with Powers and Scypher (2015) using the reduced growth data and modeled assumptions to estimate potential production of shrimp lost due to DWH effects in the northern Gulf of Mexico coastal marshes that were oiled (DWH NRDA Trustees 2016a). The authors demonstrated that growth of juvenile white shrimp was reduced by 31% to 46% in heavier persistently oiled and heavier oiled shorelines compared to shrimp growth in sites that were not oiled. Unlike brown shrimp, the white shrimp juveniles would not have been affected by the release of fresh water into the estuaries by the diversions because juvenile white shrimp occur in the marshes later in the summer and fall. The reductions in white shrimp growth were assumed to occur only when they were in the marsh edge and not after they move to deeper waters as late juveniles and subadults (Powers and Scyphers 2015). Powers and Scyphers (2015) estimated that the effect of marsh shoreline oiling caused approximately 913 million tons of white shrimp production to be lost in the marsh system over 2010 and 2011. As long as any marshes remained heavily oiled, the same injury to white shrimp juvenile production could be assumed to have occurred (DWH NRDA Trustees 2016a). The reported DWH effects are not necessarily coincident with the somewhat stable and higher annual basin-wide CPUE estimates demonstrated from the LDWF fishery-independent data for 2010–2012 (Figure 5.4.2-2), although the results are not directly comparable.

5.5 Highly Migratory Species

HMS EFH is established for 6 shark species, yellowfin tuna, and the sailfish in the estuarine and nearshore waters of the action area (Table 5.0-1).

HMS are mobile, pelagic species such as tuna, sailfish, and sharks that have wide distributions in open ocean, coastal, and estuarine waters, and vertically within the water column. Adult, juvenile, and especially early life stages (larvae for tuna and sailfish and neonates [newborn] for sharks) may be limited by temperature, salinity, or oxygen levels (NMFS 2006a). Atlantic sharks are widely distributed as adults but often use specific estuaries as nursery areas for neonate and young-of-the-year (YOY) life stages. Coastal sharks use the inshore shallow waters of the northern Gulf of Mexico as their spawning and nursery grounds. They tend to move into inshore shallow waters in the Gulf of Mexico during the spring to give birth to offspring. Young sharks spend summers in the inshore waters for feeding and refuge from predators. For example, estuarine environments, such as Barataria Basin, provide young bull sharks protection from predation and abundant food sources that allow it to achieve high growth and survival rates (Hunt and Doering 2013). Tuna and billfish distributions are typically associated with hydrographic features such as density fronts between different water masses (for example, the river plume of the Mississippi River and ocean fronts over the DeSoto Canyon in the Gulf) and do not use estuarine waters during any portion of their life.

5.5.1 Blacktip Shark

The blacktip shark (*Carcharhinus limbatus*) is circumtropical in shallow coastal waters and offshore surface waters of the continental shelves. It is a fast-moving shark that is often seen at the surface, frequently leaping and spinning out of the water. It often forms large schools that migrate seasonally north-south along the eastern United States. Blacktip sharks can be found year-round in the Gulf of Mexico and are common from Virginia through Florida. Juvenile and adult blacktip sharks are regularly observed around the barrier islands at the mouth of Barataria Bay in fisheries surveys conducted by LDWF (SEDAR 2012).

Garrick (1982), on examining a large number of museum specimens, believed that blacktip sharks are a single worldwide species. However, Dudley and Cliff (1993), working off South Africa, and Castro (1996), working on blacktip sharks off the southeastern United States, showed that there were significant differences among the various populations. Because of these differences, the Gulf of Mexico and Atlantic stocks of blacktip sharks are managed separately (NMFS 2006x; NOAA Fisheries 2017, 2018x).

EFH for the various life stages of blacktip shark are as follows:

- Neonate and YOY juvenile (≤61 cm fork length [FL]) EFH covers coastal areas, including estuaries, out to the 30-meter depth contour in the Gulf of Mexico from the Florida Keys to southern Texas. Important EFH includes important pupping and nursery areas in central Louisiana's nearshore coastal waters, such as habitats north of Dauphin Island, in the lower reaches of the Mobile Bay, Fort Morgan, Sand Island, north of Horn Island, and near the mouth of Bay St. Louis. Neonates EFH is associated with water temperatures ranging from 20.8 to 32.2 °C, salinities ranging from 22.4 to 36.4 ppt, water depth ranging from 0.9 to 7.6 meters, and DO ranging from 4.32 to 7.7 mg/L in silt, sand, mud, and seagrass habitats (Figure 5.5.1-1) (NOAA Fisheries 2017).

- Juvenile (62 to 118 cm FL) and adult (≥ 119 cm FL) EFH covers coastal areas out to the 100-meter depth contour in the Gulf of Mexico from the Florida Keys to southern Texas. EFH also covers coastal bays in Mississippi and Louisiana, including Mississippi Sound, Mobile Bay, Terrebonne Bay, Timbalier Bay, and Chandeleur Sound. EFH is associated with water temperatures ranging from 19.8 to 32.2 °C, salinities ranging from 7.0 to 36.8 ppt, water depth ranging from 0.7 to 9.4 meters, and DO ranging from 4.28 to 8.30 mg/L. EFH habitats include silt, sand, mud, and seagrass substrates. (Figure 5.5.1-2) (NOAA Fisheries 2017).

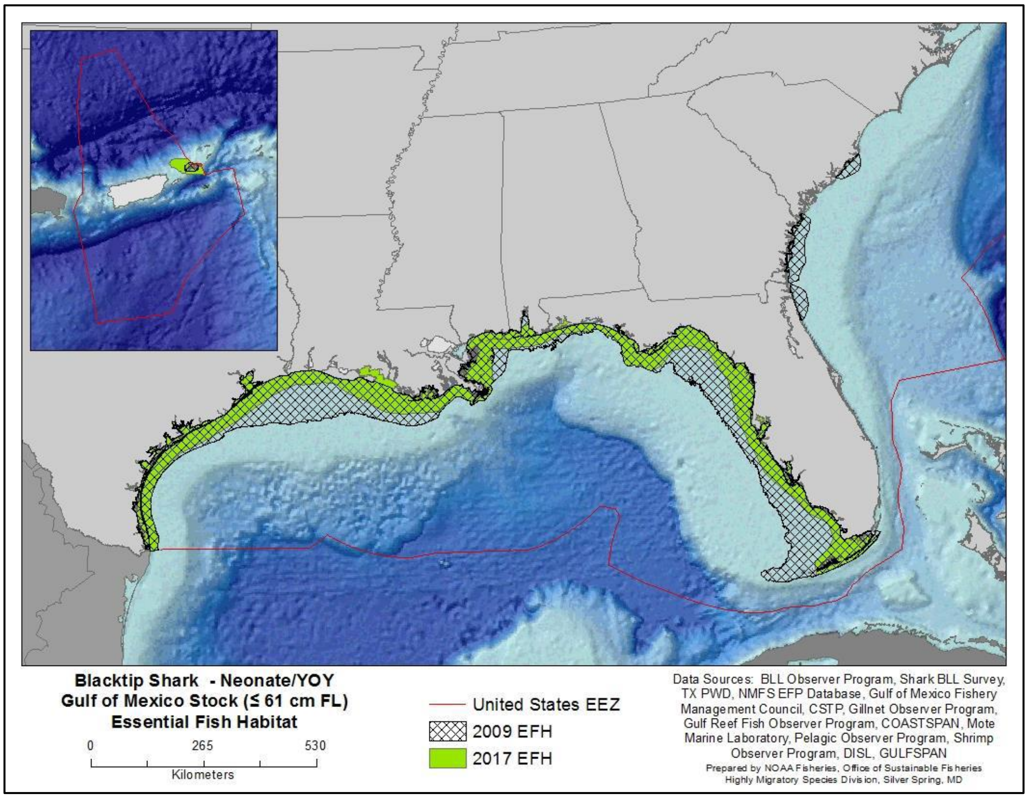


Figure 5.5.1-1. Blacktip Shark: Neonate and YOY (≤61 cm FL) EFH (Source: NOAA Fisheries 2017)

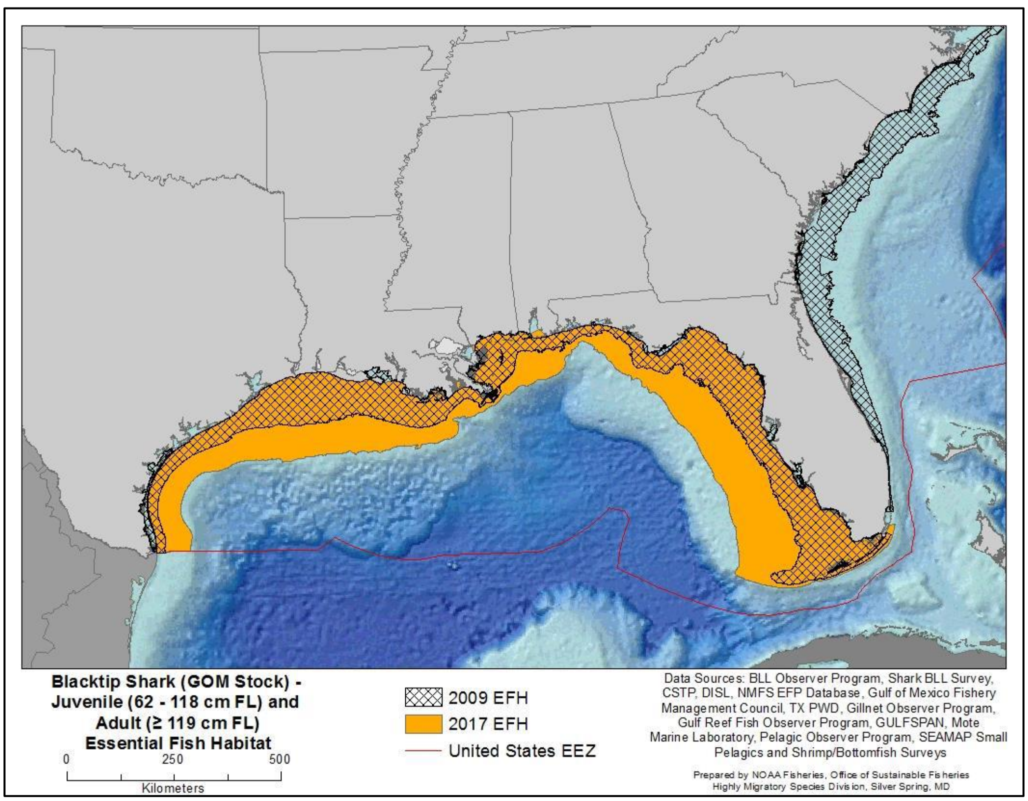


Figure 5.5.1-2. Blacktip Shark: Juvenile (>62 cm FL) and adult (≥119cm FL) EFH (Source: NOAA Fisheries 2017)

5.5.2 Bull Shark

The bull shark (*Carcharhinus leucas*) is a large, shallow-water shark that is common in warm seas and estuaries (Castro 1983). Bull sharks are distributed from New York to Brazil, including the Gulf of Mexico and Caribbean Sea, though they are rarely seen north of Delaware. Their primary habitat includes shallow coastal waters, but they are also common in lagoons, bays, and river mouths. Bull sharks regularly move into fresh water and may travel hundreds of kilometers upstream (NMFS 2006, Drymon et al. 2014). Juvenile bull sharks are routinely observed in LDWF gill net and trawl surveys of the Barataria Basin and surroundings, with distribution extending from nearshore marine waters seaward of the barrier islands to low-salinity habitats in Lake Salvador (GMFMC 2016).

EFH for the various life stages of bull shark are as follows:

- Neonate and YOY (≤77 cm FL) EFH in the Gulf of Mexico includes localized areas off the west coast of Florida such as the Caloosahatchee River area, Yankeetown, Tampa Bay, Charlotte Harbor, Ten Thousand Islands, and the Keys; the Florida Panhandle; and coastal habitats between Mobile Bay and Lake Borgne; and coastal areas along Texas to the mouth of the Mississippi River, particularly the inland bay and bayou systems of Louisiana (for example, the interior of Lake Pontchartrain, the Pearl River system, Little Lake/Barataria Bay and its inland waters, the Terrebonne/Timbalier Bay system, and the Atchafalaya/Vermilion Bay system). EFH for neonates/YOY includes areas of shallow depth (less than 9 meters) in lower salinity estuaries and river mouths (as low as 0.9 ppt) until water temperatures reach 21 °C (Figure 5.5.2-1) (NOAA Fisheries 2017).

- Juvenile (78-188 cm FL) and adult (≥ 189 cm FL) EFH in the Gulf of Mexico includes the Florida Keys, Ten Thousand Islands, Charlotte Harbor, Tampa Bay, Yankeetown, Pine Island Sound, the Florida panhandle, Mississippi Sound and Mobile Bay off the coasts of Mississippi and Alabama, the interior of Lake Pontchartrain, the Pearl River system, Chandeluer Sound on the east side of the Mississippi River Delta, Little Lake/Barataria Bay and its inland waters, the Terrebonne/Timbalier Bay system, and the Atchafalaya/Vermilion Bay system in the coastal waters off Louisiana, the west side of Mississippi River Delta, and coastal areas along the Texas coast, especially Matagorda Bay and San Antonio Bays. EFH includes freshwater creeks, ocean inlets, and seagrass habitats; temperatures as low as 16.4 °C; salinities ranging between 1.7 to 41.1 ppt; and DO concentrations ranging between 4 and 7 mg/L. EFH is located in shallow depths less than 9 meters (Figure 5.5.2-2) (NOAA Fisheries 2017).

The NMFS 2006 management plan and 2017 EFH Amendment 10 (NOAA Fisheries 2017) note mounting evidence that bull sharks are found over a broad range of freshwater, estuarine, and marine habitat types across salinities ranging from 0 to 33 ppt. Bull sharks are commonly found in highest abundance in areas adjacent to freshwater inflow (NMFS 2006).

In the Gulf of Mexico, bull shark habitat use has only been widely examined in the eastern and western Gulf, with knowledge of their movements and populations lacking in the more temperate north-central Gulf of Mexico. Drymon et al. (2014) studied estuarine habitat use in Mobile Bay, Alabama, and found bull shark presence associated predominantly with temperatures less than 30° C and salinities between 10 ppt and 20 ppt (Figure 5.5.2-3, Drymon et al. 2014). Blackburn et al. (2007) observed that Louisiana's coastal and inland estuarine waters are important nursery areas. They found neonate and juvenile bull sharks ranging from 44 to 136.2 cm FL in the inland bay and bayou systems of Louisiana. Neonates (FL ≤ 82.3 cm) and juveniles (FL ≥ 82.4 cm) were collected at all sites, with most neonate and juvenile bull sharks being collected from the Little Lake/Barataria Bay area (Blackburn et al. 2007).

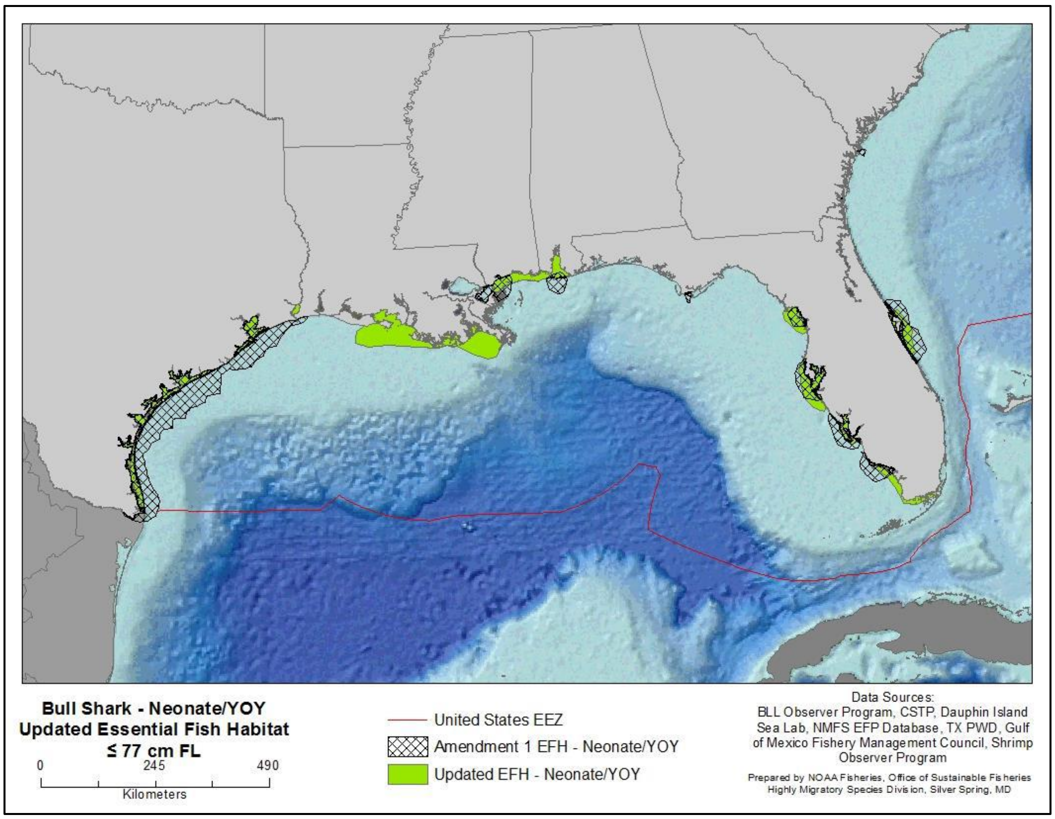


Figure 5.5.2-1. Bull Shark: Neonate and YOY (≤77 cm FL) EFH (Source: NOAA Fisheries 2017)

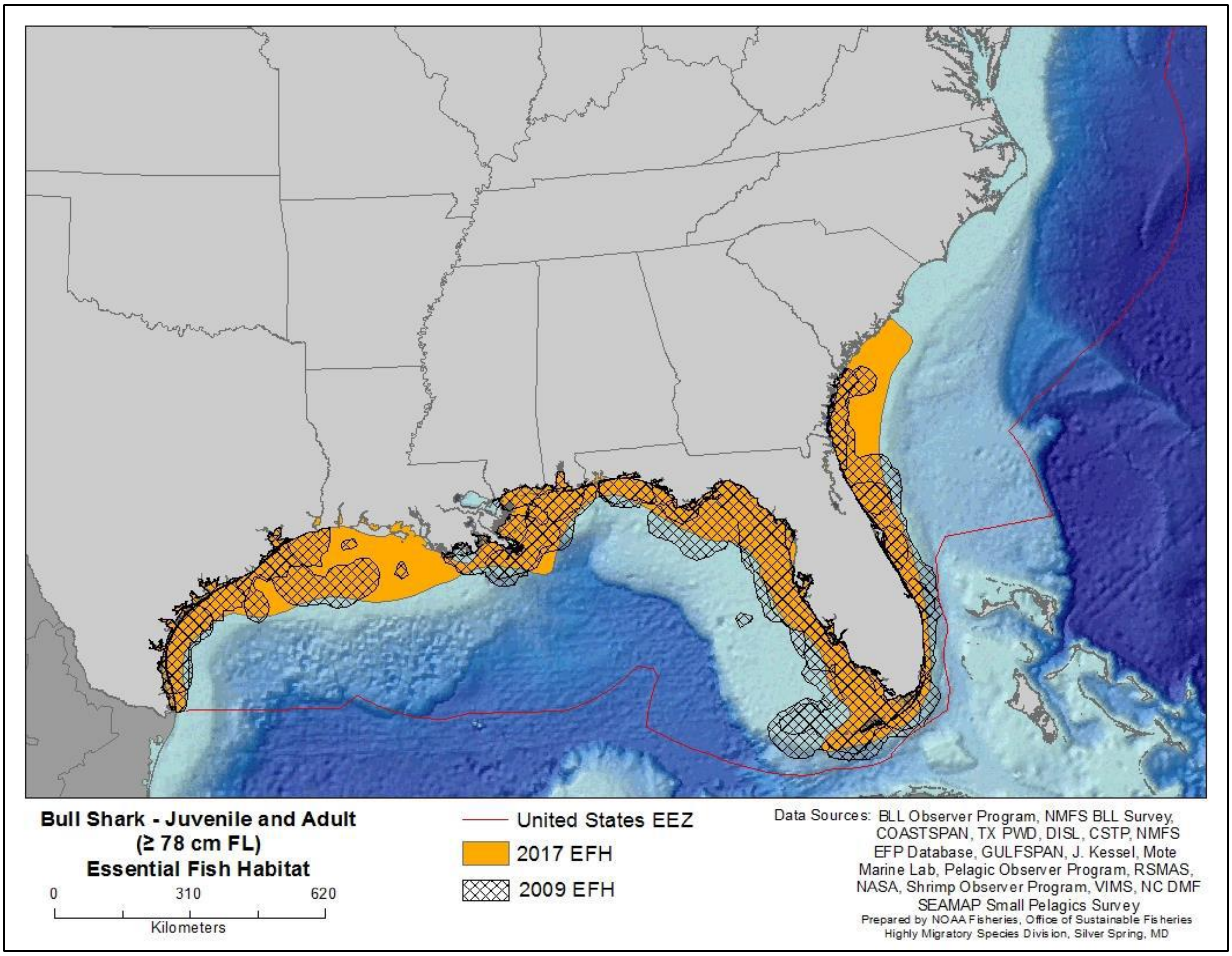


Figure 5.5.2-2. Bull Shark: Juvenile (78-188 cm FL) and adult (≥ 189 cm FL) EFH (Source: NOAA Fisheries 2017)

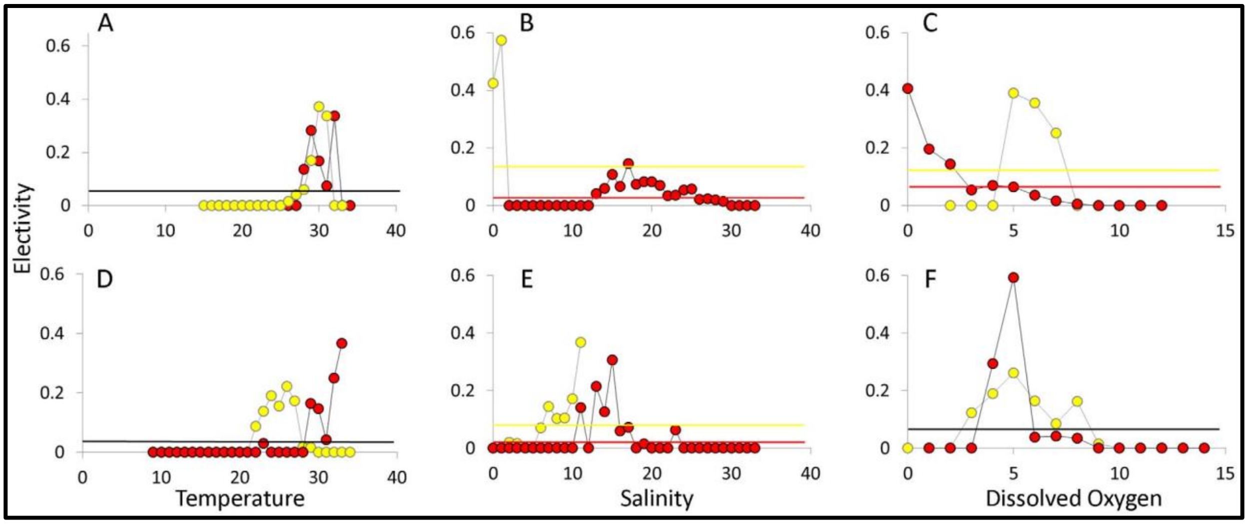


Figure 5.5.2-3. Bull Shark Electivity Plots. Electivity plots for the lower (red) and upper (yellow) portions of Mobile Bay in 2009 (A–C) and 2010 (D–F)

Electivity data are plotted for temperature (A, D) salinity (B, E) and dissolved oxygen (C, F). Horizontal lines represent neutral selection in the upper (yellow) and lower (red) bay. Horizontal black lines are used when the neutral selection value is the same between the upper and lower bay. (Source: Drymon et al. 2014).

5.5.3 Finetooth Shark

The finetooth shark (*Carcharhinus isodon*) is a migratory shark found in coastal waters of the southeastern United States and is well documented in the waters of north Florida in both the Gulf of Mexico and the Atlantic Ocean. The southernmost reports along Florida's Gulf coast are from Lemon Bay, just north of Charlotte Harbor, and from Port Salerno on Florida's Atlantic coast. Within the Gulf of Mexico, finetooth sharks are mostly residential, with 333 km (207 miles) as the longest distance travelled by an adult (SEDAR 2007). The finetooth shark is often found near beaches and in bays and estuaries. It inhabits extremely shallow waters, no deeper than 10 meters in the summer and 20 meters in the winter (Castro 1993). Juveniles and adults have been observed in beach seine and gill net surveys of shallow coastal habitats around the barrier islands at the entrance to Barataria Bay (GMFMC 2016).

EFH for neonate/YOY, juvenile, and adult finetooth shark in the Gulf of Mexico is as follows:

- Shallow coastal waters of the northeastern Gulf of Mexico with muddy bottom with temperatures ranging from 19.5 to 31.4 °C, salinity from 19 to 38 ppt, and depths of 2.3 to 5.3 meters on the seaward side of coastal islands. Core habitat areas include the mouth of the Apalachicola River and the gulf side of St. Vincent Island to just southeast of St. Andrews Bay Inlet, Florida. Also includes St. Vincent Sound, Saint Andrew Sound, Saint Joseph Bay, and Apalachicola Bay. Hyper-saline environmental conditions may spatially or temporally restrict neonate/YOY EFH in the western Gulf of Mexico and should not be included in EFH. EFH also includes Bay St. Louis; Perdido Sound; Bon

Secour Bay and lower Mobile Bay, Alabama; Terrebonne and Timbalier bay system, Louisiana (25.3-32.1 °C, 0.6 - 4.9 meter depth); the Mississippi Sound, specifically north of and off western Horn, Sound, and Round Islands (YOY), between the islands and the coast of Louisiana; coastal areas of Texas, including portions of Corpus Cristi Bay, Aransas and Copano Bays, San Antonio Bay, Espiritu Santo Bay, Matagorda Bay, Galveston Bay, and Trinity Bay) (19.2-30.6 °C, 16-36 meter depth); and beaches of the southeastern Texas coast (2.1-5.5 meter depth) (Figure 5.5.3-1) (NOAA Fisheries 2017).

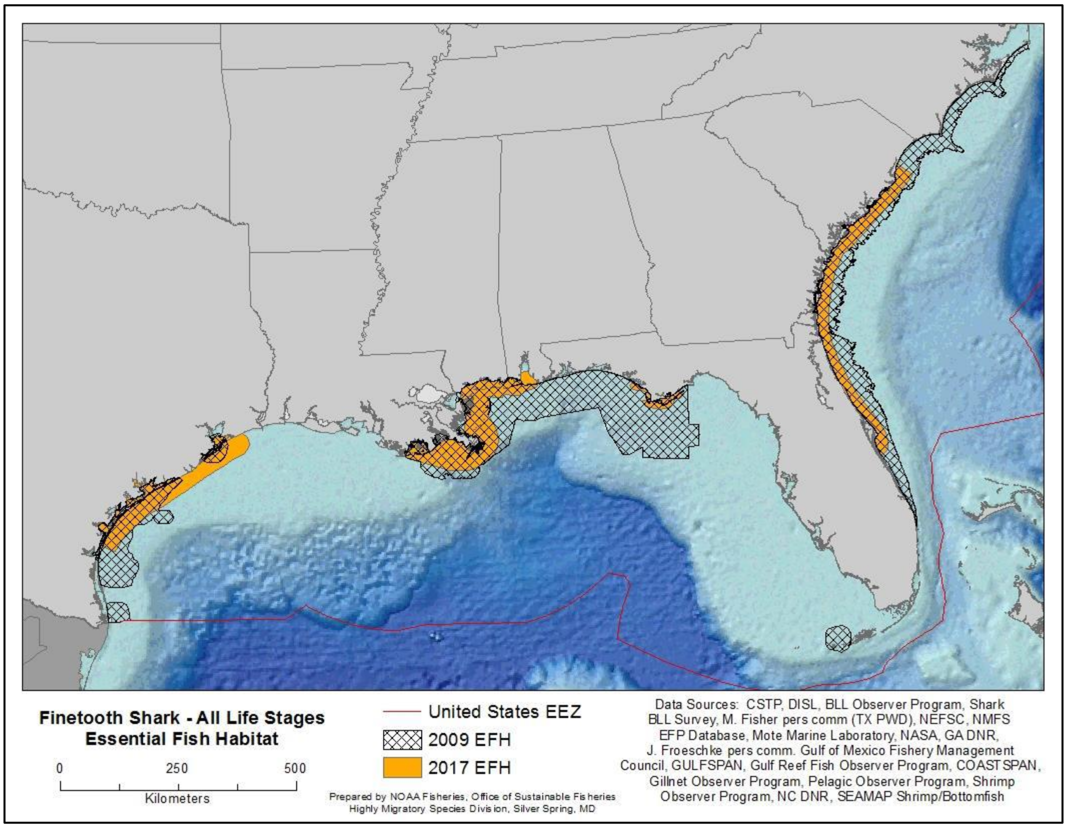


Figure 5.5.3-1. Finetooth Shark: EFH for all life stages (Source: NOAA Fisheries 2017)

5.5.4 Scalloped Hammerhead Shark

The scalloped hammerhead shark (*Sphyrna lewini*) is a common, large, schooling species found in warm waters. It is the most common hammerhead in the tropics and is commonly harvested by inshore artisanal and small commercial fisheries, as well as offshore operations (Compagno 1984). They migrate seasonally north–south along the eastern United States. Castro (1993b) found nurseries in the shallow coastal waters of South Carolina and Hueter et al. (1994) found small juveniles from Yankeetown to Charlotte Harbor on the west coast of Florida, in temperatures of 23.2 °C to 30.2 °C (73.8 °F to 86.4 °F), salinities of 27.6 ppt to 36.3 ppt, and DO of 5.1 mg/L to 5.5 mg/L. Additional life history information can be found in Lessa et al. (1998), Hazin et al. (2001), and Bush and Holland (2002).

EFH for the various life stages of scalloped hammerhead are as follows:

- Neonate and YOY (≤ 45 cm TL) EFH includes coastal areas in the Gulf of Mexico including those adjacent to Charlotte Harbor and Tampa Bay, coastal areas of Florida around Apalachicola and Cape San Blas, and coastal Texas. EFH is located in areas with temperatures of 23.2 to 30.2 °C, salinities of 27.6 to 36.3 ppt, DO of 5.1 to 5.5 mL/L, depths to 5 to 6 meters, and mud and seagrass substrate (Figure 5.5.4-1) (NOAA Fisheries 2017).

- Juvenile and adult (> 45 cm FL) EFH in the Atlantic Ocean ranges from North Carolina to the Florida Keys, including Florida Bay and the Dry Tortugas. EFH is also located in the northern Gulf of Mexico from eastern Louisiana to Pensacola Florida (Mississippi Delta to DeSoto Canyon; Figure 5.5.4-2) (NOAA Fisheries 2017).

As shown in Figures 5.5.4-1 and 5.5.4-2, the 2017 highly migratory species EFH update (NOAA Fisheries 2017) redistributed scalloped hammerhead EFH in the Gulf of Mexico. The action area and vicinity are no longer considered EFH for neonate and YOY life stages.

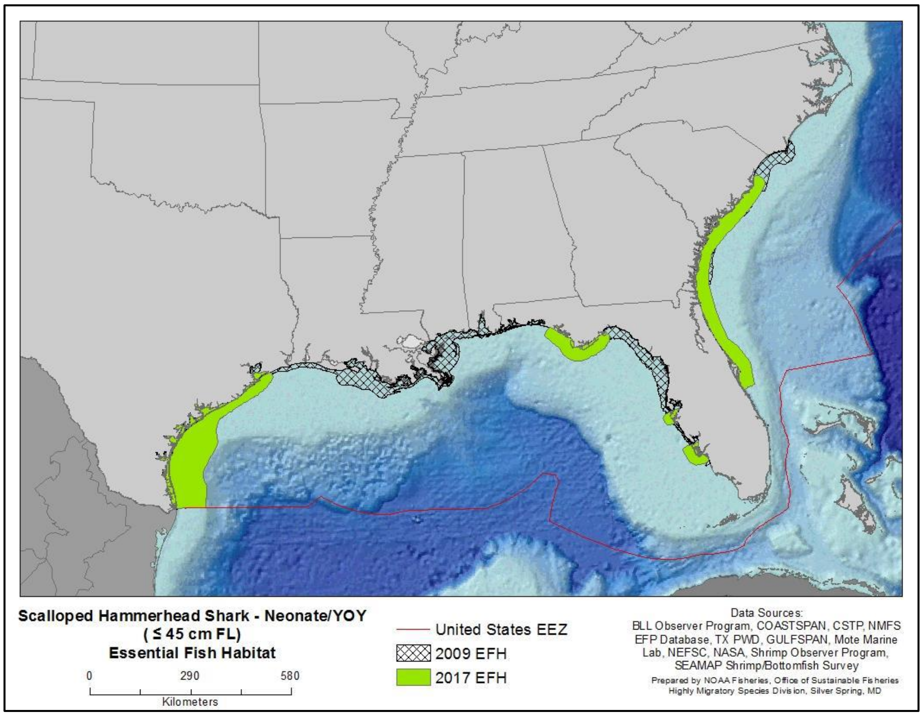


Figure 5.5.4-1. Scalloped Hammerhead Shark: Neonate and YOY (≤ 45 cm TL) EFH (Source: NOAA Fisheries 2017)

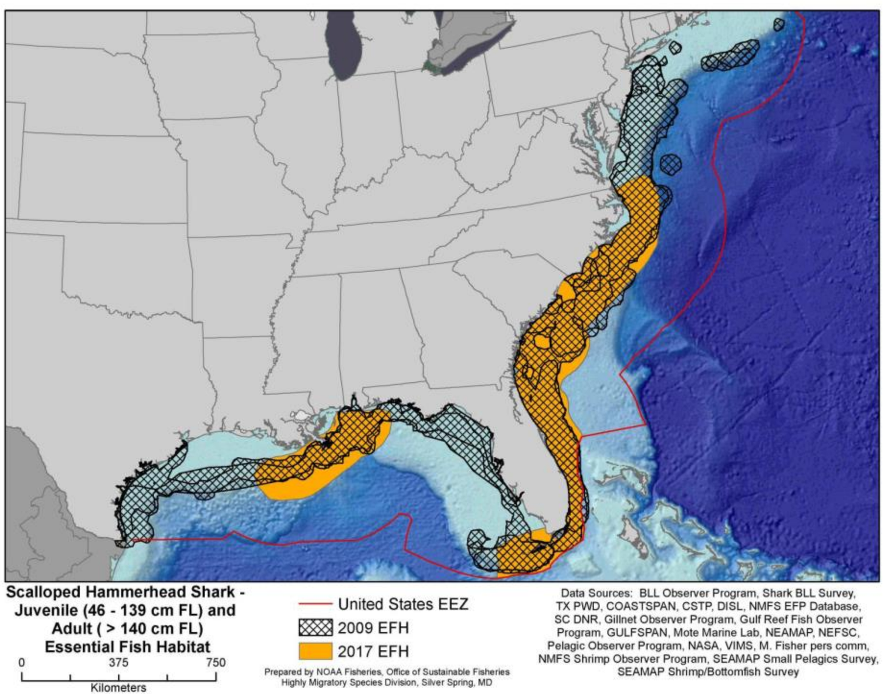


Figure 5.5.4-2. Scalloped Hammerhead Shark: Juvenile (> 45 cm FL) and adult (>140 cm) EFH (Source: NOAA Fisheries 2017)

5.5.5 Atlantic Sharpnose Shark

The Atlantic sharpnose shark (*Rhizoprionodon terraenovae*) is a small coastal shark inhabiting the waters of the southeast coast of North America. It is a common year-round resident along the coasts of South Carolina, Florida, and in the Gulf of Mexico and is an abundant summer migrant northward to Virginia. Frequently, these sharks are found in schools of uniform size and sex (Castro 1983). In the Gulf of Mexico, Atlantic sharpnose sharks are defined as a separate stock, known as the "Gulf of Mexico stock" which is geographically defined as occurring from the Florida Keys throughout the Gulf of Mexico (Heist et al. 1996). Sharpnose sharks within the Gulf of Mexico are mostly residents, with 400 km (249 miles) as the longest distance travelled by an adult (SEDAR-DW-03 2006). YOY and juveniles have been observed in net and trawl surveys in shallow nearshore waters of the action area, around the barrier islands at the entrance to Barataria Bay (GMFMC 2016).

EFH for the Gulf of Mexico stock of Atlantic sharpnose shark are as follows:

- Neonate and YOY (<50 cm FL) EFH includes Gulf of Mexico coastal areas including offshore of Naples, Florida; localized areas between Panama City, Florida to Apalachicola; and between Mobile Bay, Alabama and southern Texas. EFH is recognized in important summer nursery habitats for neonates and includes certain habitat associations: peninsular Florida near Charlotte Harbor and Naples (18.4 to 30.7 °C, salinity range of 22.8 to 33.7 ppt, 0.9 to 4 meter depth); northeastern Gulf of Mexico, including Apalachee Bay, Crooked Island Sound, St. Joseph Bay, St. Andrew Bay, and the Apalachicola Bay systems (e.g., St. Vincent Island) (21.8 to 31.7 °C, salinities of 29.0 to 37.2 ppt, and DO of 2.7 to 6.9 mL/L); mouth of St. Louis Bay to the tip of Ft. Morgan, Alabama; coastal areas of the Mississippi delta and Mississippi Sound (28.6 °C, salinity range of 22.4 to 26.4 ppt, 2.3 to 26.4 meter depth); Terrebonne/Timbalier bay systems of Louisiana; and all major bay systems along the Gulf coast of Texas from Galveston Bay to lower Laguna Madre and coastal Texas waters (16.7 to 32 °C, salinity range of 10 to 38 ppt) (Figure 5.5.5-1) (NOAA Fisheries 2017)

- Juvenile (50 to 61 cm FL) and adult (≥ 62 cm FL) EFH includes Gulf of Mexico coastal areas from the Florida Keys to Texas, out to a depth of 200 meters. Juvenile EFH combines important nursery areas with specific habitat associations, including Yankeetown, Florida to the 10,000 Islands estuary system, and coastal areas surrounding the Florida Keys (17.2 to 33.3 °C, salinity range of 22.8 to 37.4 ppt, 2.9-8.71 mg/L DO, 0.6 to 43.9 meter depth); Yankeetown and Anclote Key during the months of May to July (17.2 to 33.3 °C , salinities of 22.8 to 35.5, and DO of 4.5 to 8.6 mL/L); northeastern Gulf of Mexico, including Apalachee Bay, Crooked Island Sound, St. Joseph Bay, St. Andrew Bay, and the Apalachicola Bay systems (e.g., St. Vincent Island) (16 to 32.4 °C, salinities of 19.0 to 38 ppt, and DO of 4.5 to 8.3 mL/L); coastal Alabama off Dauphin Island and Mobile Point (24.5 to 31.5 °C, 0.3 to 7.2 mg/L DO, salinity range of 28.6 to 36.3 ppt, depth of 2.7 to 14 meters); mouth of St. Louis Bay to the tip of Ft. Morgan, Alabama; Terrebonne/Timbalier bay systems of Louisiana (22.6 to 32.4 °C, salinity range of 23 to 37.3 ppt, depth 1.5 to 4.9 meters); and all major bay systems along the Gulf coast of Texas from Galveston Bay to lower Laguna Madre and coastal Texas waters (16 to 32 °C, salinity range of 10 to 38 ppt).

- Notable EFH associations for adults are found in coastal areas of western Florida from St. George Sound to Anclote Keys Florida (19.1 to 31.8 °C, salinity range of 19.7 to 37.3 ppt, depth of 0.4 to 7.0 meters); northwest Florida (St. Andrew Bay, Crooked Island Sound, St. Joseph Bay, gulf side of St. Vincent island) (20.4 to 30.9 °C, salinity range of 25.1 to 32.7 ppt, depth of 2.5 to 8.3 meters); and Mississippi Sound (27.3 to 29.3 °C, salinity range of 19.9 to 30.3 ppt, 3.1 to 5.1 meter depth) (Figure 5.5.5-2) (NOAA Fisheries 2017)

Atlantic sharpnose sharks mate between mid-May and mid-July in inshore waters of the Gulf of Mexico. After mating the adults migrate to offshore foraging habitats. Females gestate for 10 to 11 months before returning to nearshore areas to give birth, typically beginning in June. Atlantic sharpnose sharks primarily eat small fish, including menhaden, eels, silversides, wrasses, jacks, toadfish, and filefish; but also forage upon worms, shrimp, crabs, and mollusks (SEDAR 2007). Based on known habitat associations and prey preferences, all life stages of sharpnose sharks are likely to occur anywhere in the nearshore areas of the Project area at times and locations when suitable salinity and temperature conditions are present.

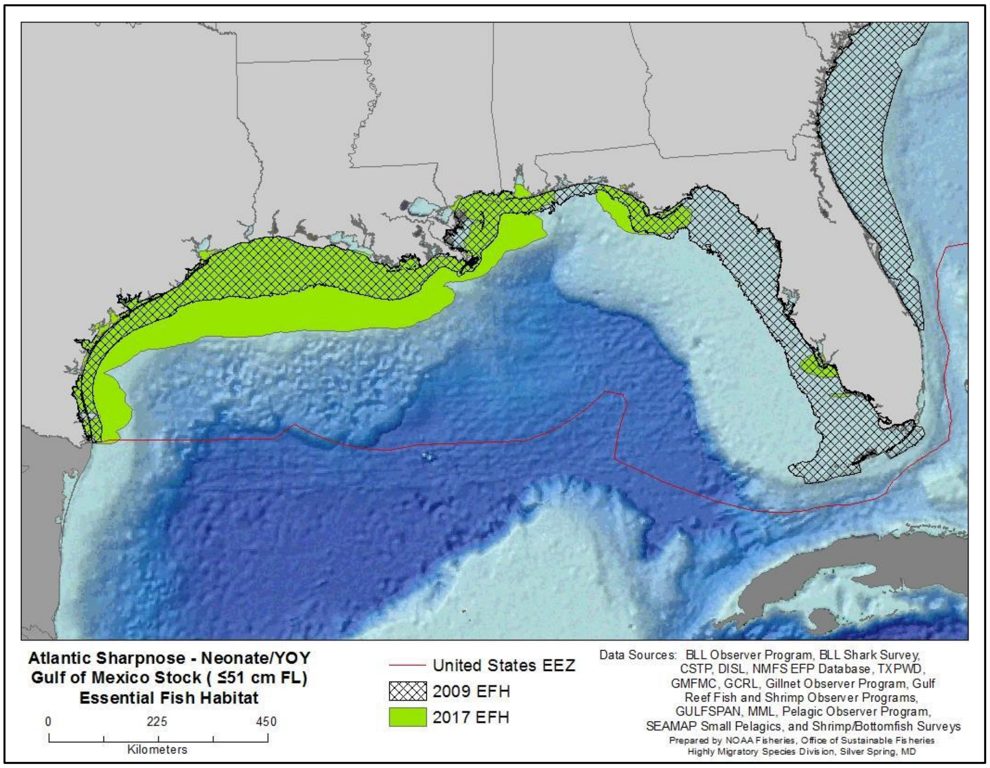


Figure 5.5.5-1. Atlantic Sharpnose Shark: Neonate and YOY (≤51 cm FL) EFH (Source: NOAA Fisheries 2017)

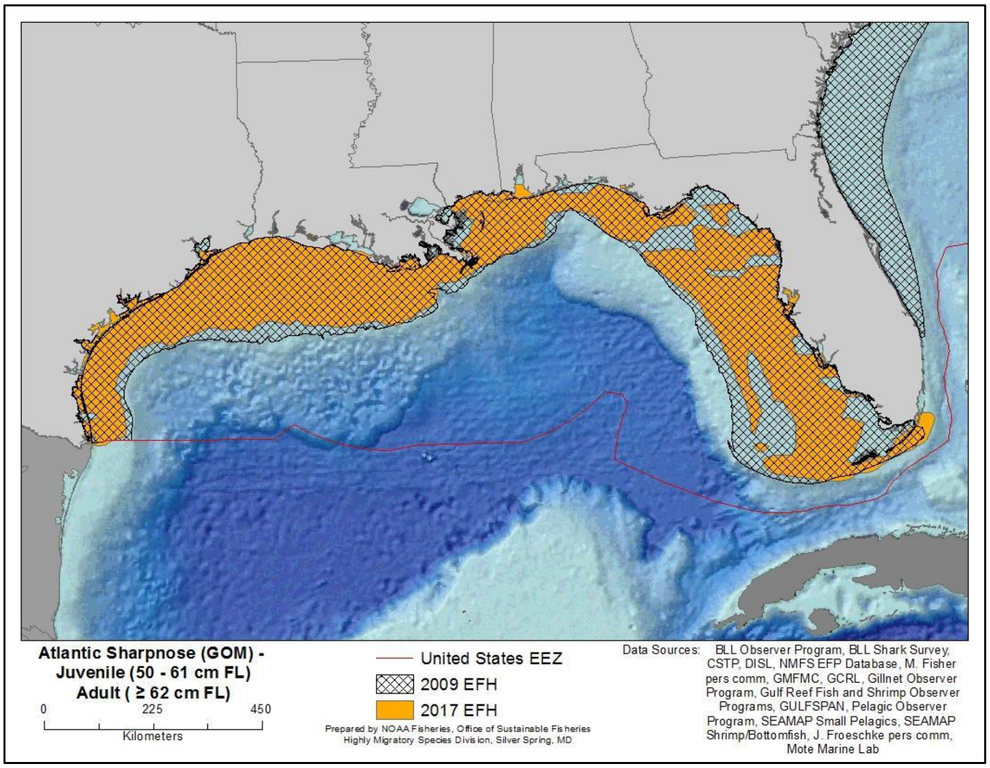


Figure 5.5.5-2. Atlantic Sharpnose Shark: Juvenile (50 - 61 cm FL) and adult (≥ 62 cm FL) (Source: NOAA Fisheries 2017)

5.5.6 Spinner Shark

Spinner shark (*Carcharhinus brevipinna*) is a common coastal-pelagic shark found on continental and insular shelf habitats in tropical and subtropical waters (Compagno 1984). It is often seen in schools, leaping out of the water while spinning. The species is known to be migratory, but its movement patterns are poorly understood. The species range in the western North Atlantic extends from Virginia to Florida and into the Gulf of Mexico (NMFS 2006). Juveniles and adults have been observed in net and trawl surveys in shallow nearshore waters of the action area around the barrier islands at the entrance to Barataria Bay (GMFMC 2016). EFH for all life stages of spinner shark are found within the action area.

EFH for spinner sharks by life stage are as follows:

- Neonate and YOY (≤67 cm) EFH in the Gulf of Mexico includes coastal areas surrounding the Florida Keys and the Big Bend Region of the Florida coast west to southern Texas. EFH consists of sandy bottom habitats with sea surface temperatures ranging from 24.5 to 30.5 °C and mean salinity of about 36 ppt. (Figure 5.5.6-1) (NOAA Fisheries 2017).

- Juvenile and adult (>57 cm) EFH in the Gulf of Mexico includes coastal areas from Apalachicola, Florida to southern Texas. Juvenile EFH extends from the shoreline to coastal shelf waters up to 20 meters deep, adult EFH extends from shore to waters 90 meters deep (Figure 5.5.6-2) (NOAA Fisheries 2017).

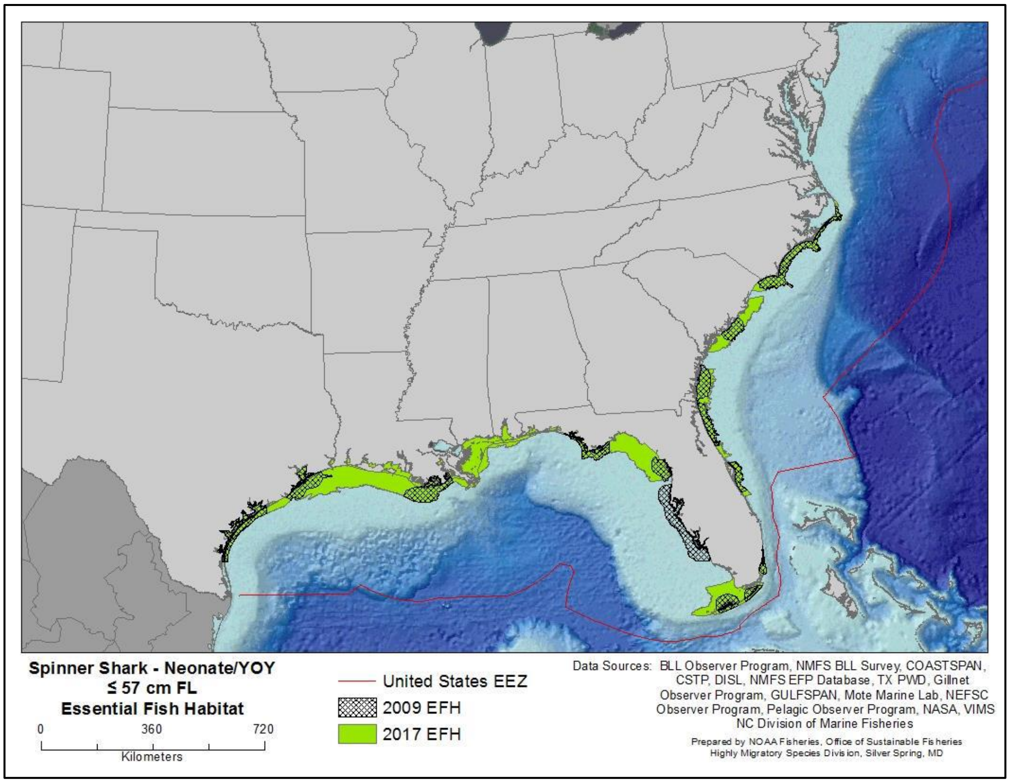


Figure 5.5.6-1. Spinner Shark: Neonate YOY (≤67 cm) EFH (Source: NOAA Fisheries 2017)

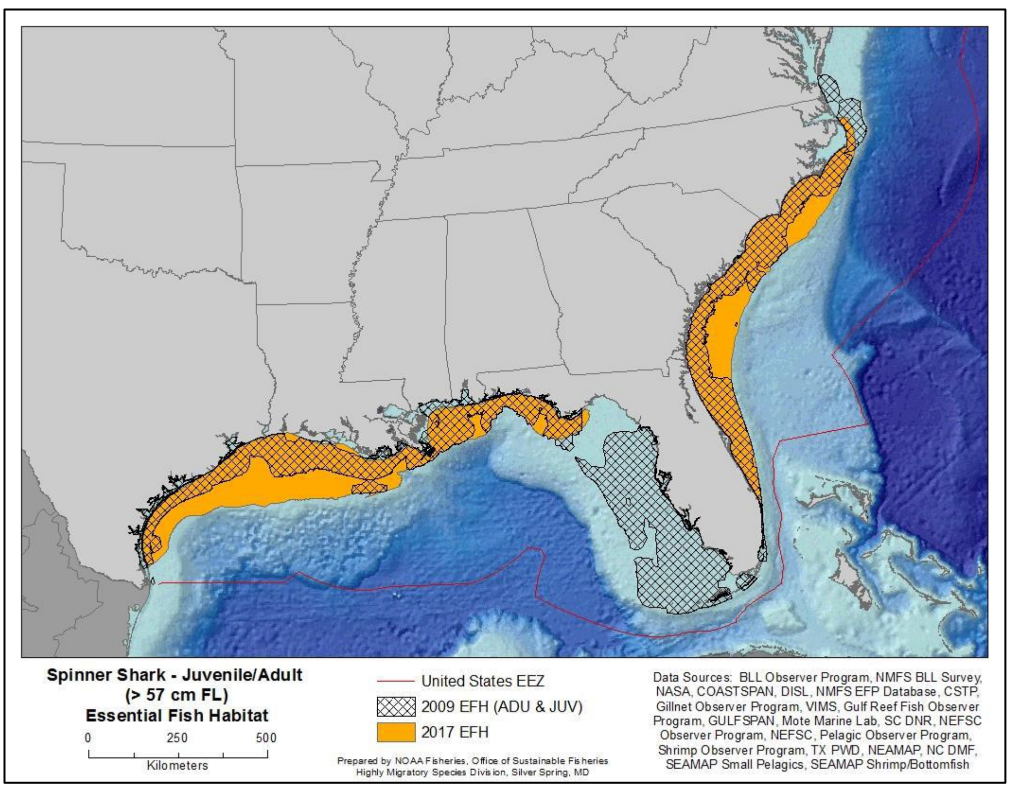


Figure 5.5.6-2. Spinner Shark: Juvenile and Adult (>57 cm FL) EFH (Source: NOAA Fisheries 2017)

5.5.7 Sailfish

Sailfish (*Istiophorus platypterus*) have a circumtropical distribution (Post 1998) ranging from 40°N to 40°S in the western Atlantic and 50°N to 32°S in the eastern Atlantic. Sailfish are epipelagic and coastal to oceanic and are usually found above the thermocline at a temperature range of 21 to 28 °C (70 to 82 °F), but periodically dive into deeper, colder water in pursuit of prey. They are the least oceanic of the Atlantic billfish, commonly occurring in inshore waters. Most often sailfish are found near shelf edges associated with nearby land masses. While prevalent in inshore waters, the species is also known to migrate well offshore (NMFS 2006).

In the winter, sailfish are found in schools around the Florida Keys, eastern Florida, the Caribbean, and offshore waters throughout the Gulf of Mexico. In the summer they appear to disperse northward along the U.S. Atlantic coast as far north as Maine, although a resident population remains off the east coast of Florida year-round. During the summer sailfish migrate northward along the inside edge of the Gulf Stream to northerly foraging habitats. Sailfish regroup off the east coast of Florida in the fall and then disperse to winter habitats. Sailfish appear to spend most of their time above the thermocline, at depths ranging from 10 to 250 meters. The 28 °C (82 °F) isotherm appears to be the optimal temperature band for this species. Larval rearing is associated with the warm waters of the Gulf Stream and warm loop currents in the Gulf of Mexico (Beardsley et al. 1975, Nakamura 1985, Post 1998). Adult sailfish EFH is the only EFH lifestage found within the Project area.

EFH for the various life stages of sailfish are as follows:

- Spawning, egg, and larval EFH in the Gulf of Mexico consists of offshore pelagic habitats from the Florida Keys to the continental shelf off of southern Texas. EFH extends from the 200-m bathymetric line to the seaward extent of the U.S. Exclusive Economic Zone (EEZ) (Figure 5.5.7-1) (NOAA Fisheries 2017).

- Juvenile and subadult (20 - 179 cm lower jaw fork length [LJFL]) EFH in the Gulf of Mexico includes localized habitats in the central and northern gulf, between Apalachicola and southern Texas (Figure 5.5.7-2) (NOAA Fisheries 2017).

- Adult (≥ 180 cm LJFL) sailfish EFH in the Gulf of Mexico spans from coastal habitats off the western Florida panhandle and coastal Louisiana to offshore pelagic habitats associated with the continental shelf westward to the coast of Texas (Figure 5.5.7-3) (NOAA Fisheries 2017). This is the only life history stage present in the action area.

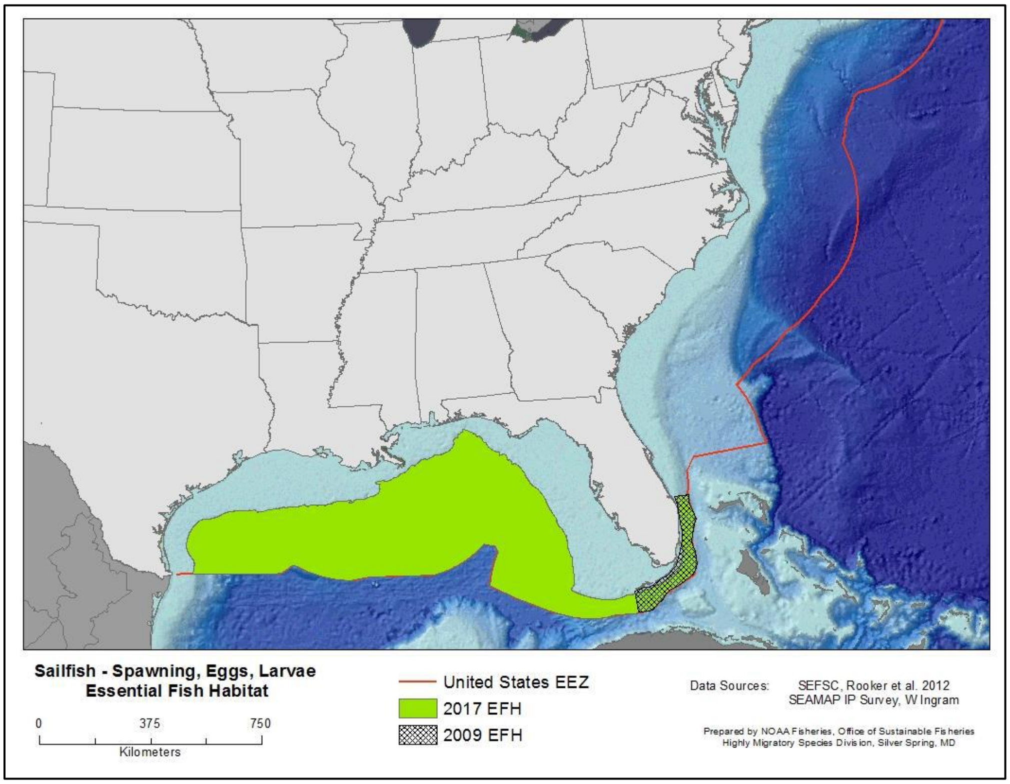


Figure 5.5.7-1. Sailfish: Spawning, Eggs, and Larvae EFH (Source: NOAA Fisheries 2017)

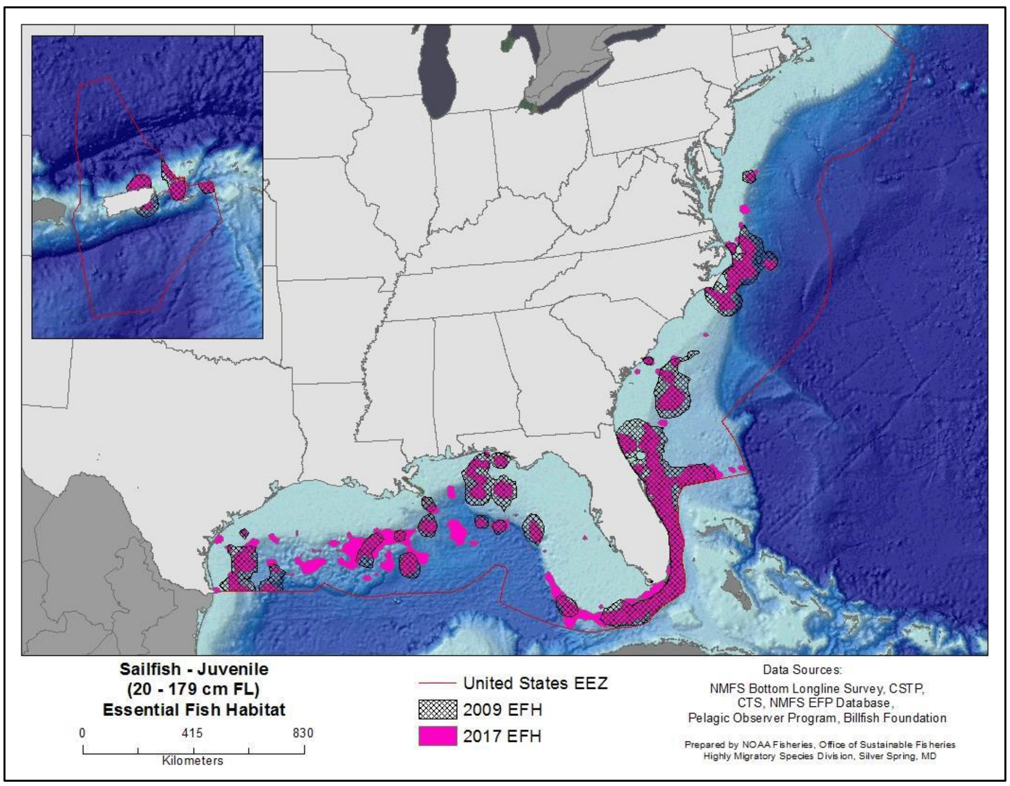


Figure 5.5.7-2. Sailfish: Juvenile and subadult (20 - 179 cm LJFL) EFH (Source: NOAA Fisheries 2017)

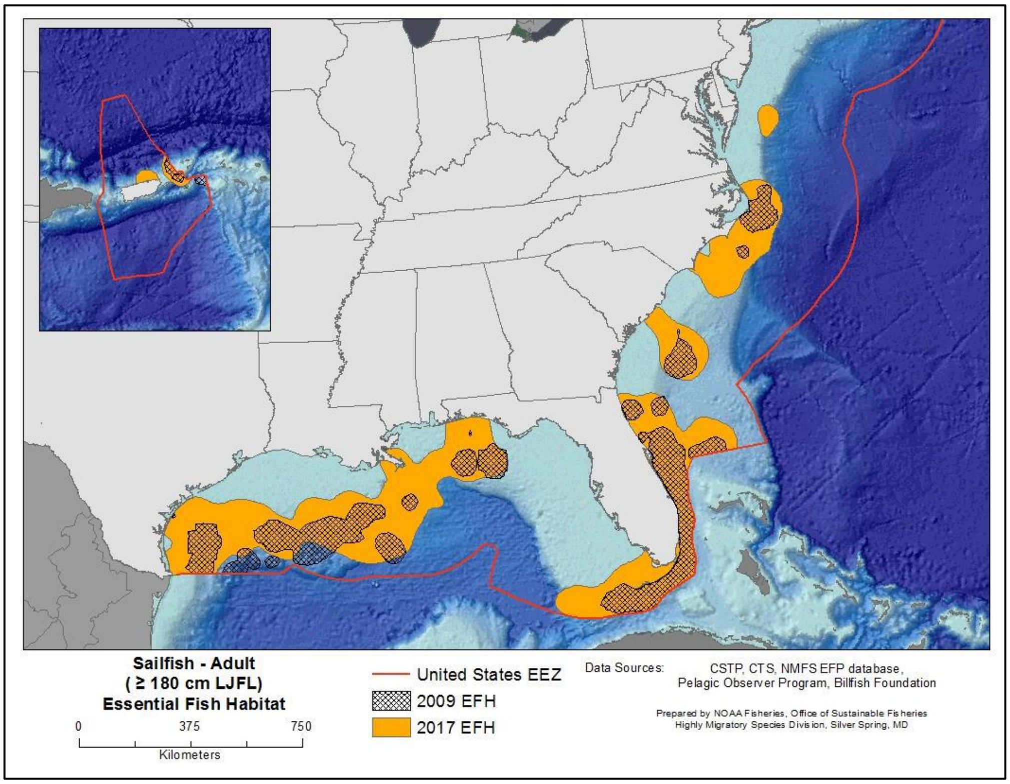


Figure 5.5.7-3. Sailfish: Adult (≥ 180 cm LJFL) EFH (Source: NOAA Fisheries 2017)

5.5.8 Atlantic Yellowfin Tuna

Atlantic yellowfin tuna (*Thunnus albacres*) are circumglobal in tropical and temperate waters. In the West Atlantic they range from 45° N to 40° S. Yellowfin tuna is an epipelagic, oceanic species, found in water temperatures between 18 °C and 31 °C (64 °F and 88 °F) (NMFS 2006). Yellowfin tuna is a schooling species, and juveniles are found in schools at the surface, mixing with skipjack and bigeye tuna. Larger fish are found in deeper water and also travel farther into higher latitudes. All individuals in the Atlantic probably comprise a single population, although movement patterns are not well known (Collette and Nauen 1983). In the Gulf of Mexico, yellowfin tuna occur beyond the 914-m (3,000 foot) isobath (Idyll and de Sylva 1963).

Adult yellowfin tuna are confined to the upper 100 meters of the water column due to their intolerance of oxygen concentrations of less than 2 mg/L (Collette and Nauen 1983). Association with floating objects has been observed, and in the Pacific larger individuals often school with porpoises (Collette and Nauen 1983). Juveniles are found nearer to shore than adults (NRC 1994). In the Gulf of Mexico, adults usually occur 75 km (46.6 miles) or more offshore. Although there appears to be a year-round population in the southern part of the Gulf of Mexico (Idyll and de Sylva 1963), in June there is some movement from the southern to the northern part of the Gulf, resulting in greater catches in the northern part from July to December (NMFS 2006). Juvenile Atlantic yellowfin tuna may be found within the action area.

EFH for the various life stages of Atlantic yellowfin tuna are as follows:

- Spawning, egg, and larval EFH includes offshore waters in the Gulf of Mexico to the EEZ and portions of the Florida Straits, and most of the U.S. Caribbean seaward of the 200-m bathymetric line (Figure 5.5.9-1) (NOAA Fisheries 2017).
- Juvenile (<108 cm) EFH includes offshore pelagic waters seaward of the continental shelf break in the central Gulf of Mexico from the Florida Panhandle to southern Texas (Figure 5.5.9-2) (NOAA Fisheries 2017).
- Adult (≥ 108 cm) EFH in the Gulf of Mexico spans most of the offshore pelagic habitat from the West Florida Shelf to the continental shelf off southern Texas (Figure 5.5.9-3) (NOAA Fisheries 2017).

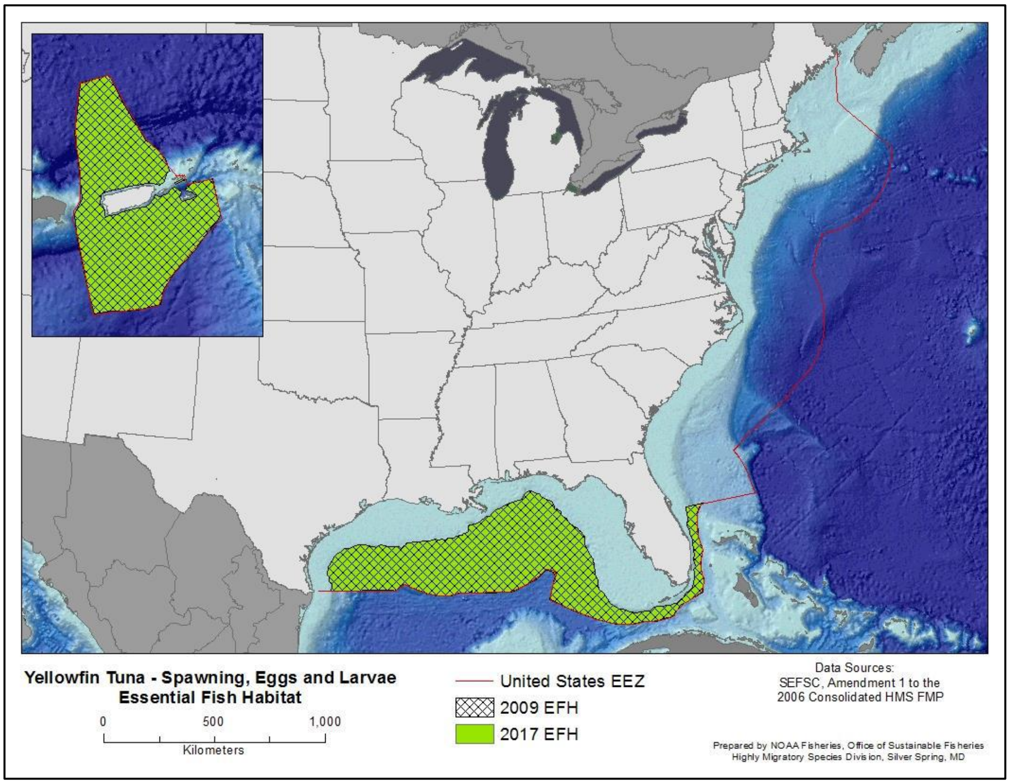


Figure 5.5.9-1. Yellowfin Tuna: Spawning, Eggs, Larvae EFH (Source: NOAA Fisheries 2017)

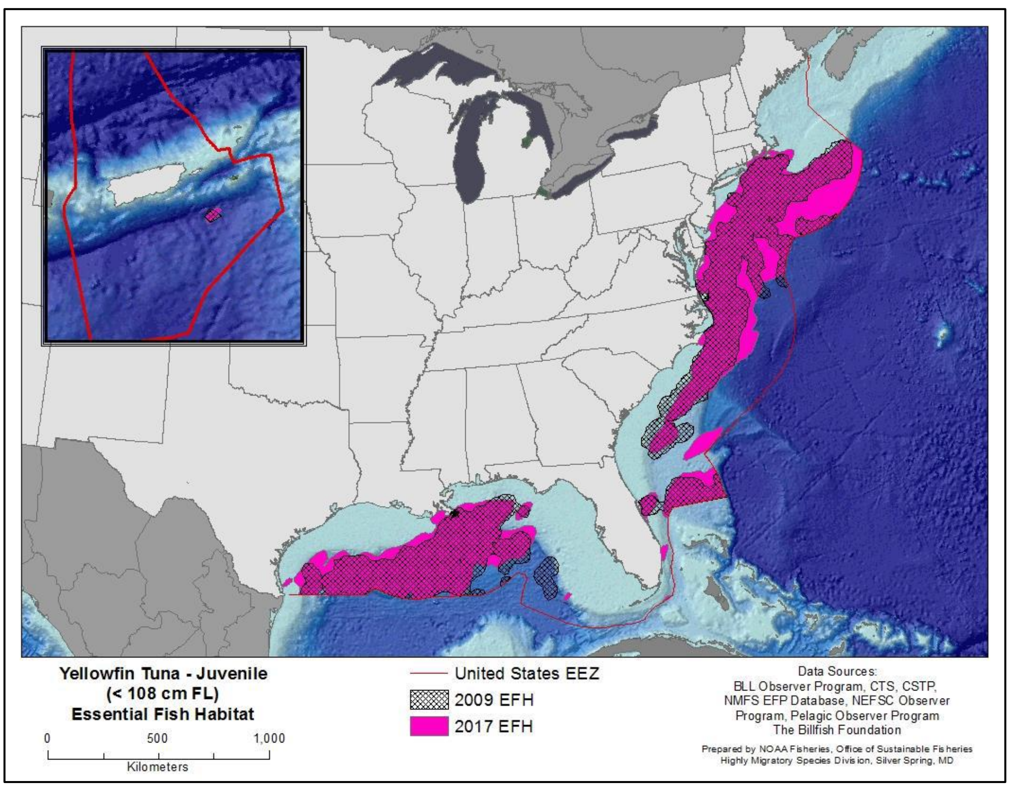


Figure 5.5.9-2. Yellowfin Tuna: Juvenile (<108 cm FL) EFH (Source: NOAA Fisheries 2017)

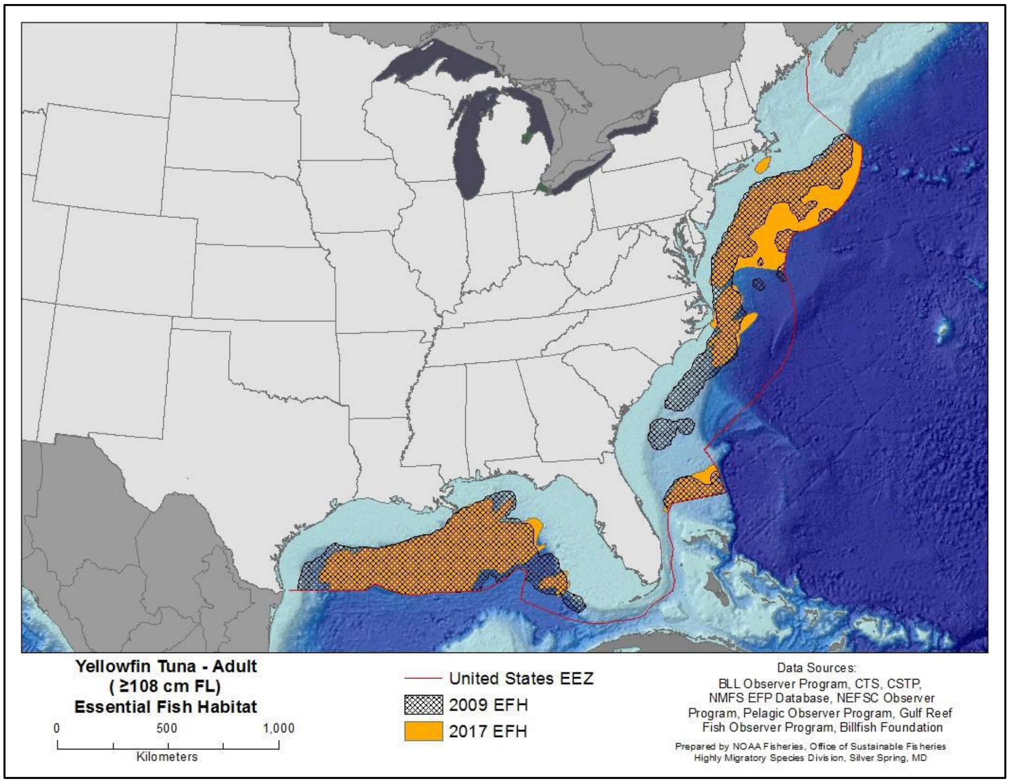


Figure 5.5.9-3. Yellowfin Tuna: Adult (≥ 108 cm FL) EFH (Source: NOAA Fisheries 2017)

5.6 Prey for Managed Species

In addition to being designated as EFH for various federally managed species, the action area provides nursery and foraging habitats for a variety of prey for species managed under the Magnuson-Stevens Act (MSA). This includes species such as blue crab (*Callinectes sapidus*), gulf menhaden (*Brevoortia patronus*), spotted seatrout (*Cynoscion nebulosus*), sand seatrout (*Cynoscion arenarius*), southern flounder (*Paralichthys lethostigma*), striped mullet (*Mugil cephalus*), Atlantic croaker (*Micropogonias undulatus*), pinfish (*Lagodon rhomboids*), spot (*Leiostomus xanthurus*), anchovies (*Anchoa* sp.), and gulf killifish (*Fundulus grandis*), as well as eastern oysters (*Crassostrea virginica*) and various benthic invertebrates.

5.6.1 Blue Crab

Blue crabs (*Callinectes sapidus*) are found in coastal bays and estuaries around the world, ranging from Nova Scotia to northern Argentina, Bermuda, and the Caribbean, and have been introduced to coastal waters of Europe and Japan. They are abundant throughout estuaries in the Gulf Coast (Patillo et al. 1997, Millikin and Williams 1984) where they typically live for 1 to 3 years, spending most of their life in the estuary. All life stages of blue crab are common to abundant in Barataria Bay (NOAA 1997).

O'Connell et al. (2017c) present details of the blue crab life cycle and the seasonal timing of peak abundances and movement of life stages in and out of Louisiana estuaries. The description from O'Connell et al. (2017c) is condensed here. Females carry eggs externally for about 2 weeks. The eggs hatch near the mouths of estuaries and the zoeal larvae are carried offshore. Zoeae are planktonic and remain in offshore waters for up to a month. The larvae can be transported up to 300 km (186 miles) in the northeastern Gulf of Mexico (Oesterling and Evink 1977), which suggests that larvae produced in one estuary could recruit into others. Re-entry to the estuaries occurs during the megalopal stage after which they molt to the first crab stage and settle in nursery habitats within the estuaries (Perry et al. 1995, Thomas et al. 1990). Juveniles (2.0 to 150 mm [0.08 inch to 5.9 inch] carapace width [CW]) and adults tend to remain in the estuary. Small juveniles prefer shallow (< 0.5 to 1 m deep) vegetated habitats while larger juveniles and adults prefer muddy or sandy substrates in deeper (≥ 1 meter deep) channels and bays. Adult males spend most of their time in low salinity waters (≤ 15 ppt) of estuaries; females move to these lower salinities as they approach their terminal molt to mate with the males (during the spring in the Gulf of Mexico). After mating, females move in June and July to higher salinity (typically 15 ppt and above) regions in the lower estuary and near barrier islands (Patillo et al. 1997, Williams 1984).

Adult blue crabs (≥ 125 mm [4.9 inches] CW) support important commercial and recreational fisheries in the Gulf and Atlantic Coasts. The Louisiana commercial fishery has supported 20% to 25% of the average annual U.S. landings of blue crab from 2000 to 2016 (NMFS 2018). A general decline in adult blue crab abundance has been observed in trawl data (West et al. 2016);

however, observed landings for Louisiana have remained high since the late 1980s (Figure 5.6.1-1). West et al. (2016) determined that the Louisiana blue crab stock is currently overfished and that the annual fishing mortality rates are extremely close to overfishing limits.

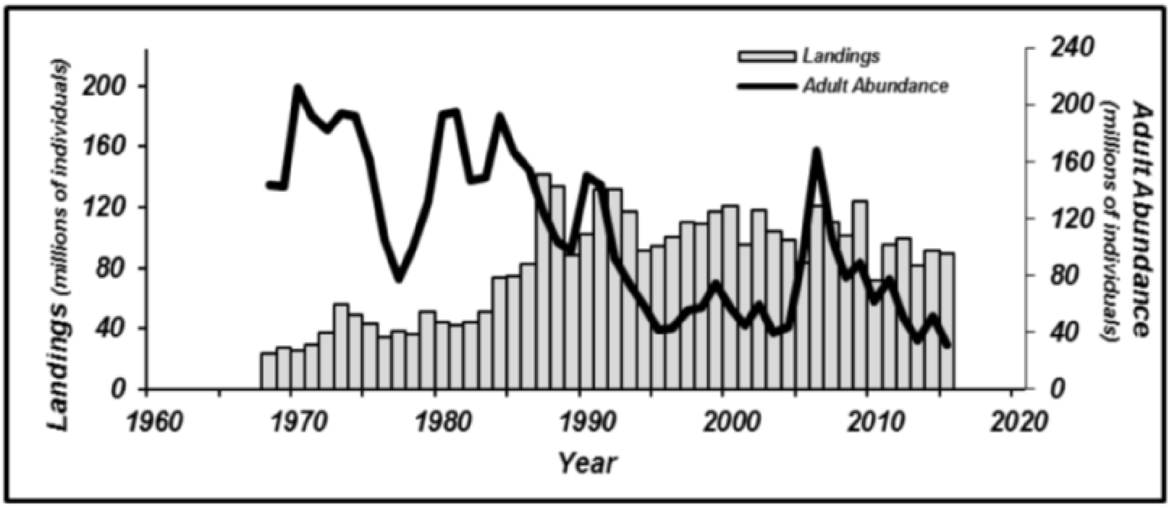


Figure 5.6.1-1. Estimated Adult Abundance from the LDWF Stock Assessment Model and Observed Landings of Louisiana Blue Crab
Commercial crab landings are expanded by 5% to approximate for the recreational harvest. Units are in millions of individuals. (Source: West et al. 2016)

The Barataria Basin accounted for 7% of the total coast-wide blue crab catch in the seines and 14% of the coast-wide catch in the 16-foot trawls (unpubl. data cited in Watkins et al. 2014). The relative abundance in seine and trawl data over time for the Barataria Basin (Figure 5.6.1-2) indicates peak numbers in 1990 that are also evident in the data for the coast-wide stock. Similarly, an annual decreasing trend observed over the past 10 years for Louisiana blue crab also exists for blue crab CPUE in the trawl samples for Barataria Basin.

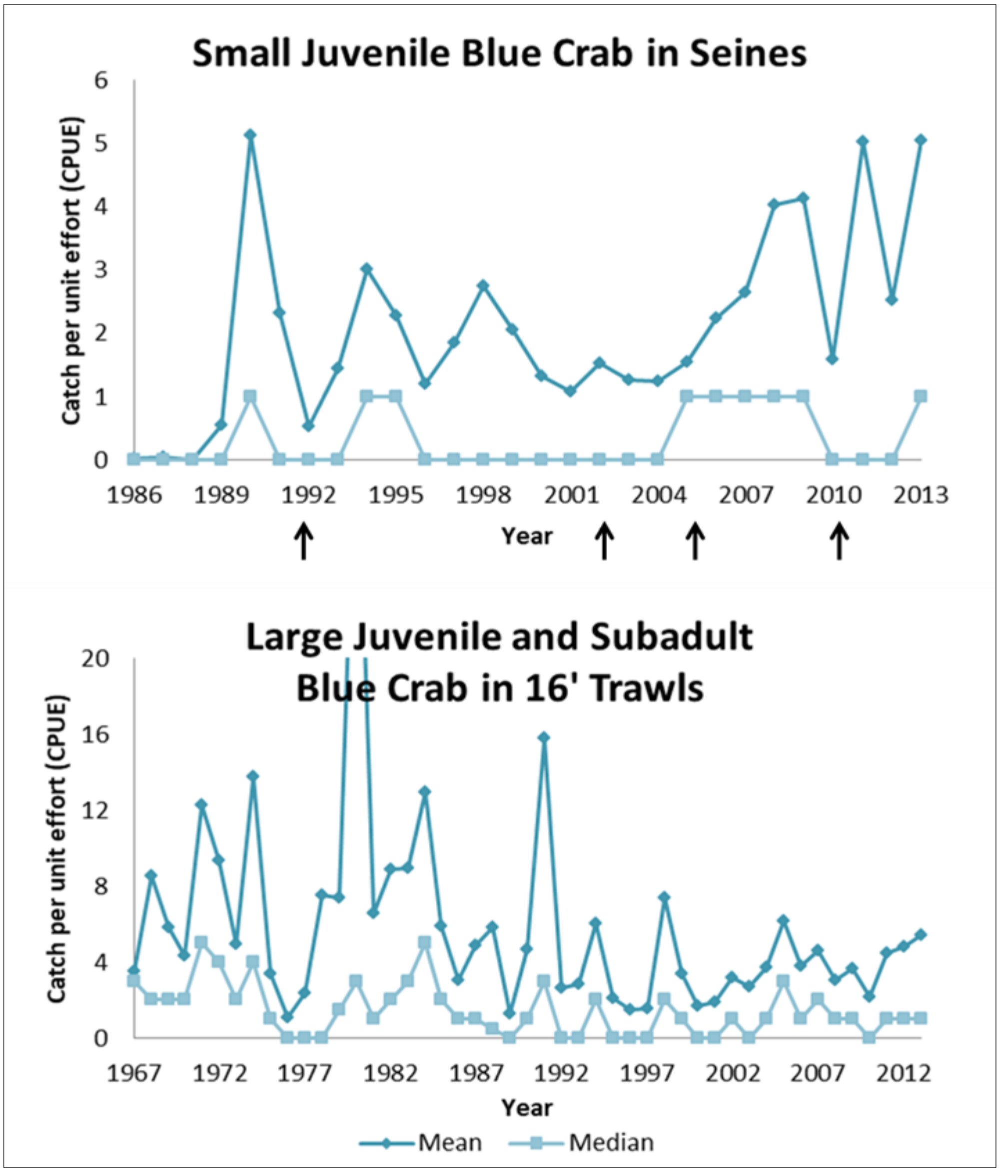


Figure 5.6.1-2. Mean and Median CPUE of Small Juvenile Blue Crab in the LDWF 50-Foot Seine Samples (Top), and CPUE of Large Juveniles and Subadults in the LDWF 16-Foot Trawl Samples (bottom) for Barataria Basin

The mean CPUE is equal to 33 crab per trawl for 1980 (bottom). The arrows indicate some recent natural and anthropogenic events for reference in the time series (Hurricane Andrew in 1992, beginning of Davis Pond Diversion Project operations in 2002, Hurricane Katrina in 2005, the DWH oil spill in 2010)

5.6.2 Gulf Menhaden

Gulf menhaden (*Brevoortia patronus*) form large schools and feed on plankton in the water column. They are found primarily in the Gulf of Mexico, with peak abundances from Apalachicola, Florida to Matagorda Bay, Texas (Patillo et al. 1997). Gulf menhaden are abundant in coastal Louisiana and constitute a high proportion of the total abundance of species caught by multiple LDWF fishery-independent gears (Watkins et al. 2014). Juvenile and larval stages of gulf menhaden are common to highly abundant in Barataria Bay (NOAA 1997). Adult menhaden rarely live beyond 4 years (Patillo et al. 1997).

Sable et al. (2016a) presents a conceptual life history diagram adapted from Christmas et al. 1982 and describes the details of the gulf menhaden life cycle in and out of the Louisiana estuaries. The description from the report is condensed here for Barataria Basin. Spawning occurs in the fall through early spring on the shelf. Yolk-sac larvae are carried inshore and to the estuaries by currents. The larval stage begins around 2.6 mm (0.1 inch) standard length (SL) and lasts 3 weeks to 5 weeks (Christmas et al. 1982). Feeding larvae move farther up the estuary into shallow bays and river tributaries. Metamorphosis to the juvenile stage occurs around 19 mm (0.75 inch) SL in the low salinity upper estuary and around river mouths (Christmas et al. 1982). Juveniles remain in the low salinity regions (typically ≤ 10 ppt) until they reach a size around 40 mm (1.57 inches) SL over 2 months to 3 months. They move farther down the estuary (≥ 10 ppt) and into deeper waters as they grow from 40 mm to about 85 mm (1.57 inches to 3.15 inches) SL. Gulf menhaden mature after 2 growing seasons. Adults typically live 2 to 3 years (Deegan 1990). Adults move inshore and up in the estuary and rivers during spring and summer (Deegan 1990) and then onto the shelf to spawn during the fall and winter (Shaw et al. 1985).

Menhaden have a critical ecosystem role as a primary consumer and generalist filter feeder (Ahrenholz 1991, Deegan 1986) and as prey to a wide variety of predators (Vaughan et al. 2007). There is an extensive Gulf menhaden fishery dating back to the late 19th century (Nicholson 1978). It is one of the largest fisheries by volume in the United States and has been managed under a regional FMP since 1978 (SEDAR 2013). The average annual landings from 2000 through 2016 for the northern Gulf of Mexico is 516,821 million tons, with Louisiana landings making up an average of 80% of the reported commercial landings (NMFS 2018). The majority of the Gulf of Mexico landings occur in Louisiana in large part because purse seining is still legal, unlike in Florida and Alabama (Vanderkooy and Smith 2002).

By comparing the total number of menhaden caught by the LDWF seines and gillnets for the coastal study areas in Watkins et al. (2014), Barataria Basin accounted for only 4% of the total catch of juvenile menhaden in seines but accounted for 30% of the total coast-wide adult menhaden catch in gillnets. Figure 5.6.2-1 uses the unpublished LDWF data from Watkins et al. (2014) to show the CPUE of juvenile menhaden in the 50-foot seines from January through June, and CPUE of adult menhaden collected by gillnets from March through October.

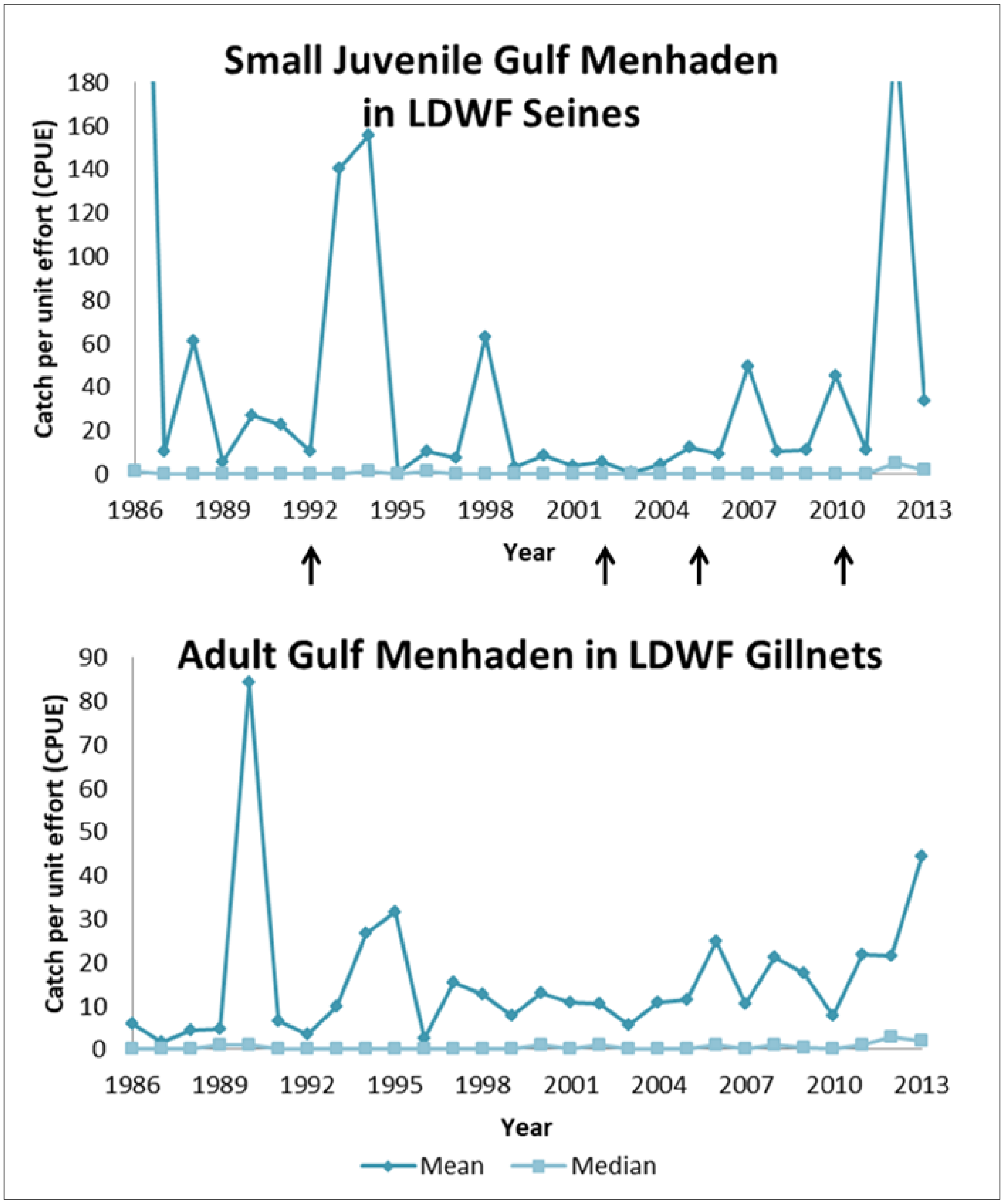


Figure 5.6.2-1. Mean and Median CPUE of Juvenile Gulf Menhaden (top) and Adult Menhaden (bottom) for Barataria Basin

The mean CPUE of juvenile menhaden is equal to 454 in 1986 and 202 in 2012 (top). The arrows indicate some recent events for reference in the time series (Hurricane Andrew in 1992, beginning of Davis Pond Diversion Project operations in 2002, Hurricane Katrina in 2005, the DWH oil spill in 2010). (Source: Watkins et al. 2014).

5.6.3 Spotted Seatrout

Spotted seatrout (*Cynoscion nebulosus*) are found in coastal waters from Cape Cod, Massachusetts to the Bay of Campeche, Mexico. Spotted seatrout are non-migratory and estuarine-dependent; tagging and telemetry studies show that adults usually remain in and very near to their natal estuaries (Callihan 2011, Callihan et al. 2013, Murphy et al. 2011). All life stages of spotted seatrout are common in Barataria Bay (NOAA 1997). Spotted seatrout reach maturity by age 2 and have an typical life span of 5 years to 9 years (Murphy and Taylor 1994). Age 2 and age 3 seatrout in the Louisiana recreational harvest data are typically 300 mm to 380 mm (11.8 inches to 14 inches) TL (West et al. 2014). A maximum reported length of a single age-6+ fish exceeded 580 mm (22.8 inches) TL (West et al. 2014).

Spotted seatrout generally spend their entire life cycle in and near their natal estuary, showing less than 30% of the adult population moving between estuaries (Wagner 1973, Saucier and Baltz 1993, Ditty and Shaw 1994, Killam et al. 1992, Callihan 2011). The life stages of spotted seatrout are found within different regions or salinity zones of the estuary (Helser et al. 1993, Shepard 1986). Sable et al. (2017b) provides a conceptual life cycle diagram to describe the seatrout life stages within the estuarine habitats. Eggs are spawned in seagrasses or around barrier island passes in the late spring and summer in the lower estuary and hatch within a day. After larvae absorb their yolk-sac and begin feeding, they move along the deep channels towards shallower channels up the estuary into intermediate and brackish salinity zones (typically around ≤ 15 ppt). Metamorphosis of larvae to juveniles occurs after about 23 days and around 12 mm (0.5 inch) TL. Early young-of-year juvenile seatrout remain in shallow marsh edge or submerged aquatic vegetated habitats for 4 to 5 months until they grow to around 180 mm to 200 mm (7 inches to 7.9 inches) TL (Nieland et al. 2002). Late juvenile and adult spotted seatrout move throughout the estuary, likely in response to temperature and food supply, moving to warmer shallow waters along shorelines and the mid-and upper estuary in the winter and deeper cooler waters of the bays and barrier island passes in the summer. Male seatrout mature around 220 mm (8.7 inches) TL while female seatrout typically mature around 300 mm (11.8 inches) TL. Adult seatrout move to the deep channels and the barrier island passes to spawn in the summer.

The spotted seatrout is an opportunistic carnivore at the top trophic level within coastal and estuarine ecosystems, and probably plays a significant role as a predator in the structure of estuarine communities (Lassuy 1983, Killam et al. 1992). Juveniles have been found to consume a wide variety of zooplankton, mysids, copepods, isopods, amphipods, gastropods, bivalves, caridean and penaeid shrimp, and fish, with shrimp being the most important diet component (Stewart 1961, Hettler 1989, McMichael and Peters 1989). As spotted seatrout grow, they proportionally consume more fish, up to 90% as larger adults. Fish species consumed include bay anchovy, gulf menhaden, shad (*Dorosoma spp*.), silversides (*Menidia spp*.), striped mullet, sheepshead minnow (*Cyprinodon variegatus*), rainwater killifish (*Lucania parva*), gulf toadfish (*Opsanus beta*), inshore lizardfish (*Synodus foetens*), pipefish (*Syngnathus spp*.), pinfish, pigfish (*Orthopristes chrysopterus*), silver jenny (*Eucinostomus gula*), gray snapper, unidentified snappers (*Lutjanus spp*.), hardhead silverside (*Atherinomorus stipes*), goldspotted killifish (*Floridichthys carpio*), code goby (*Gobiosoma robustum*), naked goby (*G. bosct*), clown goby (*Microgobius gulosus*), Atlantic croaker, and spotted seatrout (Gunter 1945, Darnell 1958, Seagle 1969, Danker 1979, Levine 1980, Hettler 1989, McMichael and Peters 1989). Known predators of juvenile spotted seatrout include alligator gar (*Lepisosteus spatula*), striped bass (*Morone saxatilis*), ladyfish (*Elops saurus*), tarpon (*Megalops spp.*), bluefish (*Pomatomus salatrix*), silver perch *Bairdella chrysoura*), Atlantic croaker (*Micropogonias undulates*), snook (*Centropomus undesimalis*), yellow bass (*Morone mississippiensis*), spotted seatrout, barracuda (*Sphyraena barracuda*), Spanish mackerel (*Scomberomorus maculatus*), and king mackerel (Miles 1949, Darnell 1958, Benson 1982, Killam et al. 1992).

Spotted seatrout support an important recreational fishery in the South Atlantic and Gulf of Mexico state waters. The Louisiana seatrout catch has steadily increased since the 1980s, supporting the highest annual recreational catch of 8 million to 12 million pounds in the United States since the mid-1990s (NMFS 2018). Louisiana constitutes an average annual 62% of the total U.S. landings for the Atlantic and Gulf Coasts. The states manage their own fishery stocks, which are evaluated under a regional fisheries management plan (Blanchet et al. 2001).

The LDWF seines do not collect high numbers of juvenile seatrout because the seatrout can outswim the gear (LDWF pers. comm.). By comparing the total number of seatrout caught by the LDWF gillnets for the coastal study areas in Watkins et al. (2014), Barataria Basin accounted for 17% of the total Louisiana coast-wide catch. Figure 5.6.3-1 shows the mean and median annual CPUE of adult spotted seatrout in the LDWF gillnets from April through August (unpubl. data cited in Watkins et al. 2014). Although adult seatrout catch has declined to about one-half to one-third of the seasonal catches recorded in Barataria Basin from about 1988 to 1995, the CPUE has been relatively steady since 2000 at around 4 trout per gillnet sample (Figure 5.6.3-1).

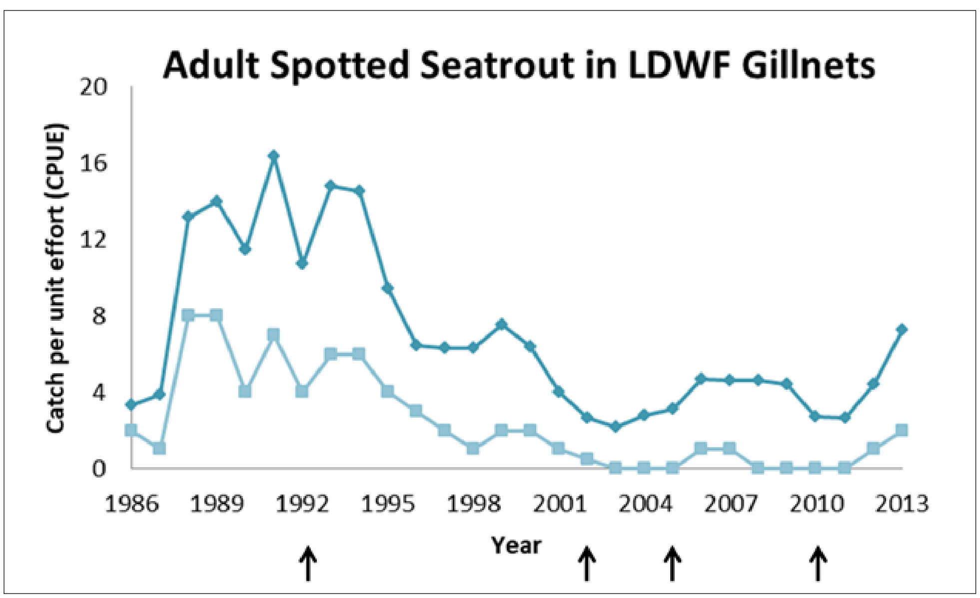


Figure 5.6.3-1. Mean and median CPUE of adult spotted seatrout in the LDWF gillnet samples for Barataria Basin

The arrows mark Hurricane Andrew, the opening of the Davis Pond Diversion, Hurricane Katrina, and the DWH oil spill.

5.6.4 Sand Seatrout

Sand seatrout (*Cynoscion arenarius*) is one of the most abundant fishes in estuarine and nearshore waters of the Gulf of Mexico (NOAA 1997). Their range is limited to the coastal and shelf waters of the Gulf, from Florida Bay to the Bay of Campache (Fischer 1978, NOAA 1985, Shipp 1986). Sand seatrout spend most of their lives as demersal in estuarine habitats, with the exception of pelagic eggs, larval stages, and larger pelagic adults (Johnson 1978, Benson 1982, Ditty and Shaw 1994). Juveniles prefer muddy bottoms; adults are found over most estuarine bottom types; and larvae and juveniles prefer emergent marshes and seagrasses with soft bottoms (Conner and Truesdale 1972, Benson 1982). Larvae have been collected in inshore to midshelf waters in depths ranging from 5 meters to 70 meters, with most occurring between 10 meters and 25 meters (Cowan 1985, Cowan and Shaw 1988, Cowan et al. 1989). Adult and juvenile life stages of sand seatrout are common to highly abundant in Barataria Bay (NOAA 1997). When schooling, they often form schools together with spotted seatrout (Vetter 1977).

The sand seatrout serves as an important link between estuarine and marine food webs, as it directly links the food web between the primary consumers and the top predators. The sand seatrout feeds mostly on shrimp, bay anchovies, and Gulf menhaden (Moffet et al. 1979, Overstreet and Heard 1982). Juvenile sand seatrout may be an important food item in the diets of piscivorous sport and food fish. However, the larger sand seatrouts' piscivorous, predacious habits possibly place them in competition with other predators that target similar prey species (NOAA 1997).

5.6.5 Southern Flounder

Southern flounder (*Paralichthys lethostigma*) are found all along North America's Atlantic coast, from North Carolina to Mexico. In the Gulf of Mexico, they are present from Florida, to Texas, and into northern Mexico (Heese and Moore 1977, Lee et al. 1980, Manooch 1984). Southern flounder are found within estuarine and nearshore habitats within the Gulf and are particularly abundant along Texas's coast. Adult, juvenile, and larval life stages of southern flounder are common to highly abundant within Barataria Bay (NOAA 1997).

Southern flounder eggs and larvae are planktonic and found throughout the nearshore water column, while juveniles and adults are primarily demersal in estuaries (King 1971, Powell and Schwartz 1977). Juvenile fish have been reported in association with seagrass beds (Stokes 1977). In wetlands, southern flounder are found equally abundant in vegetated and non-vegetated habitats (Minello et al. 1989). Juveniles and adults are associated with fine sediments in flooded Spartina marshes, seagrasses, and muddy substrates of estuaries (Stokes 1977, Ward et al. 1980). Southern flounder can tolerate low-salinity environments, and are occasionally found in freshwater habitats. Spawning adults move from estuaries to offshore waters to spawn during the fall and winter, before returning once again to estuaries and nearshore bays (Stokes 1977).

Southern flounder are important predators in estuarine ecosystems, feeding on small crustaceans as juveniles, and becoming piscivorous as they grow (Diener et al. 1974, Fitzhugh et al. 1996). Little information is known about predation upon southern flounder. Known and suspected species that prey on flounder species in the Gulf of Mexico are tiger shark (*Galeocerdo cuvier*), gafftopsail catfish (*Bagre marinus*), inshore lizard fish (*Synodus foetens*), various searobins (*Triglidae spp*), various sculpins (*Cottidae spp*), goliath grouper (*Epinephelus itajara*), and larger-sized southern flounder (Kemp 1949, Miles 1949, Diener et al. 1974, Tanaka et al. 1989).

5.6.6 Striped Mullet

Striped mullet (*Mugil cephalus*) occur worldwide in tropical, subtropical, and temperate waters. Striped mullet occur throughout the Gulf of Mexico in shallow marine and estuarine habitats (Gunter 1945, Moore 1974, Ward and Armstrong 1980). They are very common along the west coast of Florida, and most abundant along the south Florida coasts. They are also one of the most numerous species in the bay flats along the Texas coast (Gunter 1945, Broadhead 1953, Collins 1985, Killam et al. 1992). Adults, juveniles, and larvae are common to abundant within Barataria Bay (NOAA 1997).

All life stages of striped mullet are water-column associated and most are found primarily in the shallow water column of marine and estuarine habitats (Arnold and Thompson 1958, Thomson 1966, Hoese and Moore 1977, Finucane et al. 1978, Martin and Drewry 1978, Ward and Armstrong 1980). They live in a wide range of habitats and depths throughout their life cycle. Juveniles and adult striped mullet are one of the most abundant species in shallow waters of the Gulf of Mexico, occupying virtually all shallow marine and estuarine habitats including open beaches, flats, lagoons, bays, rivers, salt marshes, and grass beds (Gunter 1945, Kilby 1949, Breuer 1957, Renfro 1960, Hellier 1962, Franks 1970, Perret et al. 1971, Swingle 1971, Christmas and Waller 1973, Moore 1974, Henley and Rauschuber 1981, Cech and Wohlschlag 1982, Sogard et al. 1989, NOAA 1997). Eggs and larvae, as well as spawning, occurs offshore (Ditty and Shaw 1996).

Striped mullet is an important forage fish, forming a major component in the flow of energy through the estuarine system by feeding at the lowest trophic levels and providing food to birds and many important commercial and game fish (Kilby 1949, Fontenot and Rogillio 1970, Moore 1974, Sogard et al. 1989). Early life stages of striped mullet forage upon plant debris, algae (diatoms), copepods, mosquito larvae, and fish residue (Harrington and Harrington 1961). Juveniles and adults consume organic detritus, diatoms, filamentous algae, benthic organisms, plant tissue, foraminifera, and plankton of correct particle size, but have also been observed with fish scales, sponge spicules, and minute gastropods in their stomach contents (Hiatt 1944, Broadhead 1958, Darnell 1958, Tabb and Manning 1961, Moore 1974). Piscine predators of striped mullet include red drum, spotted seatrout, hardhead catfish (*Ariopsis felis*), southern flounder, bull shark, alligator gar (*Atractosteus spatula*), and longnose gar (*Lepisosteus osseus*)

(Gunter 1945, Breuer 1957, Simmons 1957, Darnell 1958). Wading birds, pelicans, and dolphins also prey upon this species (Sogard et al. 1989).

5.6.7 Atlantic Croaker

Atlantic croaker (*Micropogonias undulatus*) is a highly abundant demersal fish species (NOAA 1997). They are found all along the western Atlantic, from the Gulf of Maine to the Greater Antilles. In the Gulf of Mexico, they are found from southern Florida to central Mexico (Chao and Musick 1977, Hoese and Moore 1977, Fischer 1978). Juveniles and adults are estuarine dependent, while eggs and larvae are pelagic, and found within the mid to outer continental shelf. Adults may move between estuarine and marine environments, in 1 meter to 90 meters, but prefer salinities above 10 ppt (Parker 1971, Christmas and Waller 1973, Wagner 1973, Ditty and Shaw 1994, Lassuy 1983, Cowan 1985, Cowan and Shaw 1988). All life stages of Atlantic croaker, with the exception of eggs and larvae, prefer soft bottom habitats (Lassuy 1983).

Many adult Atlantic croaker have seasonal inshore and offshore migrations, although some appear to remain in offshore waters all year (Perry 1970). Adults move up bays and estuaries in spring, are found in diverse locations in summer, and more seaward and southerly in fall. Larvae are carried by longshore currents into nearshore areas where tidal flow transports them into estuarine areas (Cowan and Shaw 1988). Larval recruitment into estuaries occurs from October to May, peaking between November and February (Wagner 1973, Marotz 1984). As they mature into juveniles, Atlantic croaker move up into lower salinity upper estuaries. After spending 6 months to 8 months in the estuary, offshore emigration begins in late March or early April and continues until November (Kelley 1965, Perry 1970, Wagner 1973, Yakupzack et al. 1977, Rogers 1979, Marotz 1984).

Larval Atlantic croaker feed upon zooplankton (Lassuy 1983), while juveniles and adults are opportunistic benthic carnivores and prey upon benthic invertebrates and some fishes (Mercer 1989). Adults may feed on a secondary or higher trophic level (NOAA 1997). Predators of Atlantic croaker are larger piscivorous species such as striped bass (*Morone saxatilis*), southern flounder, bull shark, blue catfish (*Ictalurus furcatus*), yellow bass, spotted seatrout, Atlantic croaker, red drum, sheepshead (*Archosargus probatocephalus*), blue fish (*Pomatomus saltatrix*), and weakfish (*Cynoscion regalis*) (Levine 1980, Mercer 1989).

5.6.8 Pinfish

Pinfish (*Lagodon rhomboides*) occur in coastal waters from Massachusetts, through the Gulf of Mexico and the north coast of Cuba, to the Yucatan peninsula. They are rare north of Maryland and most common south of North Carolina through to the northern Gulf of Mexico (Fischer 1978, Lee et al. 1980, Muncy 1984). Pinfish are abundant throughout the Gulf of Mexico, except in the very turbid brackish waters of Louisiana, west of the mouth of the Mississippi River

(Hoese and Moore 1977). Only the juvenile life stage of pinfish is found within Barataria Bay (NOAA 1997).

Juvenile pinfish are marine, estuarine, and riverine, and common over areas of seagrass, where activity appears to be associated with high tides (Fischer 1978, Sogard et al. 1989). Pinfish are generally non-schooling, though small aggregations have been observed (Kloth 1970). Juveniles feed primarily on shrimps, mysids, and amphipods (Carr and Adams 1973, Stoner 1979, Levine 1980, Schmidt 1993). They are an important prey item for many fish species (Darcy 1985). Known piscine predators include alligator gar, longnose gar, ladyfish (*Elops saurus*), spotted seatrout, red drum, bighead searobin (*Prionotus tribulus*), southern flounder, and gulf flounder (*Paralichthys albiguttata*) (Gunter 1945, Kemp 1949, Darnell 1958, Diener et al. 1974, Muncy 1984, Rozas and Hackney 1984). Pinfish are also preyed on by bottle-nosed dolphin (*Tursiops truncatus*) (Kemp 1949).

Pinfish are often so abundant and predaceous that the species is believed to alter the composition of estuarine epifaunal communities (Orth and Heck 1980, Coen et al. 1981, Stoner 1980, Stoner 1982, Muncy 1984). They are numerically dominant in the shallow, subtidal seagrass communities in the Gulf of Mexico, and their predation on amphipod communities probably limits amphipod abundance in these areas. In addition, the consumption of plants and detritus by pinfish is important in the export of organic materials in estuaries (NOAA 1997).

5.6.9 Spot

Spot (*Leiostomus xanthurus*) occurs within coastal waters from Maryland into Mexico, and is most abundant from Maryland to the Carolinas (Fischer 1978, Wang and Kernhan 1979). In the Gulf of Mexico, spot are common in both bays and open Gulf areas, found throughout the coastal shelf from Florida Bay to the Rio Grande River (Hoese and Moore 1977, Shipp 1986). Larval and juvenile spot are highly abundant in Barataria Bay, and are the only life stages found within Barataria Bay (NOAA 1997).

Spot larvae are found in more saline nearshore habitats, and have been collected in the northern Gulf of Mexico on the continental shelf up to the 40-meter isobath, or 130 km (80.8 miles) offshore. They occur at all depths, but are found primarily in the upper 30 meters of the water column (Sogard et al. 1987, Cowan and Shaw 1988). Larvae are transported inshore into estuarine nursery areas where postlarval and juvenile spot are found. Younger juveniles are often found in the shallow upper estuaries of tidal creeks, and sometimes in seagrass beds, while older juveniles move to deeper, more saline areas of estuaries (Wang and Kernahan 1979, Mercer 1989, Hales and Van Den Avyle 1989).

Early spot larvae have only been collected in waters over 19.3 °C (66.7 °F). Later larvae have been found below 20 °C (68 °F), with the majority collected in temperatures ranging from 7 °C to 15 °C (44 °F to 59 °F). The upper incipient lethal temperature for post larval and small juvenile spot has been estimated at 35.2 °C (95.4 °F) (Mercer 1989). Spot larvae tolerate a wide range of estuarine salinities, and have been collected in salinities ranging from 9 ppt to 36 ppt (Cowan and Shaw 1988, Killam et al. 1992).

Spot juveniles are primarily found in nursery areas with soft bottom (mud and detritus) habitats (Mercer 1989). They can tolerate temperatures from 1.2 °C to 36.7 °C (34 °F to 98 °F); however, extended periods of low temperature exposure can result in stunning or mortality (Benson 1982). Spot are a euryhaline species (tolerant of large ranges in salinity), and juveniles can be found from 0 ppt to 35 ppt (Kelley 1965, Wang and Raney 1971, Wagner 1973, Pineda 1975, Lee et al. 1980, Benson 1982); they are found in highest abundances in salinities over 10 ppt.

Larvae are likely carried by longshore currents or by direct across-shelf transport into nearshore waters, and into estuarine areas by tidal flow (Cowan and Shaw 1988, Mercer 1989). Immigration into estuaries of postlarvae begins in December and continues through May (Joseph 1972, Warren and Sutter 1982, Cowan and Shaw 1988, Mercer 1989). Postlarvae have been recorded as recruiting along the sandy shorelines and seagrass beds of Tampa Bay (Killam et al. 1992). These protected regions appear extremely beneficial in promoting the rapid growth of postlarvae. Juveniles move up into low salinity upper estuary habitats, and may ascend from brackish water to fresh water during the spring and summer (Hildebrand and Cable 1930). Older fish tend to seek out deep, higher salinity waters in bays, and begin to emigrate from estuaries in May or June after reaching TL of about 60 mm to 80 mm (2.4 inches to 3.1 inches) or after about 8 to 9 months; they become absent in estuaries by late fall (Kilby 1955, Townsend 1956, Nelson 1967, Parker 1971, Wagner 1973, Warren and Sutter 1982, Killam et al. 1992).

Larval spot are size-selective planktivores (Livingston 1984, Mercer 1989, Govoni and Chester 1990). They feed on zooplankton such as tintinnids, fish and invertebrate eggs, bivalve veligers, copepod nauplii; postlarvae spot feed predominantly on copepods (Livingston 1984, Mercer 1989, Govoni and Chester 1990). Juvenile spot are nocturnal, opportunistic bottom feeders (Hales and Van Den Avyle 1989, Killam et al. 1992), consuming primarily crustaceans (especially copepods), molluscs, nematodes, and polychaete worms (Ruebsamen 1972, Sheridan 1979, Levine 1980, Livingston 1984). A study in the Cape Fear River estuary in North Carolina found that silversides and killifish prey on larval and early juvenile spot (Weinstein and Walters 1981). Other predators of spot include sand bar shark (*Carcharhinus plumbeus*), silky shark (*Carcharhinus falciformis*), longnose gar, striped bass, bluefish, different species of seatrout, king mackerel, and flounders (Dawson 1958, DeVane 1978, Medved and Marshall1981, Rozas and Hackney 1984, Hales and Van Den Avyle 1989, Mercer 1989, Killam et al. 1992), as well as wading birds such as the clapper rail (Heard 1982).

5.6.10 Bay Anchovy

Bay anchovy (*Anchoa mitchilli*) range from Maine to Tampico, Mexico and likely have the greatest biomass of any fish in estuarine waters of both the southeastern U.S. and the Gulf of Mexico (Morton 1989, Patillo et al. 1997). All life stages of bay anchovy are abundant in Louisiana estuaries and Barataria Basin, and are water-column associated (NOAA 1997, Jones et al. 2002). Larger bay anchovy tend to use deeper water farther from shore, over coarser substrates and cooler temperatures (Jones et al. 2002). LDWF does not target the fish or actively monitor their abundances, though their early life history and population dynamics are well studied in the northern Gulf of Mexico (for example, Chesney 2008). Bay anchovy reach maturity within 3 months and have a maximum lifespan of about 3 years (Houde and Zastrow 1991). Jones et al. (2002) reported that trawl surveys in Barataria Bay found bay anchovy to be the dominant species, comprising a high percentage of their total survey catch. Because of its high biomass and importance within estuarine food webs, bay anchovy is often used as an indicator species of estuarine health. Bay anchovies prey exclusively upon zooplankton and are a dominant prey item for many predatory coastal bird and fish species (Shipp 1986). Their abundance and distribution in estuaries appear to be primarily influenced by zooplankton distribution (Houde and Zastrow 1991).

The Barataria Basin accounted for 7% of the total Louisiana coast-wide anchovy catch in the LDWF 50-foot seines and 14% of the coast-wide catch in the 16-foot trawls (Watkins et al. 2014). The relative abundance in the trawls appeared higher and more variable through the early 1980s compared to the last 30 years in the Barataria Basin (Figure 5.6.10-1). Abundance data for other coastal anchovy species exhibit multi-decadal cycles with large-scale climatic changes (Chavez et al. 2003). It is unknown whether bay anchovy populations in Louisiana's estuaries exhibit such cycles; however, the CPUE trend for trawls appears to preliminarily indicate these multi-decadal patterns.

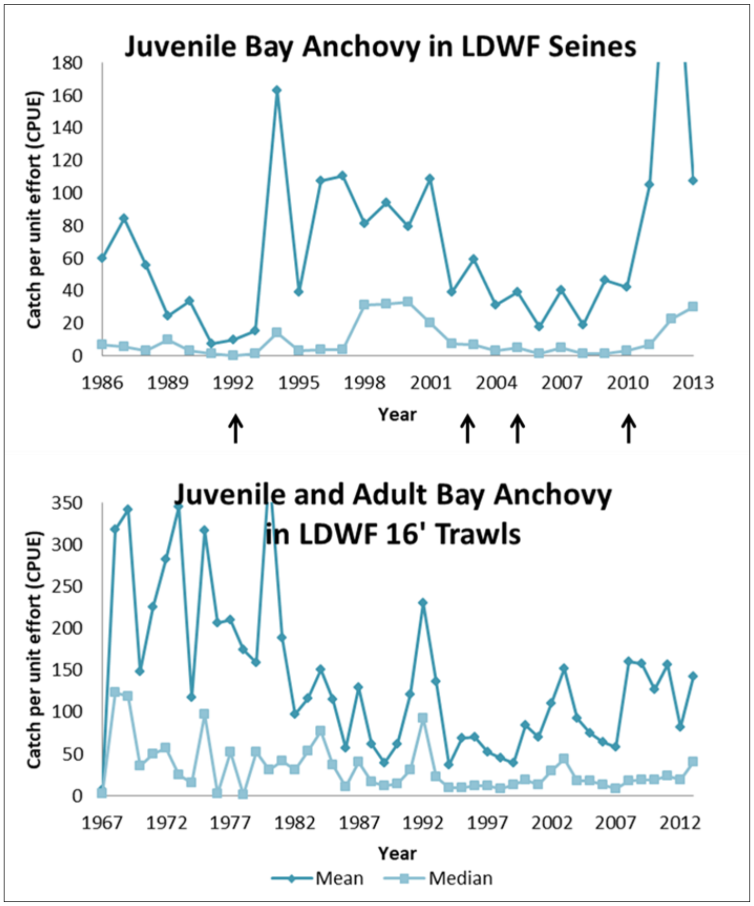


Figure 5.6.10-1. Mean and Median CPUE of Juvenile Bay Anchovy in the LDWF 50-Foot Seine Samples (top), and of Juvenile and Adult Bay Anchovy in the 16-Foot Trawls (bottom) for Barataria Basin
The mean CPUE is equal to 298 anchovies per seine for 2012 (top), and equal to 387 anchovies per trawl for 1980 (bottom). The arrows indicate some recent natural and anthropogenic events for reference in the time series (Hurricane Andrew in 1992, Davis Pond Diversion began operations in 2002, Hurricane Katrina in 2005, the DWH oil spill in 2010).

5.6.11 Gulf Killifish

Gulf Killifish (*Fundulus grandis*) within the Gulf of Mexico occur within estuaries from Florida to Texas (Springer and Woodburn 1960, Price and Schlueter 1985, Camp 1985, NOAA 1997). Their distribution is continuous from Laguna de Tamiahua, Veracruz, Mexico throughout the Gulf of Mexico and along the Atlantic coast of northeastern Florida up to the Matanzas River (Rivas 1948, Blair et al. 1968, Kushlan and Lodge 1974, Relyea 1983, Duggins et al. 1989). It is closely related to the mummichog (*F. heteroclitus*) (Duggins et al. 1989, Bernardi and Powers 1995), which occurs in estuaries of the U.S. east coast as far south as Indian River Lagoon, Florida (Nelson et al. 1991). All life stages of gulf killifish are highly abundant in Barataria Bay (NOAA 1997)

All life stages of gulf killifish are estuarine residents. They inhabit shallow waters near the shores of oyster bars, tidal ponds, sloughs, salt water creeks, bayous, marsh pools, and coastal inland ponds (Gunter 1945, Gunter 1950, Reid 1955, Simpson and Gunter 1956, Renfro 1960, Gunter 1967, Wagner 1973, Haese and Moore 1977, Swift et al. 1977). They have a wide saline tolerance and have been reported from fresh to hypersaline habitats (Simpson and Gunter 1956, Renfro 1960, Swingle 1971). In estuaries, they reside over bottoms that consist of hard muddy sand, mud, silt, clay, detritus, or shell, with occasional seagrass or algae present. Gulf killifish are also common among emergent marsh vegetation (Gunter 1945, Reid 1955, Simpson and Gunter 1956, Renfro 1960, Springer and Woodburn 1960, Harrington and Harrington 1961, Tabb and Manning 1961, Strawn and Dunn 1967, Franks 1970, Swingle 1971, Swift et al. 1977, Greeley and MacGregor 1983, Thayer et al. 1987).

The gulf killifish moves onto marshes with flooding tides to feed and returns on the outgoing tide to tidal streams (Harrington and Harrington 1961, Perschbacher and Strawn 1986, Perschbacher et al. 1990), and shoreline flats (Reid 1954). One study reports movement to deeper waters during cold weather (May 1977) (NOAA 1997).

The gulf killifish is important in the export of energy from marshes by serving as food for larger fish and piscivorous birds (Jenni 1969, Perschbacher and Strawn 1986), and in the control of mosquito populations through predation (Harrington and Harrington 1961). They forage opportunistically and omnivorously. Depending on their habitat, they can be found eating small crustaceans, insects, microzooplankton, benthic invertebrates, detritus, and vascular plants (Simpson and Gunter 1956, Springer and Woodburn 1960, Harrington and Harrington 1961, Odum 1971, Ruebsamen 1972, Subrahmanyam and Drake 1975, May 1977, Levine 1980, Relyea 1983, Perschbacher and Strawn 1986, Rozas and LaSalle 1990). Predators of gulf killifish include wading birds and larger piscivorous fishes (Jenni 1969, Perschbacher and Strawn 1986).

The gulf killifish has been occasionally used as an indicator organism (Courtney and Couth 1984) as studies have suggested that it may be responsive to the effects of water-soluble fractions of fuel oil, organochlorides, and carcinogens (Ernst and Neff 1977, Courtney and Couch 1984), as well as ocean acidification (McFarlane and Livingston 1983, Courtney and Couch 1984).

5.6.12 Eastern Oysters

Eastern oysters (*Crassostrea virginica*) are sessile filter feeders distributed from the Gulf of St. Lawrence to the Gulf of Mexico and have been introduced in other locations around the world. Genetic data suggest the Atlantic Coast populations are separate from those in the Gulf, with a transition zone occurring along Florida’s eastern coast (Banks et al. 2007). Oysters are common in all of the Louisiana coastal basins and are most abundant in the southeastern and central regions, including the Breton and Chandeleur Sounds and the Atchafalaya and Vermilion bays (Nelson et al. 1992), areas which all receive freshwater inflow. All life stages of eastern oysters are abundant in Barataria Bay (NOAA 1997). Seed oysters are small, about 2 to 25 mm long. Sack oysters are mature adults larger than 75 mm (3 inches) and are considered of harvestable size in Louisiana; on average, it takes about 18 months in Louisiana to reach this size (Stanley and Sellers 1986). Adult oysters form clumps on existing reefs or bars within the estuaries; their distribution in the estuary depends upon larval settlement and spat survival. In the Gulf Coast, oysters spawn when salinities are higher than 10 ppt and water temperatures exceed 20 °C (68 °F), with mass spawning initiated above 25 °C (77 °F), which typically results in a bimodal peak from May through June and from September through October (Banks et al. 2007, Stanley and Sellers 1986). Eastern oyster production zones have been identified for the Barataria Basin based on interacting temperature and salinity effects that promote optimum oyster survival and growth (Melancon et al. 1998, Lowe et al. 2017). Reduced salinities below 10 ppt for prolonged periods in the warm summer months cause excessive oyster mortality from parasites and disease (Craig et al. 1989, La Peyre et al. 2009), while salinities above 15 ppt show higher predation mortality on the reefs by marine oyster drills (a predatory snail species) and stone crabs (Miller et al. 2017).

Eastern oysters are important to Louisiana's economy. Louisiana regularly leads the U.S. in oyster production with an annual averaged contribution of 34% of the nation's total landings from 1997 through 2013 (LDWF 2014). Louisiana accounts for nearly 60% of all oysters landed in the Gulf of Mexico for this time period. LDWF manages the statewide oyster fishery for the public oyster areas in the CSAs (Figure 5.6.12-1). The public oyster grounds are monitored by the LDWF Fisheries-Independent Monitoring (FIM) program and are primarily used as seed grounds for private leases located in in the same CSAs. Figure 5.6.12-1 demonstrates the small scale of the public oyster grounds in the Barataria Basin relative to the statewide public oyster grounds in other CSAs.

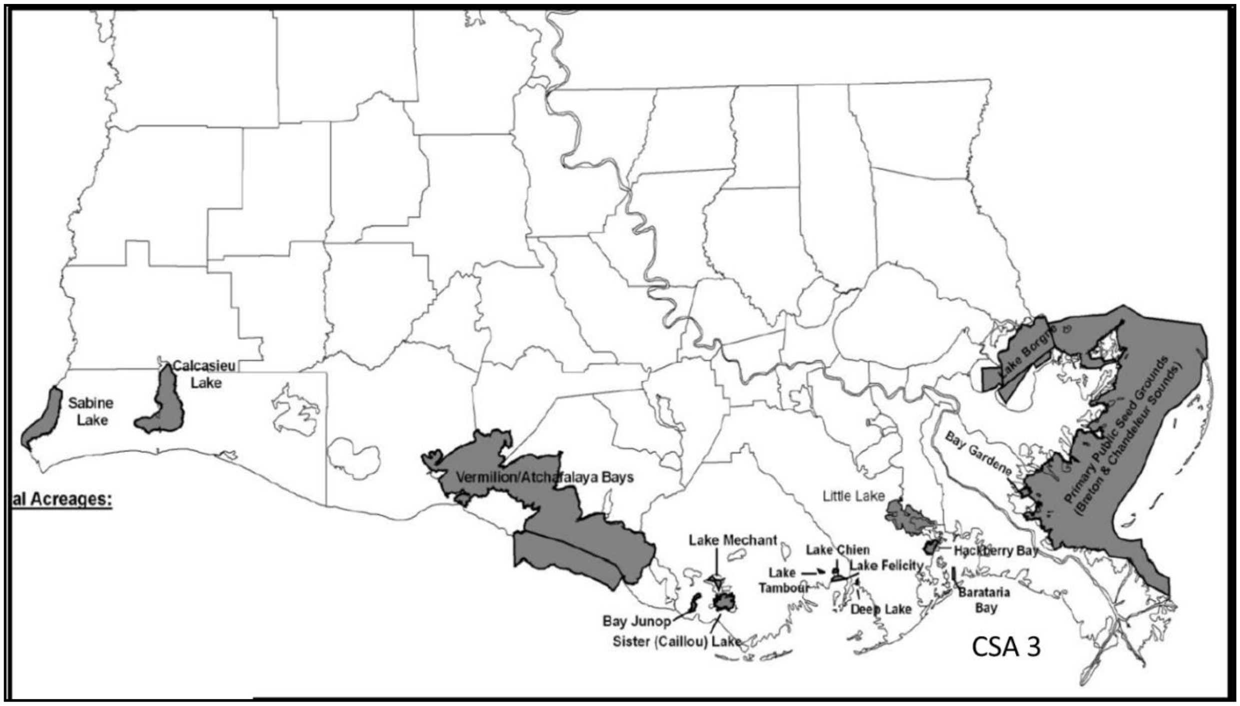


Figure 5.6.12-1. Map of Public Oyster Areas for Louisiana.
CSA 3 is labeled to reference the Little Lake and Barataria Bay public oyster grounds and the Hackberry Bay public seed reservation. Source: LDWF 2014 Oyster Stock Assessment Report)

Most oyster landings are produced from private leases within the coastal basins (LDWF 2014). Total oyster landings in Louisiana have met or surpassed 10 million pounds of meat every year since 1994, with the exception of 2010, when the DWH oil spill occurred; landings in 2010 fell under 7 million pounds. The annual total number of seed and sack oysters estimated from the statewide public oyster grounds has generally declined since the peak in the 1990s through 2001 (LDWF 2014). The public oyster grounds in Barataria Basin (see Figure 5.6.12-1) account for only a small annual portion of the estimated annual statewide oyster stock (1.6% in 2015; LDWF 2014). Barataria Basin public oyster grounds have not produced 13,000 barrels of seed oysters since the late 1990s, with the exception of 2011, 2013, and 2014.

Oyster reef populations at the fringes of marshes are not harvested and therefore can provide a stable source of larvae to oysters in the deeper waters (Murray et al. 2015). Shoreline oiling and related cleanup efforts associated with the DWH oil spill (that is, washing, raking, laying oil booms parallel to shoreline) caused large reductions in cover of fringing oysters within about 152.4 meters (500 feet) of marsh shorelines (Powers et al. 2015 a). Nearshore oyster cover was dramatically reduced over an estimated 155 miles of shoreline (Roman 2015). Reduction of oyster cover along the shoreline translates directly to fewer adult oysters that would be produced over time in the marsh habitats, and reduced larvae to recruit to the harvestable subtidal beds (Roman 2015). Roman (2015) used the estimated numbers of dead oysters due to marsh oiling and cleanup actions to estimate a total of 8.3 million adult equivalent oysters lost, which translated to a total of 1.3 million pounds of oyster meat over their 5-year lifespan lost for the region (DWH NRDA Trustees 2016). Reduced salinity from the extended periods where diversions were opened in response to the DWH oil spill, in an effort to repel oil, significantly drove the decline in subtidal oyster abundance. While nearshore oysters were impacted most heavily by oiling, subtidal oyster impacts were driven by long periods of sustained decreases in salinity (DWH NRDA Trustees 2016).

5.6.13 Benthic Invertebrates

Coastal regions are among the most productive ecosystems in the world, and links between benthic and open water environments are significant in the transfer of energy between these habitats (Valiela 1995, Marcus and Boero 1998). For example, marsh epifauna, such as periwinkles (*Littoraria irrorata*), graze on algae and fungi that grow on the stems of marsh vegetation and soils, support the production of organic matter and nutrient cycling within the marshes, and are prey for salt marsh predators such as blue and mud crabs, turtles, large fishes, and wading birds (Montague et al. 1981, Kemp et al. 1990, Sillman and Bertness 2002). Benthic resources of the Barataria Basin described in this section include benthic algae, infauna (live in the sediment), and epifauna (live on top of the sediment). These benthic producer species and lower trophic level consumer species can also live on the shoots of marsh grasses and SAV, as well as the oyster reefs. Benthic macroinvertebrates such as grass shrimp, penaeid shrimp, and crabs are often referred to as benthic resources. The penaeid shrimps (brown shrimp, white shrimp) and blue crab are presented in detail in Sections 5.4 and 5.6.1, respectively, because they support valuable commercial fisheries and are key ecological species for coastal Louisiana. Likewise, oysters are sessile bivalves often addressed under benthic resources in assessment reports and environmental impact statements (for example, DWH NRDA Trustees 2016). Eastern oysters are presented in Section 5.6.12 because they also support a valuable commercial fishery and important ecological functions in Louisiana estuaries.

Within the Barataria Basin, these lower trophic level benthic groups include benthic algae (e.g., chlorophytes, cyanophytes, and diatoms), infauna (e.g., amphipods, polychaetes, nematodes, and oligochaetes), and epifauna (e.g., small clams, snails, and marsh periwinkles). Changes in the distribution and composition of benthic resources have been linked to shifts in food web structure, increases in invasive species, and declines in the abundance of historical fish populations in other major U.S. estuaries (Kimmerer 2002 and 2004, Dynamic Solutions 2012, Tango and Batiuk 2013, Kimmerer and Thompson 2014, Adamack et al. 2017). Studies after DWH oil spill have found that salt marsh plant restoration is a significant driver of benthic invertebrate recolonization of marsh habitats, with much higher impacts than nutrient inputs (Johnson et al. 2018). There is a strong connection between the abundance and health of salt marsh vegetation health and benthic invertebrate communities.

The major benthic groups and the predominant taxa for the Barataria Basin are listed in Table 5.6.13-1, including any known differences in benthic abundance, density, or biomass (per area or volume) by salinity zones, water quality conditions, or habitat type. Growth of benthic algal taxa depends on temperature, light, and nutrients. Like most aquatic organisms, benthic taxa have lower and upper threshold values for these conditions, outside of which they cannot grow. Cold temperatures generally reduce growth of benthic algae, infauna, and epifauna. Increased turbidity reduces light availability and generally reduces algal growth. Benthic taxa exhibit increasing growth with increasing temperature, light availability, and nutrient concentrations to some optimum growth based on these conditions (Thomann and Mueller 1987, Thornten and Lessem 1978); however, growth can become limited or even reduced if these functions get too high. For example, increased nutrient availability generally increases growth, but excessive nutrient concentrations can cause algal blooms, which can reduce light and DO levels for the benthic lower trophic level groups.

Table 5.6.13-1. Benthic Lower Trophic Level Taxa and Habitat Associations in Barataria Basin

Benthic Group	Predominant Taxa	Habitat Associations/Environmental Requirements
Benthic algae	chlorophytes, cyanophytes, diatoms	Growth depends on temperature, available light, and nutrients. Tidal range and winds determine benthic diatom suspension and affect production (Shaffer 1988, Shaffer and Sullivan 1988). Chlorophytes prefer low salinity, high-nutrient, fast-flowing (short residence time) waters (Reynolds 2006). Low flow waters with high salinity and low nutrients favor cyanobacterial assemblages (Pinckney et al. 1999).
Infauna	amphipods, polychaetes, nematodes, oligochaetes	Mean infaunal density highest in vegetated marsh edge and non-vegetated bottom 1 meter (3.3 feet) from edge; density decreases with distance from marsh edge onto marsh surface and into deeper water (Rozas and Minello 2011, 2015, Whaley and Minello 2002) Species richness higher in shallower vegetated sites due to predator exclusion (Sikora and Sklar 1987 and reference therein). Mean number of infauna per sample were 10.5 in fresh, 7.5 in mesohaline, and 7.1 in polyhaline (Philomena 1983); Rozas and Minello (2015) demonstrate slight dip in spring infauna density for salinities at 4-7 ppt compared to fresh (1-2 ppt) and 2 higher salinity zones (≥ 13 ppt) but increasing density with salinity in fall samples by salinity zones. Benthic infaunal diversity decreased with salinity (Brown et al. 2000) and density was reduced with contaminated sediments (Brown et al. 2000)
Epifauna	mollusks such as small clams, marsh periwinkles, ribbed mussels	Epifauna attached to marsh and SAV stems within the estuary Marsh periwinkles highest in salt marsh (*Spartina alterniflora*) and sea grasses; periwinkles can graze *Spartina* down without predation regulation by blue crabs, turtles, and birds (Siliman and Bertness 2002) Ribbed mussel density is highest (with lowest mortality rates) at mid-estuary (salinity ~8 ppt) on *Juncus* spp. and higher at marsh edge than interior sites (Honig et al. 2015)

The DWH oil spill severely impacted benthic species, including amphipods, fiddler crabs, and marsh periwinkles along oiled marsh shorelines, including the Barataria Basin (DWH NRDA Trustees 2016a). The heavier and heavier persistently oiled marsh sites in Louisiana were expected to reduce survival of amphipods by 36% to 95% in 2010 (Powers and Scyphers 2015). Densities of periwinkles were reduced by 80% to 90% at the oiled marsh shoreline edge and by 50% in the oiled marsh interior due to oiling and cleanup actions (Zengel et al. 2015). An estimated 204 metric tons of periwinkles were lost in the 62 km (38.5 miles) of heavy persistently oiled marsh edge shorelines in Louisiana (Powers and Scyphers 2015). Recovery of the periwinkles was expected to take 3 years to 5 years if wetland vegetation recovered enough to support the animals, but normal-sized ranges of the snails are not expected to recover until at least 2021 (Powers and Scyphers 2015). Reductions in the benthic resources along the oiled marsh shoreline and interior habitats resulting from the oil spill could affect the prey availability and distribution of shrimp, crab, and fish that depend on the benthic resources for growth and recruitment in the Barataria Basin.

6.0 PROJECT EFFECTS TO EFH AND MANAGED SPECIES

This section describes the potential effects from Project elements for construction, operation, and maintenance as identified in the Deconstruction Table of Project Construction and Operation Activities and Effects (Table 6.1-1). This document describes Project effects that lead to potential effects to Essential Fish Habitat (EFH) and does not include the additional components of the Project that may affect upland habitats or portions of the Mississippi River where there is no EFH present. The additional components of the Project are fully described in the Project Biological Assessment and other project evaluations.

The Deconstruction Table addresses environmental attributes and habitat qualities important to EFH species and their habitats. This information is then compared to the EFH present in the action area and EFH species tolerances to potential project effects. Then the range of potential effects to EFH is described. This discussion is then followed by a review of interactions between habitat, prey resources, and predator-prey relationships to assess trophic level effects associated with the Project.

6.1 Deconstruction Table of Project Construction and Operation Activities and Effects

The Deconstruction Table (Table 6.1-1) provides a summary overview of the relationship between Project activities and environmental attributes that may affect those waters and substrates necessary to fish for spawning, breeding, feeding, or growth to maturity that are identified as Essential Fish Habitat. The Deconstruction Table addresses aquatic Project activities and major environmental attributes and habitat qualities (i.e., project effect pathways) important to EFH that may be affected by the Project. Project activities that are limited to upland areas and not expected to influence EFH are not included in Table 6.1-1. Potential effects range from no interaction or effect to minor and major effects from the Project activity on the environmental effect pathway. Minor effects are interactions where there is an expectation that the effect pathway may be affected; however, that effect will be small, may not be detectable at the scale of the Project, and may be within the range of disturbance attributable to seasonal or natural variation (i.e., insignificant and/or discountable; negligible). Major effects are those where a measurable and potentially substantial change to an effect pathway is predicted to occur. The major changes to an effect pathway are then further analyzed to determine the potential extent of effect to EFH species and their habitats.

Table 6.1-1. Deconstruction Table of Project Construction and Operation Activities and Effects with potential to affect EFH **Table 6.1-1. Deconstruction Table of Project Construction and Operation Activities and Effects with potential to affect EFH**

Project Description							Effect Pathways												
Project Element	Project Feature	Project Action & Phase	Action Category	Action	Habitat (Aquatic/ Terrestrial)	Location of Aquatic Interaction (River/Basin)	Salinity	Turbidity/SS	Nutrients (N and P)	Dissolved Oxygen	Water Temp	pH	Sediment Deposition/ Land Creation	Water Quality/ Contaminants	Sound/Noise Effects	Entrainment/Stranding	Physical Disturbance of Species	Change in Habitat Type	Shading (over water structure)
Diversion Complex	All	Diversion Operation	Operation	Baseline diversion flow (5,000 cfs diverted)	A	R,B	xx	xx	xx	xx	x	xx	xx	xx	n	xx	n	x	n
Diversion Complex	All	Diversion Operation	Operation	Intermediate flow (between 5,000 and 75,000 cfs diverted)	A	R,B	xx	xx	xx	xx	xx	xx	xx	xx	n	xx	n	xx	n
Diversion Complex	All	Diversion Operation	Operation	High diversion flow - river >1,000,000 cfs (75,000 cfs diverted)	A	R,B	xx	xx	xx	xx	xx	xx	xx	xx	n	xx	n	xx	n
Diversion Complex	All Diversion Complex Features (Intake Channel, Diversion Structure,	Construction Activities: Phase 1	Site Prep	Clearing and grubbing: limits of terrestrial construction	T	R, B	n	n	n	n	n	n	n	n	n	n	n	n	n

Project Description							Effect Pathways												
Project Element	Project Feature	Project Action & Phase	Action Category	Action	Habitat (Aquatic/ Terrestrial)	Location of Aquatic Interaction (River/Basin)	Salinity	Turbidity/SS	Nutrients (N and P)	Dissolved Oxygen	Water Temp	pH	Sediment Deposition/ Land Creation	Water Quality/ Contaminants	Sound/Noise Effects	Entrainment/Stranding	Physical Disturbance of Species	Change in Habitat Type	Shading (over water structure)
	Outfall Transition Feature, Guide Levees)			Access: haul road excavation and construction, unloading areas, parking pads, fencing	T	R, B	n	n	n	n	n	n	n	n	n	n	n	n	n
				Staging: constructing and/or stabilizing staging areas	T	R, B	n	n	n	n	n	n	n	n	n	n	n	n	n
				Clearing and Grubbing: limits of aquatic construction	A	R, B	n	x	n	n	n	n	n	n	n	n	x	x	n
				Access: dredging for barge access (basin side)	A	B	n	x	x	x	n	n	n	n	x	x	x	x	x
				Equipment and materials staging: barge	A	R	n	n	n	n	n	n	n	n	n	n	n	n	x

Project Description							Effect Pathways												
Project Element	Project Feature	Project Action & Phase	Action Category	Action	Habitat (Aquatic/ Terrestrial)	Location of Aquatic Interaction (River/Basin)	Salinity	Turbidity/SS	Nutrients (N and P)	Dissolved Oxygen	Water Temp	pH	Sediment Deposition/ Land Creation	Water Quality/ Contaminants	Sound/Noise Effects	Entrainment/Stranding	Physical Disturbance of Species	Change in Habitat Type	Shading (over water structure)
		Construction of Foundation Systems: Phase 1-3	Construction	Pile driving (cofferdam and trestle)	A	R	n	n	n	n	n	n	n	n	x	x	x	n	n
				Trestle	A	R	n	n	n	n	n	n	n	n	n	n	x	x	x
				Surcharge area with excess fill to consolidate sediments	T	R, B	n	x	n	n	n	n	n	x	N	n	n	n	n
				Dewatering/ rewatering	A	R, B	n	x	n	n	n	x	n	x	n	x	x	n	n
				Excavation	A	R, B	n	x	n	n	n	n	n	x	n	n	x	x	n

Project Description							Effect Pathways												
Project Element	Project Feature	Project Action & Phase	Action Category	Action	Habitat (Aquatic/ Terrestrial)	Location of Aquatic Interaction (River/Basin)	Salinity	Turbidity/SS	Nutrients (N and P)	Dissolved Oxygen	Water Temp	pH	Sediment Deposition/ Land Creation	Water Quality/ Contaminants	Sound/Noise Effects	Entrainment/Stranding	Physical Disturbance of Species	Change in Habitat Type	Shading (over water structure)
	Inlet Channel	Construction Activities: Phase 2-3	Construction	In-the-dry construction: headworks - sheet pile installation/ removal	A	R	n	n	n	n	n	n	n	n	x	n	x	n	n
				In-the-dry construction: dewatering/ rewatering	A	R	n	x	n	n	n	n	n	n	n	x	x	x	n
				Sediment excavation and disposal	A	R	n	x	n	n	n	n	n	x	n	n	x	x	n
				Staging during construction. Barge delivered materials and equipment	A	R	n	n	n	n	n	n	n	n	n	n	n	x	x
	Diversion Structure	Construction Activities: Phase 1-3	Construction	In-the-dry construction: sheet pile installation	A	R	n	n	n	n	n	n	n	n	x	n	x	n	n

Project Description							Effect Pathways												
Project Element	Project Feature	Project Action & Phase	Action Category	Action	Habitat (Aquatic/ Terrestrial)	Location of Aquatic Interaction (River/Basin)	Salinity	Turbidity/SS	Nutrients (N and P)	Dissolved Oxygen	Water Temp	pH	Sediment Deposition/ Land Creation	Water Quality/ Contaminants	Sound/Noise Effects	Entrainment/Stranding	Physical Disturbance of Species	Change in Habitat Type	Shading (over water structure)
				In-the-dry construction: dewatering/ rewatering	A	R	n	x	n	n	n	x	n	n	n	x	x	n	n
				Sediment excavation and disposal	A	R	n	x	x	n	n	n	n	x	n	n	n	x	n
				Sediment excavation: mechanical	A,T	R	n	x	x	x	n	n	x	x	n	n	x	x	n
				Sediment excavation: hydraulic	A,T	R	n	x	x	x	n	n	x	x	n	n	x	x	n
				Sediment excavation: laydown area for processing clay borrow	A,T	R	n	n	n	n	n	n	n	n	n	n	n	n	n
	Diversion Structure & Transition Structure	Construction Activities: Phase 2-3	Construction	In-the-dry construction: transition walls and	A,T	B	n	x	n	n	n	x	n	n	n	x	x	n	n

Project Description							Effect Pathways												
Project Element	**Project Feature**	**Project Action & Phase**	**Action Category**	**Action**	**Habitat (Aquatic/ Terrestrial)**	**Location of Aquatic Interaction (River/Basin)**	**Salinity**	**Turbidity/SS**	**Nutrients (N and P)**	**Dissolved Oxygen**	**Water Temp**	**pH**	**Sediment Deposition/ Land Creation**	**Water Quality/ Contaminants**	**Sound/Noise Effects**	**Entrainment/Stranding**	**Physical Disturbance of Species**	**Change in Habitat Type**	**Shading (over water structure)**
				installation of armoring															
Basin Outfall Area	**Outfall Transition Feature**	**Construction Activities: Phase 1**	**Site Prep**	Clearing and grubbing the limits of aquatic construction	A	B	n	x	n	n	n	n	n	n	n	n	x	x	n
		Construction Activities: Phase 2-3	**Construction**	If in-the-dry construction: drive sheet pile	A	B	n	n	n	n	n	n	n	n	x	n	x	n	n
				If in-the-dry construction: dewatering/ rewatering	A	B	n	x	n	n	n	n	n	n	n	x	x	n	n
				Staging during construction: barge stored materials and equipment	A	B	n	n	n	n	n	n	n	x	n	n	x	x	x
				Dredging/ excavation	A	B	n	x	n	n	n	n	n	x	n	n	n	x	n

Project Description							Effect Pathways												
Project Element	Project Feature	Project Action & Phase	Action Category	Action	Habitat (Aquatic/ Terrestrial)	Location of Aquatic Interaction (River/Basin)	Salinity	Turbidity/SS	Nutrients (N and P)	Dissolved Oxygen	Water Temp	pH	Sediment Deposition/ Land Creation	Water Quality/ Contaminants	Sound/Noise Effects	Entrainment/Stranding	Physical Disturbance of Species	Change in Habitat Type	Shading (over water structure)
Auxiliary Features	Linear Infrastructure	Auxiliary Activities	Railway Bridge (NOGC)	Railway: bridge construction	T	R	n	n	n	n	n	n	n	n	n	n	n	x	n
			Highway LA 23	Raised and Relocated	T	R	n	n	n	n	n	n	n	n	n	n	n	x	n
			Utilities - Power	Relocation: existing power right-of-way	T		n	n	n	n	n	n	n	n	n	n	n	n	n
			Utilities - Fiber Optic	Relocation: existing Fiber Optic right-of-way	T		n	n	n	n	n	n	n	n	n	n	n	n	n
			Utilities - Water	Relocation: 16-inch water main for Plaquemines Parish	T		n	n	n	n	n	n	n	n	n	n	n	n	n
			Drainage System	Siphon drain option	A,T	R	x	x	x	n	n	n	n	n	n	n	n	x	n
	Beneficial Use Placement Areas		BU Areas	BU Areas	A	B	n	x	n	x	n	n	n	n	n	n	n	x	n
Diversion Complex	ALL		Maintenance	Debris management	A	R, B	n	x	n	n	n	n	n	n	n	n	x	n	n

Project Description							Effect Pathways												
Project Element	Project Feature	Project Action & Phase	Action Category	Action	Habitat (Aquatic/ Terrestrial)	Location of Aquatic Interaction (River/Basin)	Salinity	Turbidity/SS	Nutrients (N and P)	Dissolved Oxygen	Water Temp	pH	Sediment Deposition/ Land Creation	Water Quality/ Contaminants	Sound/Noise Effects	Entrainment/Stranding	Physical Disturbance of Species	Change in Habitat Type	Shading (over water structure)
		Maintenance of Sediment Diversion		Channel repairs/ modifications	A	R, B	n	x	n	n	n	n	n	n	x	x	x	n	n

SS = suspended sediments; N = nitrogen; P = phosphorus; DO = dissolved oxygen; BU = beneficial use placement
n = No effect or negligible effect
x = Minor effect (e.g., short duration, small geographic extent).
xx = More than Minor effect (to be assessed in more detail)

6.2 Comparison of Alternatives

The analysis presented here presents the EIS Alternative 1 (the Future With Project of variable diversion flow up to 75,000 cfs maximum sediment diversion) as the Project (referred to herein as the Future With Project). Additional alternatives being considered include the Future Without Project (referred to herein as the Future Without Project), EIS Alternative 3 (variable flow up to 50,000 cfs), and EIS Alternative 5 (variable flow up to 150,000 cfs). In addition, alternatives are under consideration that include the presence of terraces (Alternatives 2, 4, and 6). Each of the following effect sections evaluates the proposed Project (Future With Project) as compared to the Future Without Project, and subsequently evaluates differences between the proposed Project and alternatives (3 and 5).

6.3 Physical and Ecosystem Models

6.3.1 Delft3D Model Overview

The Barataria Basin is a dynamic system that has experienced extensive land loss and is predicted to continue to experience substantial additional land loss into the future. The basin is also predicted to be impacted by SLR. These changing baseline conditions are expected to influence a wide range of environmental factors within Barataria Basin. Therefore, the project team has worked with TWI to develop a basin-wide model that can be used to assess conditions in the basin at various points in time with and without the Project and Project alternatives. Outputs from this model are used to evaluate a wide range of potential effects from operations of the MBSD.

TWI has developed successive versions of the basin-wide Delft3D model to simulate morphological changes and water quality-related dynamics in the Mississippi River and in the Barataria and Breton Sound basins, including the Birdfoot Delta. The Delft3D model incorporates the existing Breton Sound Basin connections to the Mississippi River at Fort St. Philip and Bayou Lamoque, as well as Breton Sound Sediment diversion operations (Sadid et al. 2018). The Delft3D model is a modeling suite developed by Deltares (2014) and designed to model "hydrodynamics, sediment transport and morphology and water quality for riverine, estuarine, and coastal environments" (Sadid et al. 2018). As developed by TWI, the Delft3D model integrates several modules, including hydrodynamics, morphodynamics, nutrient dynamics, and vegetation dynamics. Vegetation dynamics are modeled using 2 Louisiana specific vegetation modules to simulate the spatial distribution of wetland vegetation and allocate biomass above and below-ground.

The results presented here and used in the evaluation of alternatives are based on Version 3 of the basin-wide Delft3D model, implemented specifically to model the proposed Project and Project alternatives. The Delft3D model predicts how conditions would change over 50 years for each Project alternative, including changes in wetland area, water level, water quality (including salinity), and vegetation characteristics. Many of the results from the Delft 3D model are expressed as the difference between the “future with project” (FWP) and “future without project” (FWOP) scenarios. (Herein, the FWOP is referred to as the “Future Without Project.”) Delft3D modeling projections allow for comparisons of environmental conditions over time with and without the proposed Project.

Model Description

The model domain covers Barataria and Breton basins and the Mississippi River Delta. Adjacent bays were included to account for water and nutrient exchange and longshore currents. The model domain was intentionally sized larger than the action area to allow for potential far-field effects of larger-scale restoration projects and to avoid influences from model boundaries. Model outputs are at multiple scales with the finest grid resolution (100 m X 100 m) near the proposed sediment diversion outfall with the grid size gradually increased (and resolution reduced) with distance from the outfall areas. Most of Barataria Basin is characterized at 100 m X 100 m grid size, increasing to 200 m X 200 m grid size in the Birdfoot Delta and 400 m X 400 m grid size in outer basin areas. Far-field locations in the Gulf of Mexico are characterized at a 2 X 2 km to 4 X 4 km grid size.

Model Assumptions

Sea level rise is incorporated in the model based on the 2017 Master Plan moderate projection of 1.5-meter increase by 2100 (CPRA 2017). Relative to the North American Vertical Datum 1988 (NAVD88), sea level elevations are predicted to increase from 0.0 meters in 2015 to 0.04 meter in 2020, 0.13 meter in 2030, 0.25 meter in 2040, 0.39 meter in 2050, 0.54 meter in 2060 and 0.72 meter in 2070.

The model implementation uses a series of assumptions about the Mississippi River hydrograph, the landscape in the basin, and representative simulation of initial conditions for vegetation distribution in the basin. Historic hydrograph conditions from the past 50 years are used in the model to represent future conditions on a decadal scale (see Table 6.3.1-1). Hydrograph locations and geographic references for the Project are shown in Figure 6.3.1-1.

Table 6.3.1-1. Delft3D Model Simulation Components

Decade	Cycle	Time Period	Simulation Length (yrs)	Hydrology and Water Quality Simulations			
				Representative Year*	Simulated Landscape**	Model Name	Additional Simulations***
Initialization	Initialization	2015-2019	5	2014	2015	Yr 0	1994, 2006, 2010, 2011
First	0	2020-2029	10	1970	2020	Yr 1	1994, 2006, 2010, 2011
Second	1	2030-2039	10	1975	2030	Yr 10	1994, 2006, 2010, 2011
Third	2	2040-2049	10	1985	2040	Yr 20	1994, 2006, 2010, 2011
Fourth	3	2050-2059	10	2002	2050	Yr 30	1994, 2006, 2010, 2011
Fifth	4	2060-2069	10	2008	2060	Yr 40	1994, 2006, 2010, 2011
Sixth	5	2070	1	2008	2070	Yr 50	1994, 2006, 2010, 2011

*Used to estimate vegetation spatial distribution and organic accretion
** Topography/bathymetry/vegetation distribution
*** 5 hydrographs were simulated for each model period. The representative year and 4 types of flood conditions.

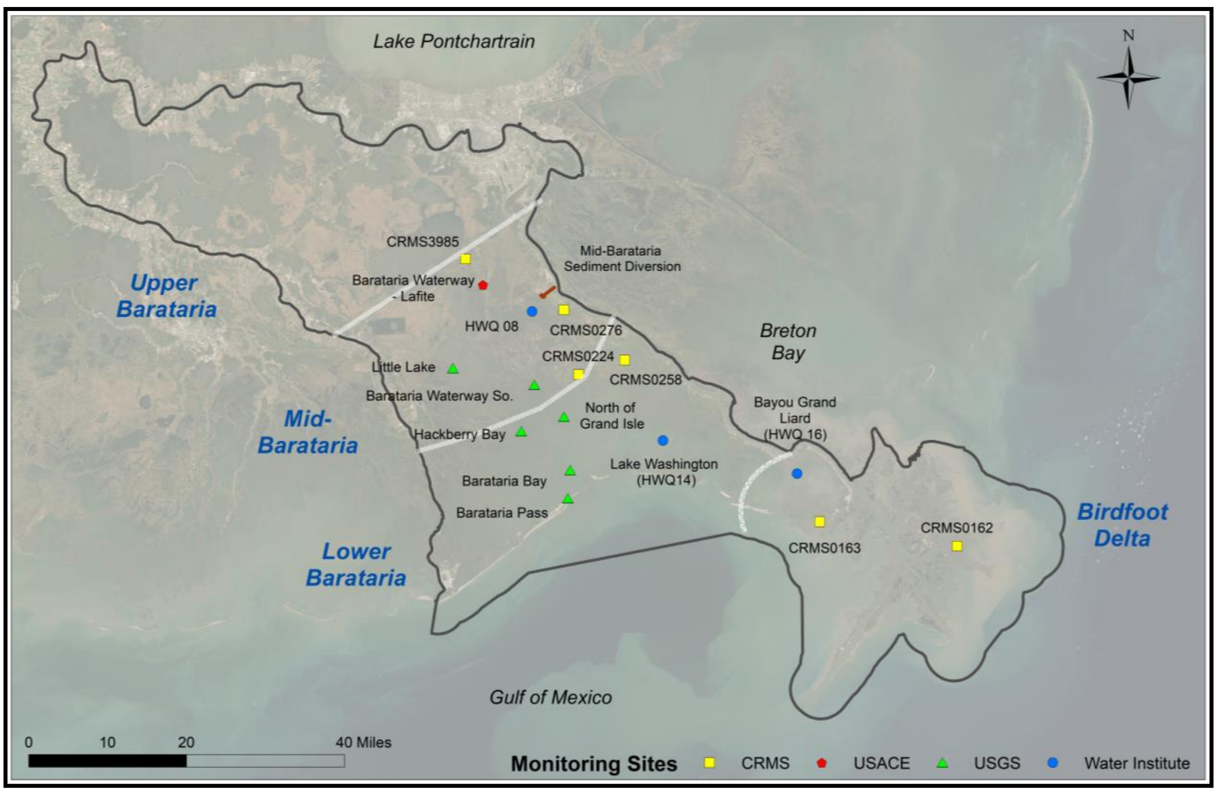


Figure 6.3.1-1. Hydrograph Locations and Geographic References (Source: Modified from TWI)

Sediment transport and deposition by the Mississippi River has been measured over a lengthy historical record. While average annual conditions are captured in the historical record, the sediment in the river is also subject to storm-scale hysteresis effects where larger amounts of sediment are mobilized during the rising limb of a storm event's hydrograph than during the peak and falling limb. Hysteresis effects exist where peak sediment concentrations generally *precede* peak river discharge rates and, in turn, sediment concentrations are usually *lower* during the peak river discharges of most high flow events. This occurs because the finest sand fractions are mobilized during initial phases of the event. Stratigraphic signatures of flood events suggest that sediment volume is more closely related to the duration and total suspended load of the event rather than the magnitude of the peak discharge (Benedetti 2003). TWI has generated Delft3D model outputs using both traditional and hysteresis assumptions for sediment concentrations. Mossa (1989) found that the lower Mississippi River has pronounced hysteresis effects, especially during high discharge years when sediment concentrations and load maximums precede discharge maximums by several months. Therefore, the analysis presented here relies on the hysteresis outputs, which more closely describe the sediment transport conditions expected for this Project.

Model Caveats

Numerical models can be used to describe coastal systems by providing information on the physical and environmental conditions of water and can be used to predict oceanographic variables. The Delft 3D model is a simplified representation of existing and future conditions with and without the Project. There are aspects of the natural environment, such as sediment movement during low flow events and sudden large changes/oscillations in river flow, which models do not predict well. In general, models are best suited for predictions regarding events that are like the historical record and may have limited utility as actual conditions diverge from that record. Further, predictions tend to be best for near-term projections. Long-term projections are built on earlier projections, and thus any errors or inaccurate projections become magnified. Therefore, uncertainties in future projections tend to become magnified as projections get further from the current period. In this case the future scenarios are also based on future projections for SLR, which may ultimately be higher or lower than the projections used here.

6.3.2 Ecopath with Ecosim (EWE) and Comprehensive Aquatic Systems Model (CASM)

Ecopath with Ecosim (EwE) and Comprehensive Aquatic Systems Model (CASM) are ecosystem models that describe the structure and energetics of the Barataria Basin food web. These models characterize predator-prey and competitive interactions between species within the food web and how environmental conditions affect the structure and energetics of the ecosystem. Both models were used to provide complementary information and increase the confidence in results and conclusions of shared results.

EwE is an ecosystem modeling framework that uses 3 related modeling modules: Ecopath, a static, mass-balanced snapshot of the ecosystem; Ecosim, a dynamic simulation model to evaluate changes over time including changes due to fishing effort, mortality, and changing environmental conditions; and Ecospace, a spatial and temporal tool that was not used in evaluating the Project (Christensen et al. 2005). CASM is a daily bioenergetics-based model that uses temperature, salinity, Chlorophyll a (Chl a) and vegetation input data to predict biomass for many species in a food web context (de Mutsert et al. 2017, CPRA 2016). Within the model primary production, Chl a is the main driver of predicted biomass for many species. This model is used to evaluate potential effects and interactions between the Project and the food web within Barataria Basin.

These tools were calibrated based on existing environmental conditions and population abundances (CPRA 2016) and then environmental conditions predicted for future scenarios with and without the Project were evaluated to predict the potential effects of the Project.

6.4 Construction Effects

Relevant issues, impact indicators and associated design parameters for project construction in the MBSD outfall vicinity are summarized in Table 6.4-1. This analysis focuses on the design parameters that would be expected to result in the greatest impact to considered resources.

Table 6.4-1. Construction Issues, Design Parameters, and Indicators Used to Assess Impacts

Issue	Relevant Design Parameter(s)	Impact Indicator
Seabed and water column alteration – construction	Cofferdams and vessel anchors/mooring	Short-term exclusion of EFH accessible to EFH-listed species
	Scour protection	Altered water column and seabed area
	Dredging	Short-term exclusion of accessible EFH
Water quality – pollutants	Vessel trips	Fuel spills
	O&M facility dredging (construction and maintenance)	Suspended sediments

6.4.1 Project Effects on Turbidity and Suspended Sediment

Numerous construction activities would cause temporary increases in turbidity and suspended sediments in the Barataria Basin.

Project construction activities on the basin-side of the diversion would include the excavation of about 34 acres of material during construction of the diversion outfall, 2 miles of channel dredging (70 feet wide by 4 feet deep) to support outfall construction, and deposition of large quantities of excavated materials throughout the construction process within designated beneficial use placement (BUP) areas in Barataria Basin.

Each of these construction activities would temporarily increase turbidity and suspended sediments in and around the areas where they occur. Increased turbidity can have consequences to plants and animals present, such as smothering of benthic vegetation and invertebrates, reducing DO levels, and species displacement from highly turbid areas. Turbidity associated with these activities is anticipated to occur during the construction phase, and is expected to return to baseline conditions shortly after the construction activity is complete.

Effects of turbidity on fish species is variable depending on the age class, size class, and predation strategy. Increased turbidity may improve the detection of fish larvae prey due to less interference from light scattering (Utne-Palm 2002). However, for most visual predators, feeding rates and prey detection distances decrease as total suspended solids (TSS) and sediment deposition rates increase (Chapman et al. 2014). Turbidity levels above 20 NTU can reduce the overall efficacy of foraging (e.g., Madej et al. 2007, and Kemp et al. 2011).

Long-term increases in turbidity or changes in sedimentation rates can influence SAV by reducing the photic zone or through burial of vegetation. SAV burial could occur in BUP areas due to the intentional sediment placement during construction; however, it is unlikely that other areas would incur sufficient sediment deposits to result in SAV loss due to burial.

Effects to fish and substrate would be greatest within the construction footprint, and would decrease with distance from the edge of construction. Turbidity generation and exposure of areas outside of the immediate construction area will be limited through implementation of protective plans including the Stormwater Pollution Prevention Plan (SWPPP), Temporary Erosion and Sediment Control Plan (TESC), and Spill Prevention, Control and Countermeasure Plan (SPCC).

Stormwater Pollution Prevention Plan

The SWPPP will be prepared to meet National Pollutant Discharge Elimination System (NPDES) permit requirements for stormwater discharges from construction sites. The SWPPP will address the following:

- Planning and organization
- Site assessment
- BMP identification
- Implementation
- Evaluation and monitoring

Temporary Erosion and Sediment Control Plan

A TESC plan is required to prevent erosive forces from damaging project sites, adjacent properties, and the environment. A TESC plan will be prepared and implemented to minimize and control pollution and erosion due to stormwater runoff.

Spill Prevention, Control and Countermeasure Plan

An SPCC plan is prepared by the contractor to prevent and minimize spills that may contaminate soil or nearby waters.

6.4.2 Potential Effects on Habitat Area

The construction of the diversion structures and access dredging would generate large quantities of excavated earthen material from upland and aquatic sources. Where material is deemed unsuitable for construction of the Conveyance Channel levees and the Mississippi River levee system, it would be used to directly support marsh creation or restoration. Two sites have been identified for restoration that are near the outfall in Barataria Basin. These sites are the West BUP Area, due west of the outfall, and the East BUP Area, southeast of the outfall (near Myrtle Grove Marina) (Figure 3.3.2-1).

BUP areas have a target elevation of +0.8 meter (2.5 ft) mean lower low water (MLLW). This elevation is appropriate for development of terrestrial wetland plants; however, this habitat will be converted from estuarine soft bottoms to emergent marsh which is a conversion from one type of EFH to another. Up to about 254 acres would be converted into marsh habitat or enhanced as a result of placement of approximately 1,522,000 cy of excess materials in BUP areas. These areas include those that have recently transitioned from terrestrial to aquatic.

Proposed access channels include habitat that will be made deeper to provide construction access for barges, equipment and vessels. These activities will affect soft bottom habitats; however, it is expected that soft bottom habitats will continue to occur in these areas after dredging. These areas will become deeper as a result of dredging and this may affect use of this EFH by some species. Some areas may have SAV, and this habitat may be temporarily or permanently lost from the dredged areas. Areas adjacent to the dredged access channel will be used for placement of dredged materials and portions of these placement areas may extend to approximately +2 ft (NAVD88). About 700 acres of soft bottom EFH habitat associated with access channels and in the outfall vicinity may be affected by dredging activities.

6.4.3 Project Effects on Nutrients and Dissolved Oxygen

Project construction will have negligible effects on nutrients and DO. Dredging will disturb bottom sediments and contribute to turbidity in the water column as discussed in Section 6.4.1.

6.4.4 Project Effects on Water Quality/Contaminants

Construction of the diversion includes the use of a large workforce, and a significant amount of equipment will be operating in or adjacent to the water. An SPCC plan will minimize the potential harm from accidental spills or releases of any chemicals from equipment.

6.5 Operation and Maintenance Effects

The Project will operate as described in Section 3.3. Operations of the diversion will be controlled by the flow of the Mississippi River. Conditions described below use historical information and high-quality hydrodynamic models to project likely conditions; however, actual conditions will depend on actual flow and water quality conditions.

6.5.1 Project Effects on Salinity

The proposed diversion will divert fresh water from the Mississippi River into the brackish marshes of the Barataria Basin. This will cause changes to the distribution, amount, and frequency of freshwater, intermediate, brackish, and saline habitats in the Barataria Basin.

Under the Future Without Project and in response to SLR, wetland loss and saltwater intrusion in the Barataria Basin are anticipated to increase over time. The analysis of effects of the Future with Project include the influence of the predicted conditions in the Future Without Project trajectories and trends, as they would continue to exert their influence.

Compared to the Future Without Project, the Future With Project is anticipated to decrease salinity throughout the Barataria Basin, with the strongest effects on the southern half of the basin below the diversion outfall, during the near and mid-term of the project. Modeled effects of the Future With Project lower salinity throughout the mid- and southern regions of Barataria Basin, throughout all seasons of the year, through the duration of modeled operations. Salinity effects due to the diversion are primarily during periods of operation and immediately following closure of the diversion; however, even base flow (5,000 cfs) would continue to exert an influence on salinity. Salinity effects are greatest during the months when high-flow diversion operations are near or at max flow capacity (75,000 cfs) are occurring, most commonly December through June (see figure 3.3.3-1). Salinity changes due to the Future With Project are not anticipated to extend north of the diversion into upper Barataria Basin where salinity is normally low. Salinity in the Birdfoot Delta is predicted to be minimally higher as a result of the Project diverting volumes of freshwater from the area. Project effects on salinity through time within each Delft3D modeled region are described in Table 6.5.1-1, while an overview of predicted salinity trends over time within the basin is shown in Figure 6.5.1-1.

The largest changes to salinity would occur in the mid-region of Barataria Basin, near the diversion outfall. Changes to salinity as a result of the Future With Project are most noticeable during periods of peak river flow and diversion flow, and the Project would continue to influence salinity throughout the rest of the year. The diversion would be adding a new source of freshwater flow into the basin, decreasing salinity substantially (by ≤ 8 ppt lower locally or ≤ 4 ppt on average regionally than the Future Without Project, to a minimum of 0 ppt) adjacent to the new flow.

The amount of difference in salinity levels decreases with increasing distance from the diversion outfall. The second greatest changes to salinity are anticipated to occur on the north side of the barrier islands, in lower Barataria Bay, during periods where the diversion is operating above baseflow. The barrier islands are an area where the basin's estuarine waters and the more saline nearshore Gulf waters mix, but additions of diversion fresh water under the Future With Project would likely move the mixing zone slightly south and decrease salinity substantially (by ≤ 6 ppt lower than the Future Without Project) just north of the barrier islands during the springtime months. However, the areas near the barrier islands, due to mixing with high-salinity Gulf waters, have higher salinity than the rest of Barataria Basin during most of the year; therefore, the lowest monthly springtime salinity predicted at the barrier islands due to the Future With Project is estimated to be approximately 1.1 ppt, as compared to a minimum of 3.9 ppt in the Future Without Project in 2070. Salinity conditions south of the barrier islands are primarily driven by nearshore and oceanic processes in the Gulf, and effects due to the Future With Project are constrained to the immediate vicinity of the barrier islands. In the mid and lower basin, the difference in salinity between the Future With Project and the Future Without Project during months when the diversion is closed (Aug-Nov) decreases over time. This decrease in predicted salinity difference over time is due to the counter pressure of SLR bringing more saline waters into the basin in both scenarios, masking the long-term project impacts during diversion base-flow periods.

Changes to salinity can have consequences to aquatic plants and animals in the basin, expanding areas available for some species, and restricting suitable areas for others. Project driven changes to salinity have the potential to result in changes to habitats (e.g., species of composition of marsh vegetation) and are predicted to shift marsh areas in the mid-basin from brackish marsh to fresh and intermediate marshes. These are in addition to changes over time in both the Future With Project and Future Without Project scenarios where saline marshes in mid and lower Barataria Basin are predicted to continue to reduce in area, followed by subsequent losses of substantial areas of brackish marsh due to continued SLR and coastal erosion (see Sections 6.5.3 and 6.5.7). The project would not alter the predominantly fresh upper basin, where the project is predicted to decrease in salinity of between 0 ppt and 1 ppt.

Table 6.5.1-1. Predicted Average Salinity in Barataria Basin by Region

Scenario				FWOP Salinity (ppt)				FWP 75K cfs Salinity (ppt)			
Location			Diversion Status	Birdfoot Delta	Lower Basin	Mid Basin	Upper Basin	Birdfoot Delta	Lower Basin	Mid Basin	Upper Basin
Time Period	Cycle 0	(2020 - 2029)	Open (Dec-Jul)	5	7	3	1	5	4	0	0
			Closed (Aug-Nov)	7	10	3	0	6	8	1	0
	Cycle 1	(2030 - 2039)	Open (Dec-Jul)	3	6	3	1	2	3	0	0
			Closed (Aug-Nov)	4	9	3	0	4	8	1	0
	Cycle 2	(2040 - 2049)	Open (Dec-Jul)	3	7	3	1	2	2	0	0
			Closed (Aug-Nov)	7	10	3	0	6	8	1	0
	Cycle 3	(2050 - 2059)	Open (Dec-Jul)	3	8	4	1	3	4	0	0
			Closed (Aug-Nov)	9	11	4	0	8	10	2	0
	Cycle 4	(2060 - 2069)	Open (Dec-Jul)	4	7	4	1	3	4	1	0
			Closed (Aug-Nov)	7	9	3	1	6	7	1	0
	Cycle 5	Year 50 (2070)	Open (Dec-Jul)	4	8	5	2	4	5	1	0
			Closed (Aug-Nov)	8	10	4	1	10	10	2	0

FWOP = Future without Project; FWP = Future with Project
Source: The Water Institute 2019

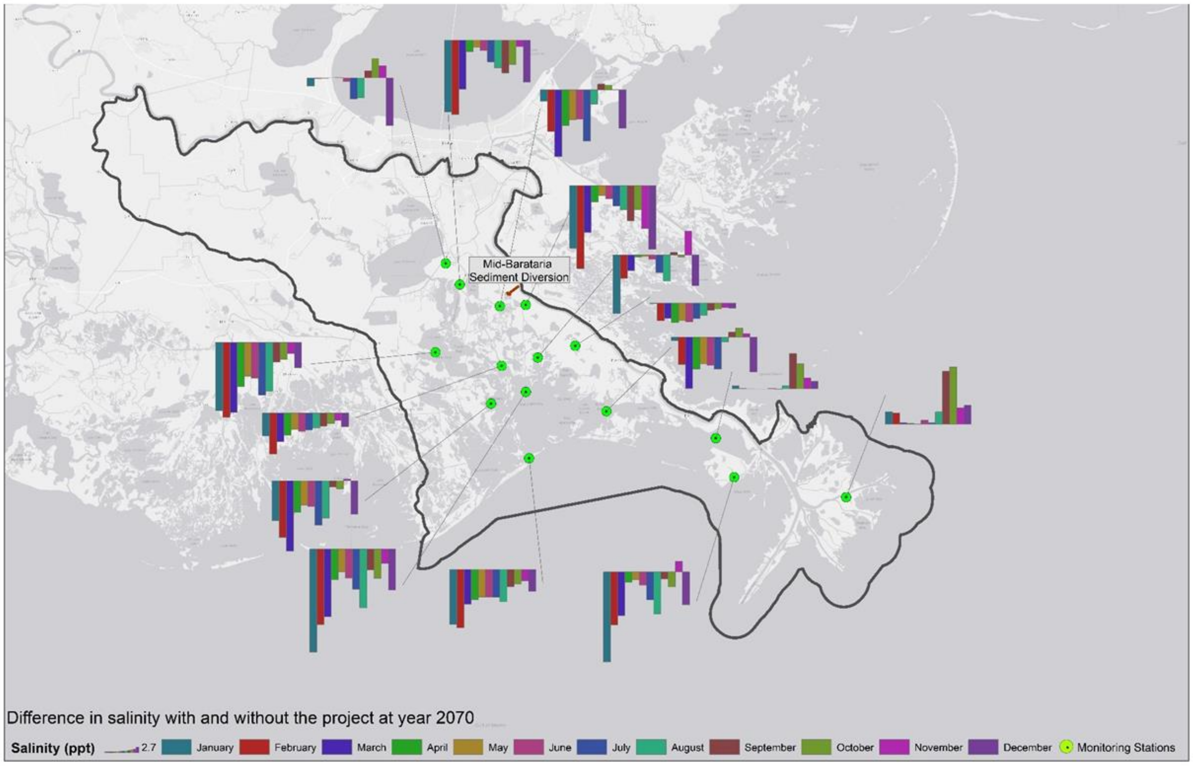


Figure 6.5.1-1. Effects of the Future With Project on Salinity in 2070 in Barataria Basin, Compared to the Future Without Project

6.5.2 Project Effects on Turbidity and Suspended Sediment

The Project will divert sediment-laden water from the Mississippi River. The purpose of this diversion is to cause sediment deposition in the Barataria Basin. This will cause changes to the distribution and frequency of sediment inputs and result in changes to habitat over time.

In the Future Without Project scenario, turbidity (as measured in TSS) is generally low (< 50 g/m^3) year-round throughout the majority of Barataria Basin, although the model does show time periods when turbidity is elevated near the barrier islands. The analysis of effects of the Future With Project below include the influence of predicted conditions in Future Without Project trajectories and trends, as they would continue to exert their influence.

The Future With Project would divert sediment-laden water from the Mississippi River into the mid-region of Barataria Basin. A key purpose of the diversion is to increase sediment deposition in the Barataria Basin in support of marsh creation and maintenance into the future. The Future With Project would increase the frequency of sediment input into the basin as compared to the Future Without Project, and result in changes to the distribution and maintenance of land area and emergent marsh habitats in the basin over time. Average turbidity of the Mississippi is 150 NTU, but average concentrations nearest the diversion at the Belle Chasse station range from 22 NTU (low flow) to 84 NTU (high flow). Typically, the Mississippi River has higher turbidity concentrations than Barataria Bay (10 NTU to 40 NTU).

The Future With Project is anticipated to add high-flow Mississippi River waters to Barataria Basin that would have higher suspended sediment concentrations, contributing substantial suspended sediment loads and elevated turbidity at and adjacent to the diversion outflow and throughout the southern half of Barataria Basin (Figure 6.5.2-1). During operations, turbidity adjacent to the diversion outflow is anticipated to increase 50% to 200%, to a maximum of $\leq$ 375 g/m^3 TSS. TSS are expected to be elevated throughout the mid- and lower basin, with levels of TSS decreasing in magnitude with distance from the diversion. Along the barrier islands, negligible changes to turbidity are anticipated due to the Project.

Increased turbidity can have consequences to plants and animals present, such as smothering of benthic vegetation and invertebrates, reduction of DO levels, and species displacement from highly turbid areas. Increased turbidity may reduce light transmission into the water column, thereby reducing the water depths where SAV can thrive. In addition, aquatic vegetation may be buried or growing shoots may be covered with sediment, thus reducing or preventing photosynthesis. Prolonged exposure to these effects may make habitat unsuitable for vegetation. Increased turbidity and sedimentation can affect normal fish behaviors (including ability to feed, move, and/or shelter). Fish can experience injury from sediment abrasion on gill surfaces, and highly turbid waters may diminish the ability of fish to detect prey or predators.

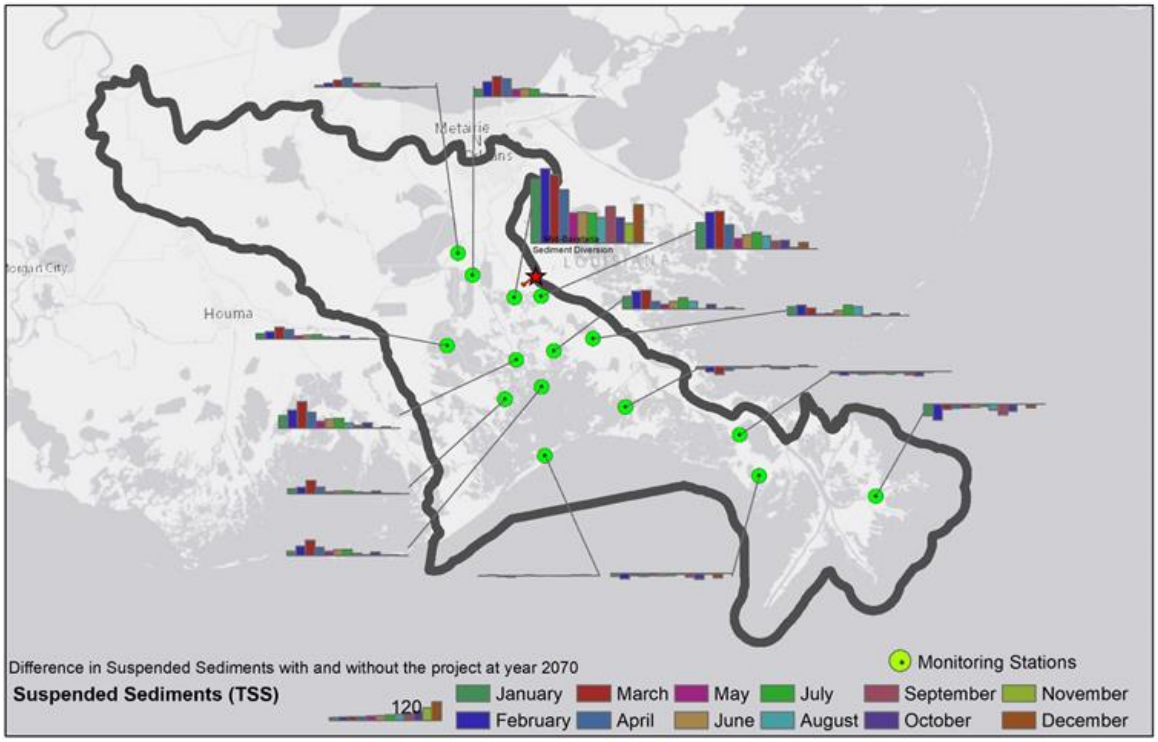


Figure 6.5.2-1. Effects of the Future with Project on Suspended Sediment in 2070 in Barataria Basin, Compared to the Future without Project

6.5.3 Potential Effects on Sediment Deposition and Wetland/Marsh and Mudflat Creation

The purpose of the Project is to restore deltaic processes in the Barataria Basin. By causing sediment deposition, areas that are currently or would otherwise become open water may become or remain terrestrial, or wetland/marsh, or shallow water habitats.

The Project is predicted to create a net increase of about 13,400 acres of emergent habitat by the year 2070. Without the Project, the Barataria Basin is estimated to have continued wetland loss declining from an estimated 326,396 acres of emergent habitat area in 2020 to about 52,077 in 2070 (Table 6.5.3-1). With the Project, the total amount of emergent habitat area in 2070 is estimated to be about 65,477 acres. There are differences in the characteristics of the wetland habitat, with the wetland area maintained or created by the Project being mostly intermediate salinity marsh while without the Project most of the marsh retained would be brackish. Total marsh habitat (excluding SAV) is estimated to increase by approximately 9,800 acres more with the Project compared to the future without the Project (Table 6.5.3-2). Operation of the diversion is projected to build new land and also increase the elevation of existing marshes or sediment beds (Carle et al. 2015).

Submerged aquatic vegetation is also projected to be positively affected by the Project. In the FWOP, SLR is predicted to decrease SAV throughout the lower basin, with SAV declining with increasing depth and decreasing light availability. In the FWP, as the Project creates land and additional shallow water habitat beneficial to SAV, it is projected to decrease SAV loss as a result of the Project. SAV was evaluated using multiple approaches; however, the premise of the SAV Likelihood of Occurrence Model (SLOO) (DeMarco et al. 2018) is believed to be the most representative data for this project. Without the project, SAV is projected to decline from approximately 9% of the basin area to 2% over the 50-year evaluation period. As a result of the project, this model approach indicates that the area suitable for SAV is about 2% (1,500 acres) higher in the fresh/intermediate portion of the Project area at the end of the Project life (USFWS 2020). The Delft3D Basinwide Model SAV outputs were not used, as the data were deemed unreliable by the Delft3D Basinwide Modeling Work Group.

As the project would seasonally decrease salinities in the mid-basin, species composition of SAV in the mid basin would likely change. Operation of the proposed Project would likely result in increased habitat suitability for SAV species in the Barataria Basin that thrive in or tolerate intermediate to fresh water, while decreasing the habitat suitability of those that are adapted to more saline waters. Aquatic vegetation in general is more diverse and abundant in low-salinity habitats (Hillmann et al. 2016a), which would likely benefit from the Project.

Table 6.5.3-1. Summary of Emergent Habitat (Vegetated Wetlands and Mud-flats) within the Action Area

Scenario	2020 (Acres > 0.04 m*)	2030 (Acres > 0.13 m*)	2040 (Acres > 0.25 m*)	2050 (Acres > 0.39 m*)	2060 (Acres > 0.54 m*)	2070 (Acres > 0.72 m*)
FWOP	n/a	298,270	249,264	186,135	115,891	52,077
FWP (75K CFS)	n/a	304,533	262,058	203,394	132,291	65,477
Net Gain with Project	n/a	6,263	12,793	17,259	16,401	13,400
* Land building is reported as the number of acres above the given elevation relative to NAVD88, as chart datum changes in response to sea level rise.						

Table 6.5.3-2 Summary of Predicted Marsh Habitats within the Action area

Aquatic Vegetation Type	Predicted Marsh Habitat (acres)					
	Cycle 0	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5
	2020-2029	2030-2039	2040-2049	2050-2059	2060-2069	2070
FWOP						
FWOP Brackish	80,969	73,217	55,635	29,069	11,972	6,352
FWOP Fresh + Intermediate	278,081	263,712	228,253	189,589	130,924	66,396
FWOP Saline	70,923	44,900	28,651	16,478	6,967	6,454
Total	429,973	381,829	312,539	235,136	149,863	79,202
FWP						
FWP Brackish	68,637	57,918	34,037	20,461	5,804	3,219
FWP Fresh + Intermediate	313,995	304,926	273,240	219,914	153,215	79,526
FWP Saline	47,367	23,062	16,533	11,308	7,335	6,248
Total	429,999	385,906	323,810	251,683	166,354	88,993
Difference (FWP-FWOP)						
FWP Brackish	(12,332)	(15,299)	(21,598)	(8,608)	(6,168)	(3,133)
FWP Fresh + Intermediate	35,913	41,213	44,987	30,324	22,292	13,130
FWP Saline	(23,555)	(21,838)	(12,118)	(5,170)	367	(206)
Total	**26 (+<1%)**	**4,077 (+1%)**	**11,271 (+4%)**	**16,547 (+7%)**	**16,491 (+11%)**	**9,791 (+12%)**

6.5.4 Project Effects on Nutrients and Dissolved Oxygen

The Project will contribute nutrients from the Mississippi River to the Barataria Basin. There are indications that the Barataria Basin may be nutrient limited in areas and/or at certain times of year, suppressing aquatic plant growth (Turner 2017). Studies (e.g., Neupane 2010) indicate concentrations of nutrients in Barataria Basin are likely to increase for nitrite, nitrate, total phosphorus, and organic nitrogen. The addition of nutrients may release this nutrient control and support primary productivity, leading ultimately to a minor drawdown of DO resources.

Multiple studies have identified the effect of bottom-up increases in consumer biomass from increased nutrients (de Mutsert 2010, Nixon and Buckley 2002). Nixon and Buckley (2002) reviewed field experiments and observations of nutrient input into Scottish lochs, the Baltic Sea, and the North Sea, and determined that there are strong correlations between primary production and the yield of fish and stranding crop of benthic macrofauna in phytoplankton-dominated marine ecosystems, where the input of inorganic fertilizers resulted in the "enhancement of benthos" and increased growth rates in fish. Therefore, impacts on fauna from nutrient loading could also result in major, permanent, and beneficial impacts on fauna within the Barataria Basin.

Under the Future Without Project scenario, there is no directional change in DO over time. When operating, the Future With Project is predicted to minimally decrease DO concentrations immediately adjacent to the diversion outfall; this is correlated with high turbidity, nutrient enrichment, and increased primary productivity at certain times of year.

The Project is anticipated to have very little effect on DO concentrations upgradient of the diversion (Figure 6.5.4-1). Although the Future With Project is predicted to minimally lower DO throughout the basin, the lowest DO concentrations predicted are about 6.0 mg/L, within the tolerance range of most organisms. However, the model is not designed to capture episodic low DO events that may occur in isolated locations such as canals.

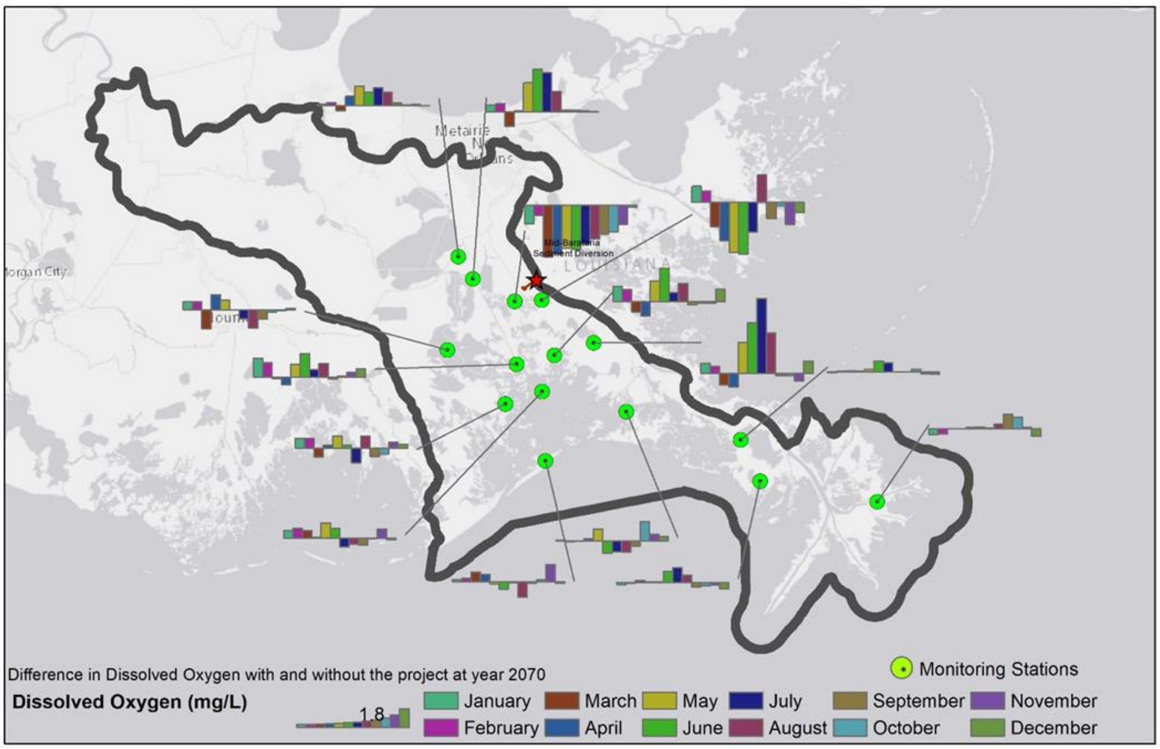


Figure 6.5.4-1. Effects of the Future With Project on Dissolved Oxygen in 2070 in the Barataria Basin, Compared to the Future Without Project

Diversion operation will divert nutrients into Barataria Basin and decrease nutrient inputs from the Birdfoot Delta into the northern Gulf of Mexico. We assume these effects in the Gulf of Mexico are indirect effects and, although they may be measurable, they are not meaningful changes. Therefore, these effects will not be analyzed further.

6.5.5 Project Effects on Water Quality/Contaminants

Water diverted from the Mississippi River has the potential to contain contaminants either from upstream sources or due to accidental releases into the river. The potential for contaminant introduction can be evaluated by reviewing findings from other Mississippi River diversions.

LDWF indicated that contaminant levels in the Caernarvon outfall were not significantly different post-diversion compared to pre-diversion (LDWF 2010). At Davis Pond Diversion, analysis of contaminants in biota showed lower levels of contaminants when sampled 6 years post-diversion compared to pre-diversion samples (Jenkins et al. 2012). These studies indicate the potential for negligible effects to fauna from the influx of water from the Mississippi River.

In contrast, water samples at Caernarvon indicated a potential for impacts on water quality; however, these effects were likely limited due to rapid assimilation of TSS, which were elevated for a short distance from the diversion (Lane et al. 1999). LDWF indicated that, as a result of USFWS monitoring, contaminant levels in the Caernarvon outfall were not significantly different post-diversion compared to pre-diversion (LDWF 2010). For the Davis Pond Diversion, analyses of several contaminants in biota tissues showed lower levels 6 years post-diversion than in pre-diversion samples, and lower than in samples from the Mississippi River, and no gross abnormalities in skeletal, skin, or internal morphology were noted in collected fish (Jenkins et al. 2012). The MBSD has a much larger potential flow rate than other diversions that have been measured and since the diversion has a goal of transporting sediment into the Barataria Basin, it is likely that river contaminants will be introduced to Barataria Basin. These contaminants are likely to be associated with the zone of sediment deposition. Although these studies imply negligible impacts on fauna from the influx of river contaminants, the significantly larger outflow of the proposed diversion may result in increased contaminant levels in biota.

6.5.6 Project Effects on Water Temperature

Under the Future Without Project scenario and in response to a warming global climate, water temperatures throughout Barataria Basin are anticipated to increase over time, with changes being most pronounced in the winter months (up to a 3 °C increase, as predicted by the Delft3D model). The analysis of effects of the Future With Project below include the influence of predicted conditions in Future Without Project trajectories and trends, as they would continue to exert their influence.

Compared to the Future Without Project, the Future With Project would divert predominantly colder flows from the Mississippi River into the Barataria Basin. Annual river temperature in the Mississippi River ranges from 6.6 °C to 30.0 °C, while the average water temperature in Barataria Basin ranges from 16 °C to 30 °C. The temperature differential between the Mississippi River and Barataria Basin is the highest between February and May, with model results predicting a maximum of 6.6 °C differential adjacent to the outfall during cycle 3 (2040 to 2050). Although temperature differentials would quickly decrease as the inflowing river waters mix into the bay, and the effects of the colder waters would decrease with distance from the outfall, the potential for faunal stress and mortality may increase during initial opening of the diversion each year, as well as in areas near the outfall during the winter. Winter and early spring temperature changes may result in changes in bioenergetics and avoidance of the outfall area (and other colder areas) by fauna. Changes in temperatures would be most apparent mid-basin (including Stations HWQ-08, CRMS 0726, B. Waterway, USACE 82875, and B. Bay North GI; see Figure 4.4-4), where temperatures are predicted to decrease more than 3 °C from the Future Without Project between December and April initially, and into May during the last 2 decades of operation. An overview of predicted temperature trends over time within the basin is shown in Figure 6.5.6-1

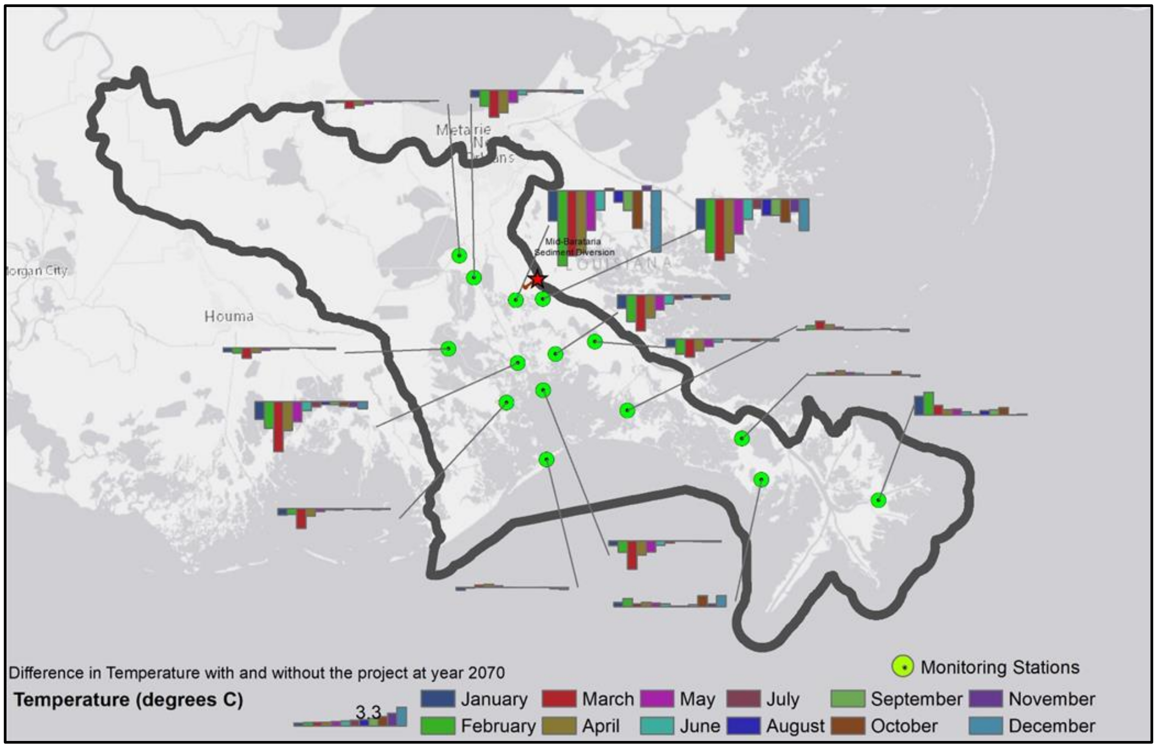


Figure 6.5.6-1. Effects of the Future With Project on Temperature in 2070 in Barataria Basin, Compared to the Future Without Project Scenario

6.5.7 Project Effects on Habitat Area

The Project will transport large annual volumes of sediment-laden water into the Barataria Basin. The settlement and deposition of sediment from the water column is expected to maintain or create wetland and upland land areas that are above MLLW. By 2070, the water levels are predicted to be about 0.72 meter above 0.0 meter NAVD88. While there are currently about 333,695 acres of land above 0.0 meter NAVD88, the amount of wetland and land is predicted to decrease over time for both the Project and the Future Without Project scenarios. By 2070 there are predicted to be about 52,077 acres of land under the Future Without Project and 65,477 acres under the Project. Therefore, the Project is expected to generate or maintain about 13,400 acres of land that would otherwise be converted into aquatic habitat.

In addition to potential direct effects to wetland area, there is a complex relationship between the soil strength and freshwater and sediment inputs from freshwater diversions. When the shear stress exceeds soil strength, as occurs during storms and wind wave events, wetland soils can be washed away. Large losses of wetland area attributed to soil strength weakness occurred during the 2005 hurricanes Katrina and Rita (Howes et al. 2010). Shallow rooting or weak layers in the soil profile could contribute to reduced soil strength. It is unclear how and whether a freshwater diversion affects soil shear strength (Teal et al. 2012).

6.5.8 Project Effects on Water Movement and Flow

Increased freshwater flows into the estuaries are expected to more strongly influence currents and circulation in the basin, with effects diminishing with distance away from the outfall. Flow conditions for the Project are shown by the orange line (75k) in Figure 6.5.8-1.

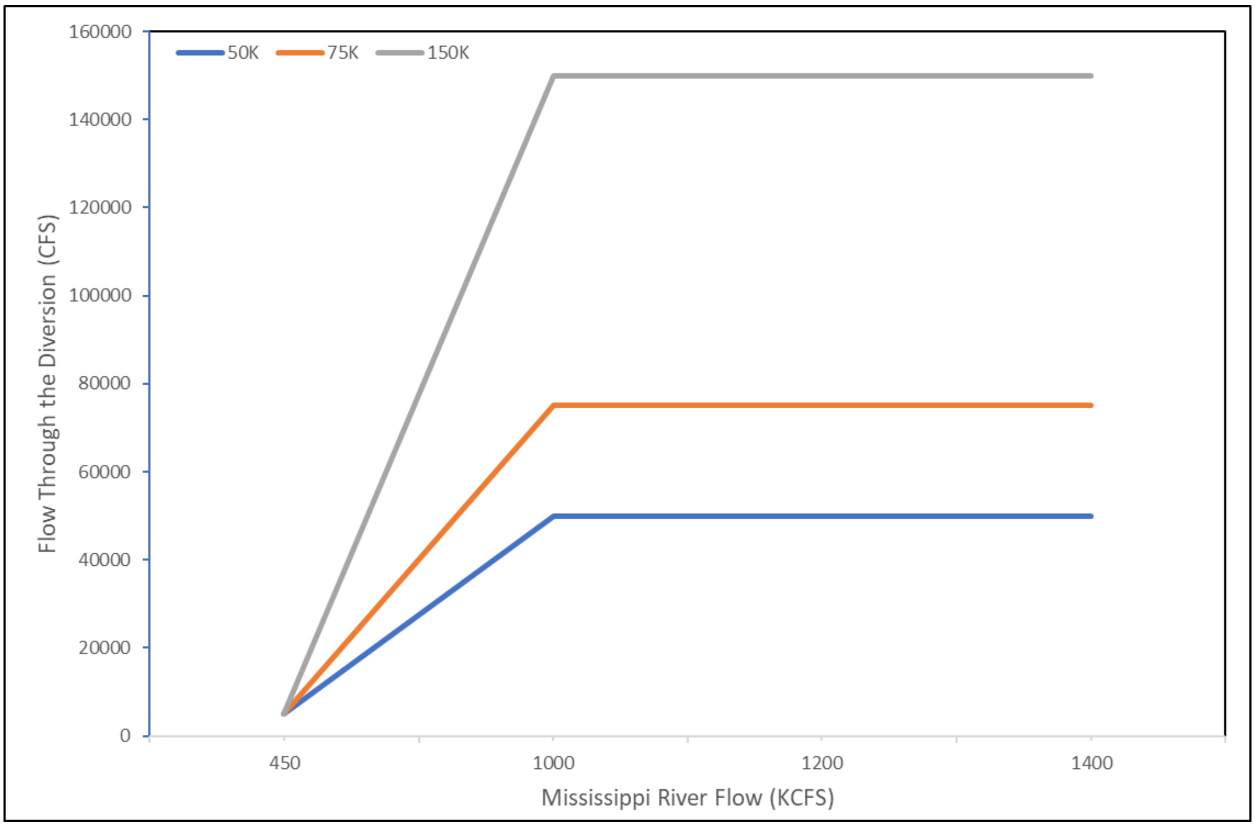


Figure 6.5.8-1 Comparison of Flow through Diversion at Various Mississippi River Flow Rates based on Mississippi River Flow at Belle Chase

Development of the Project will create a new net outflow of freshwater from the outfall to the barrier islands. This outflow could affect movement of water masses and passive organisms that rely on the movement of water. A detailed comparison of flow conditions was undertaken using the Delft 3D model outputs (TWI 2019). The comparison focused on locations where potential effects to currents from diversion operations would be most evident, namely channels and passes where existing flow velocities are the highest (Figure 6.5.8-2). Velocity magnitude was determined for peak flood, slack, and peak ebb tides with diversion operating above baseflow and diversion operating at base flow for Future With Project compared to Future

Without Project scenarios. Time series plots showing velocity magnitude and direction were also developed for both scenarios at the main channels and passes.

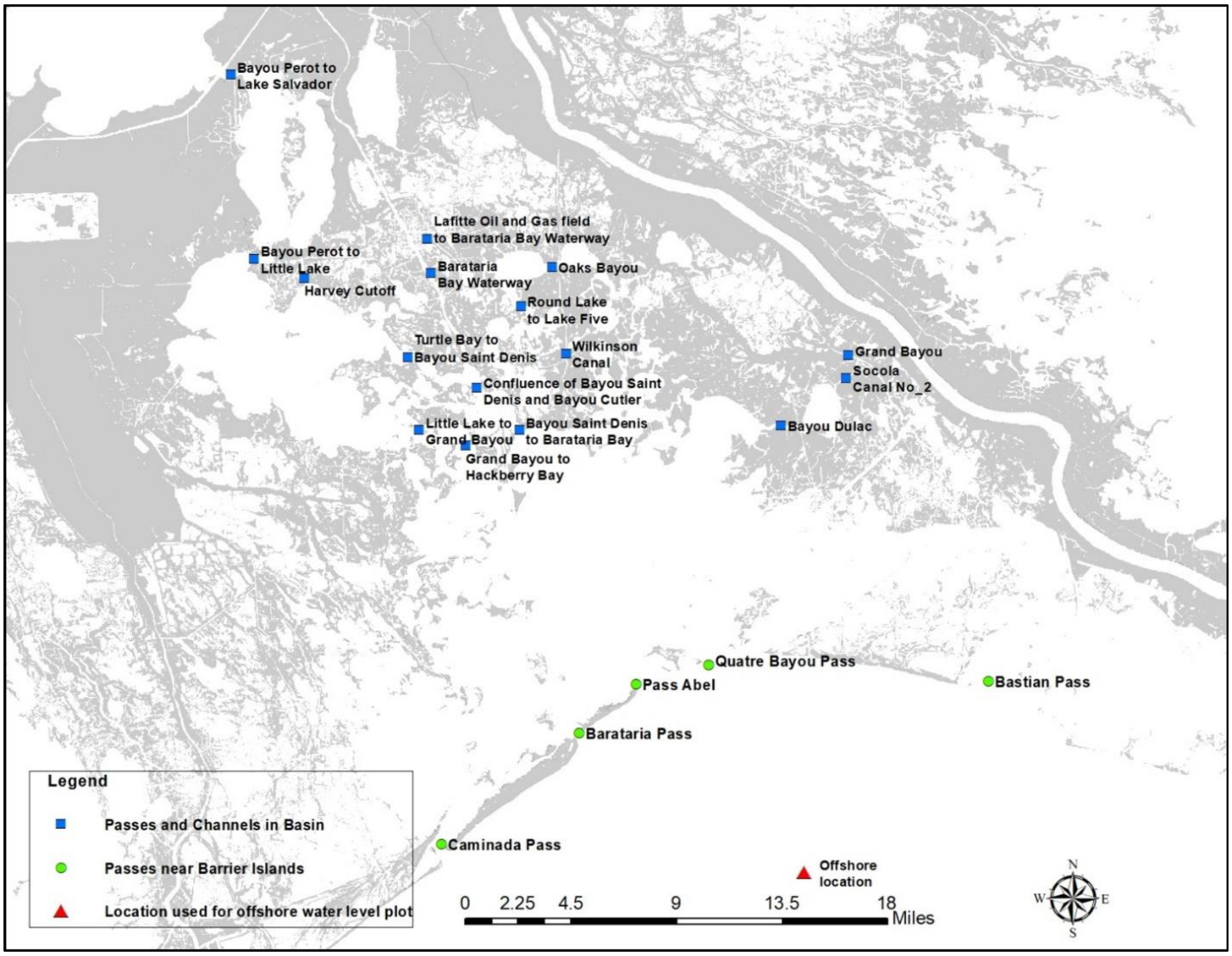


Figure 6.5.8-2. Barataria Basin Channels and Passes Evaluated

The following categories of results were observed from analysis of currents in the Barataria Basin passes and channels:

- The passes and channels closest to the outfall (Oaks Bayou, Barataria Waterway, Round Lake to Lake Five, Lafitte Oil and Gas Field to Barataria Waterway) generally are modeled to have unidirectional outflow while the diversion is operating at mid flow levels and higher (>20k cfs) (Figure 6.5.8-3). Out-flow is generally the dominant signal and the model results do not show much return flow except during larger tidal exchanges. During diversion base flow of 5k cfs, the tidal signal returns and flow vectors go in both directions and at similar velocities between Future With Project and Future Without Project scenarios (Figure 6.5.8-4).

- In the interior passes and channels slightly farther from the outfall (Wilkinson Canal, Turtle Bay to Bayou Saint Denis, Confluence of Bayou Saint Denis and Bayou Cutler), tidal flow is evident in both directions, generally similar between Future With Project and Future Without Project (Figure 6.5.8-5). However, during smaller tides, flooding tides are sometimes suppressed by outflow. Generally, there is a decrease in velocity of the flood tide in the Future With Project versus Future Without Project scenario while the diversion is operating. Under base flow conditions, flow direction and magnitude are similar in both scenarios (Figure 6.5.8-6).

- The interior passes farther away from the outfall (Little Lake to Grand Bayou, Bayou Saint Denis to Barataria Bay, Grand Bayou to Hackberry Bay) have flow directions similar between Future With Project and Future Without Project scenarios during both smaller and larger tides, but also show slightly reduced velocities for flooding tides (Figure 6.5.8-7). Under base flow conditions flow direction and magnitude are similar in Future With Project and Future Without Project scenarios (Figure 6.5.8-8).
- The passes and channels at the barrier islands (Barataria Pass, Bastian Pass, Caminada Pass, Pass Abel, and Quatre Bayou Pass) have flow directions and magnitudes that are similar between both scenarios under all conditions from baseflow of 5k to 75k full diversion operation (Figure 6.5.8-9).

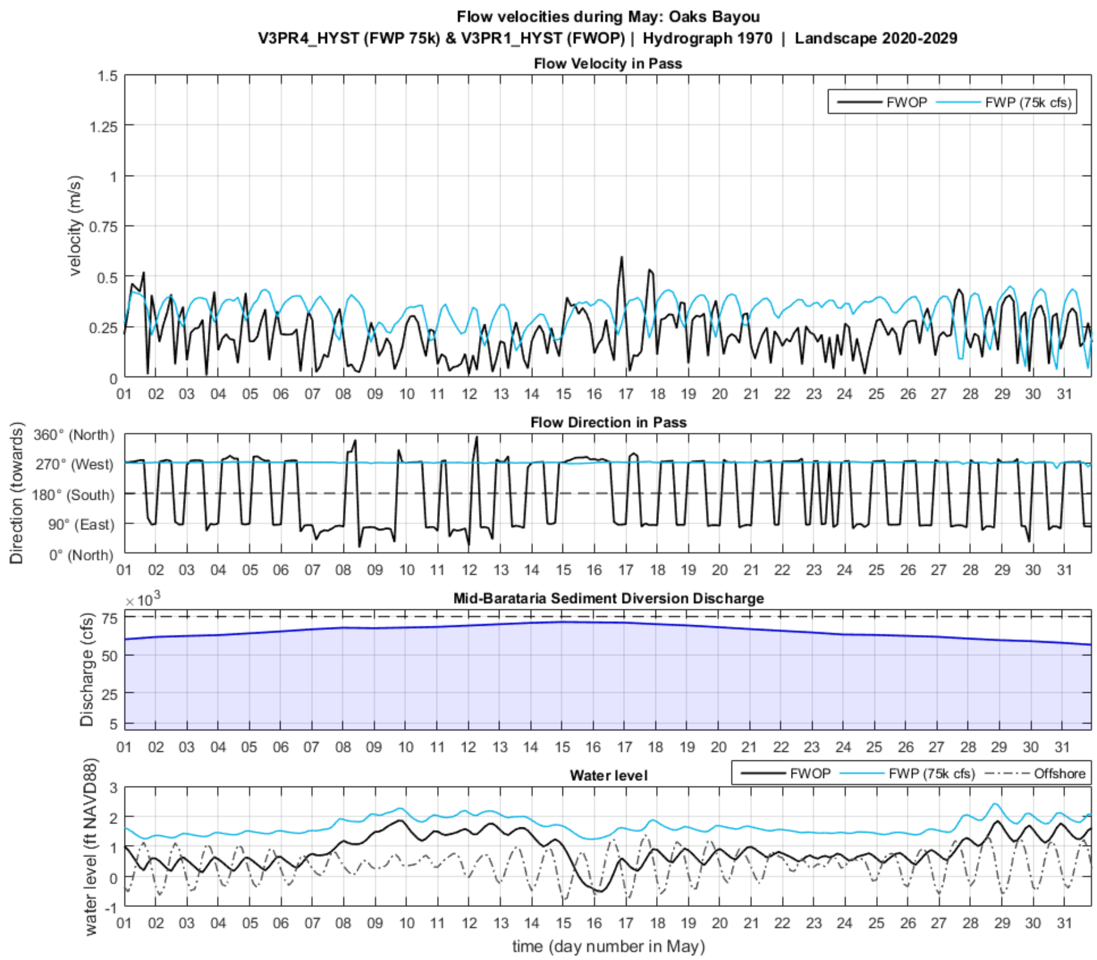


Figure 6.5.8-3. Representative Channel (Oakes Bayou) Near Diversion Outfall with Diversion Operating at ~75,000 cfs

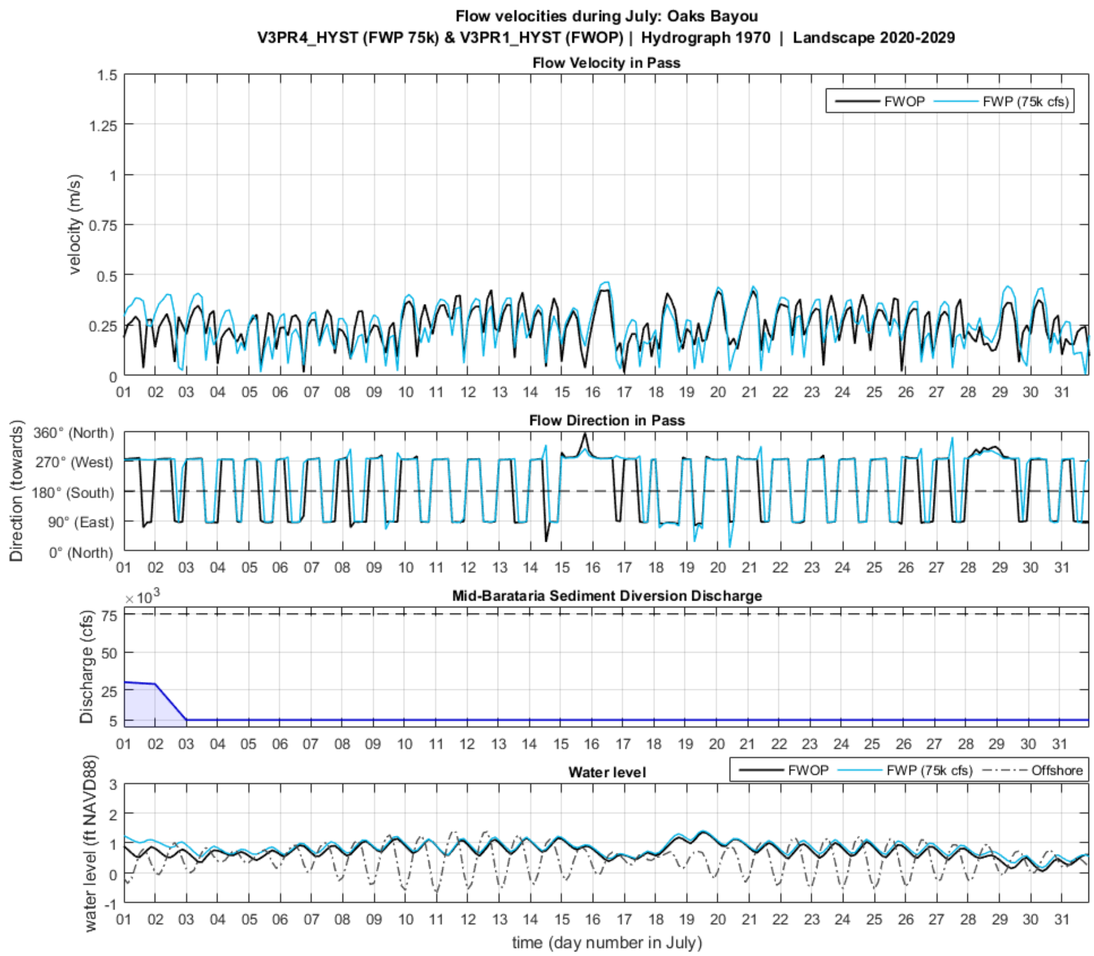


Figure 6.5.8-4. Representative Channel (Oakes Bayou) Near Diversion Outfall with Diversion Operating at Baseflow of 5,000 cfs

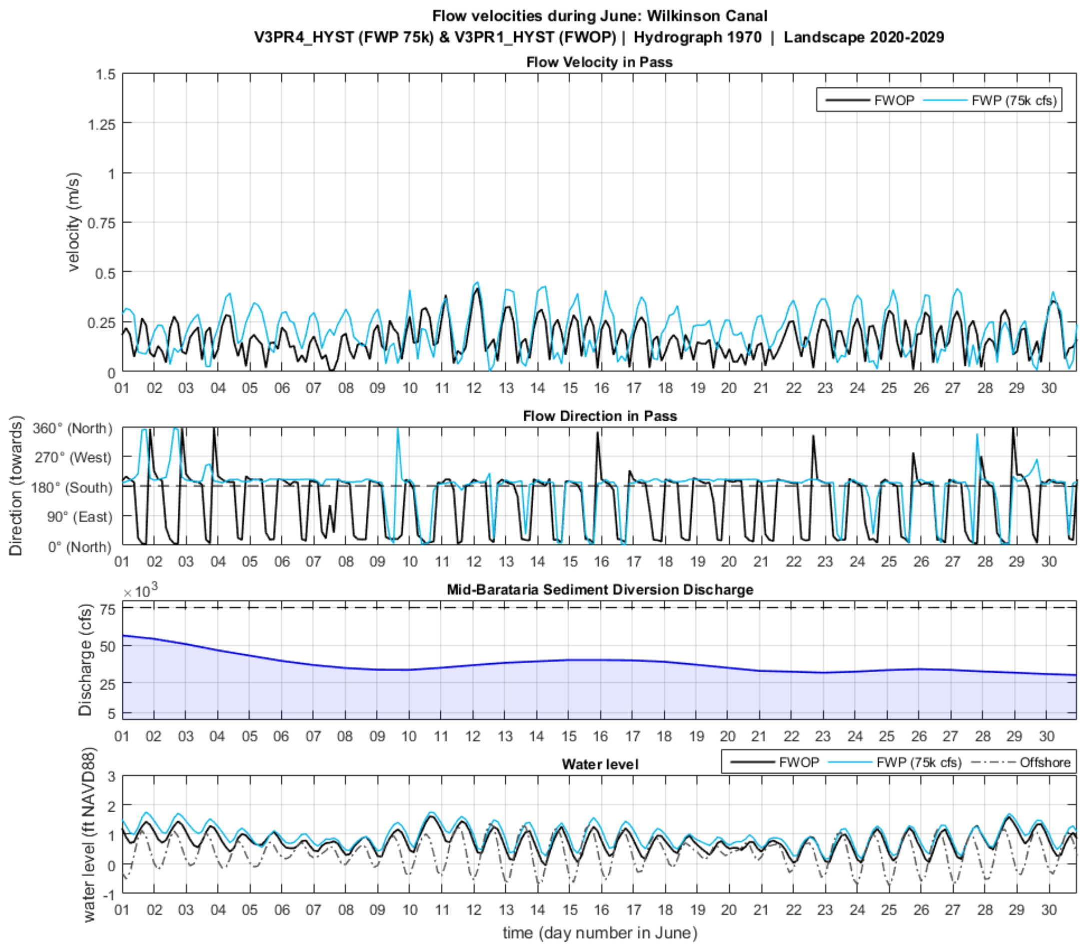


Figure 6.5.8-5. Representative Channel (Wilkinson Canal) Mid-Distance from Diversion Outfall with Diversion Operating between 25,000 and 50,000 cfs

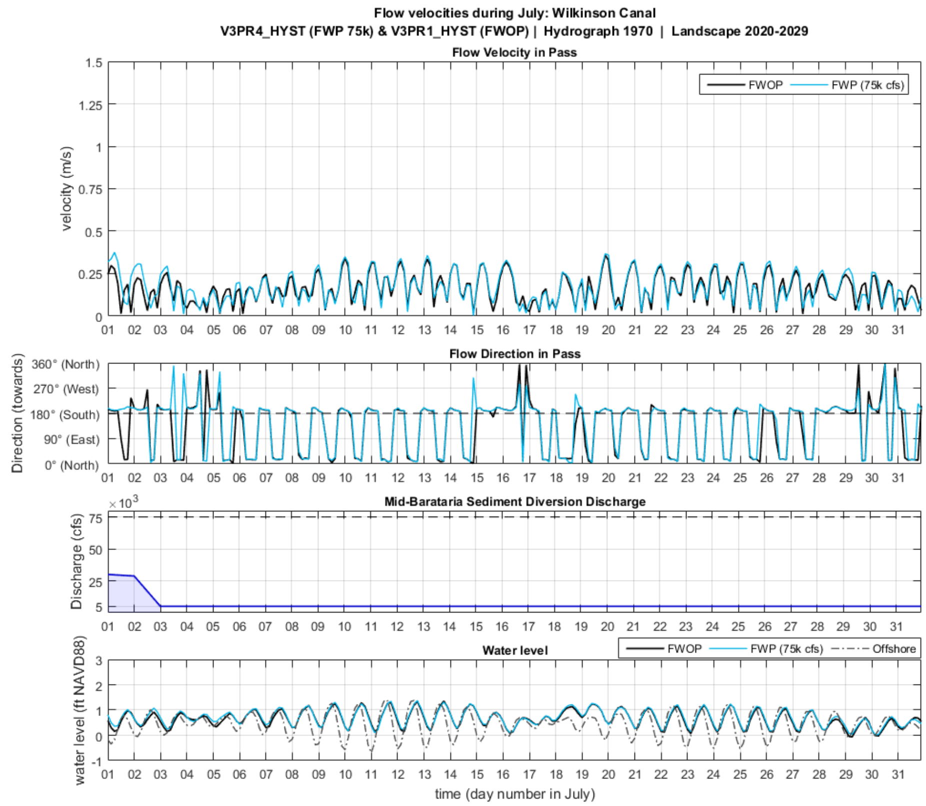


Figure 6.5.8-6. Representative Channel (Wilkinson Canal) Mid-Distance from Diversion Outfall with Diversion Operating at Baseflow of 5,000 cfs

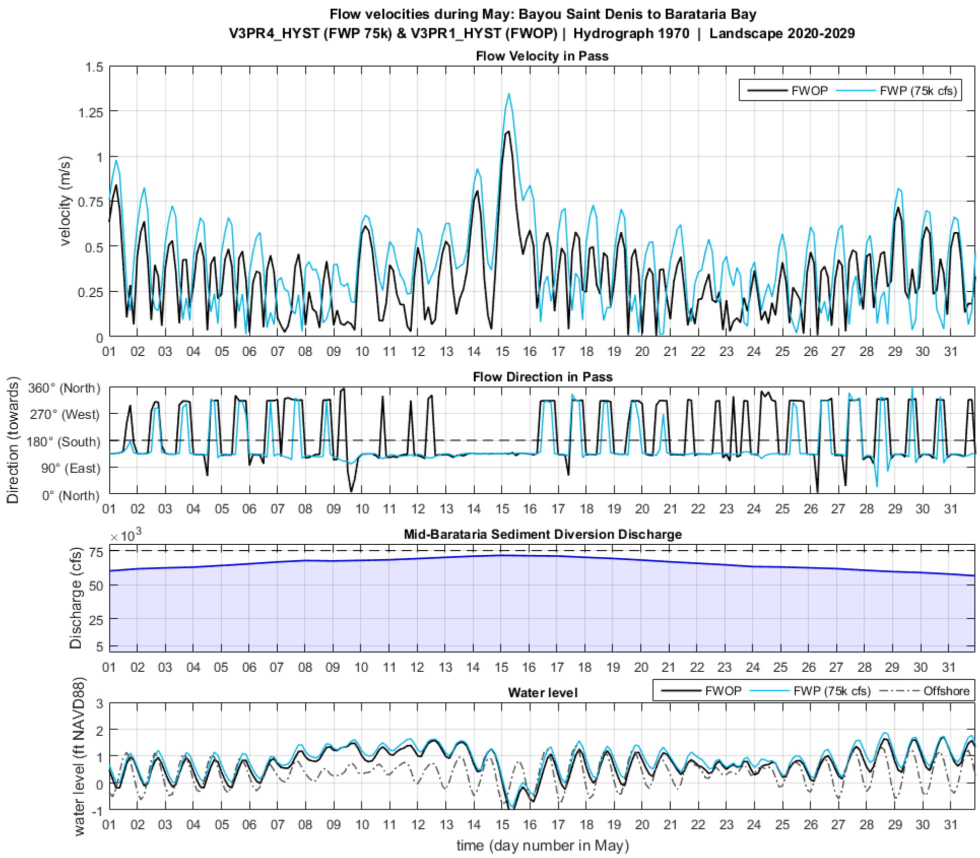


Figure 6.5.8-7. Representative Channel (Bayou Saint Denis to Barataria Bay) Distant from Diversion Outfall with Diversion Operating at 50,000 to 75,000 cfs

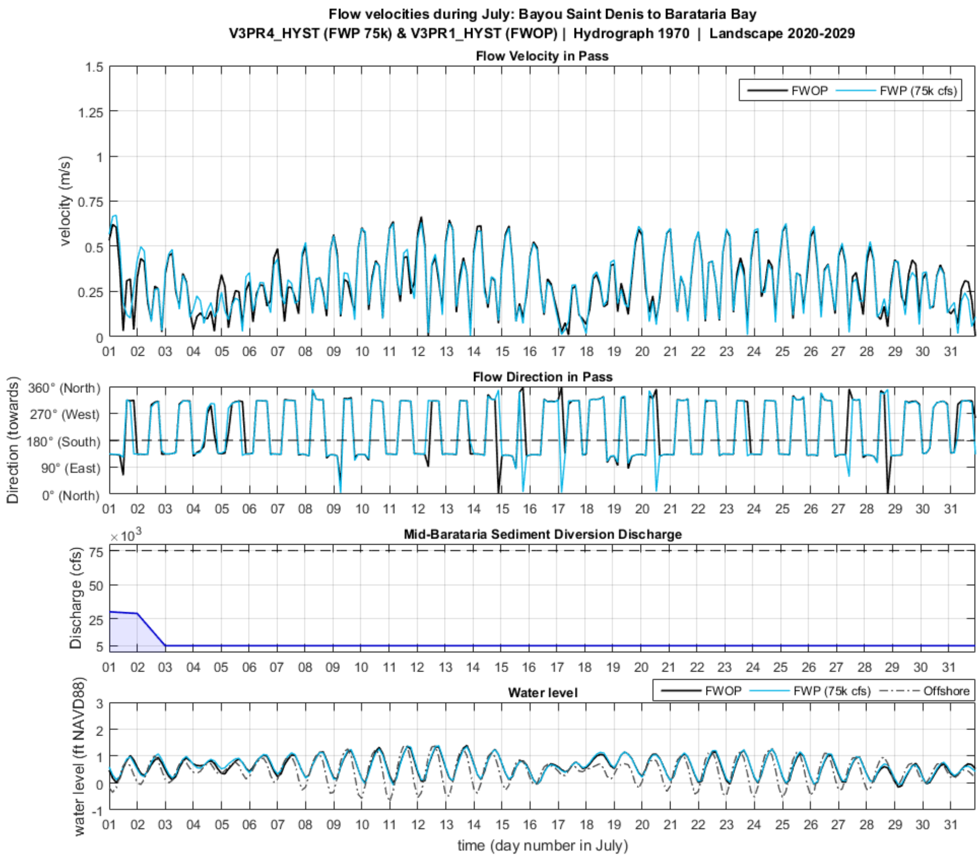


Figure 6.5.8-8. Representative Channel (Bayou Saint Denis to Barataria Bay) Distant from Diversion Outfall with Diversion Operating at Baseflow of 5,000 cfs

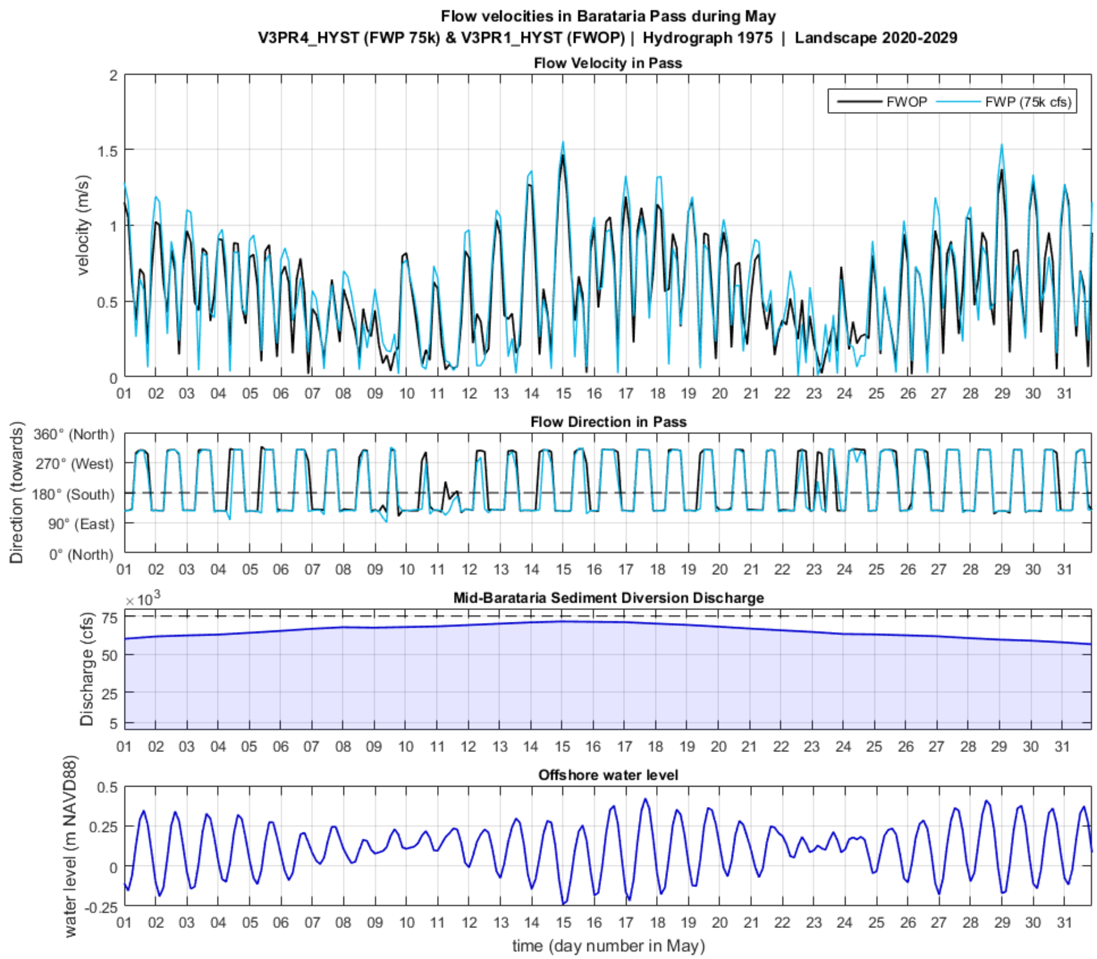


Figure 6.5.8-9. Representative Barrier Island Pass (Barataria Pass with Diversion Operating at 50,000 to 75,000 cfs

6.5.9 Project Effects on Prey Base and Food Web

Effects on Prey Base

Rose et. al. (2019) analyzed previously derived outputs from 2 food web modeling platforms for the Mississippi River Delta region, the CASM model and the Ecopath with Ecosim (EwE) model (see Section 6.3.2), as well as a suite of model-derived ecosystem indicators to illustrate the structure and energy flows of the Barataria Basin aquatic food web. This study indicated the following:

(a) detritus plays a very important role in fueling the food web;

(b) increased productivity in the spring is channeled up the food web through a relatively few pathways and species compared to the rest of the year;

(c) energy flows up the food web but quickly dissipates within the first few trophic levels with a lot of consumers eating several of the lower trophic levels (plankton, algae, infauna) as well as small shrimps, crabs;

(d) the Barataria Basin food web is relatively complicated and provides many potential pathways for energy to flow to consumers; and

(e) because of the redundancy of pathways, the food web shows a high degree of resilience.

Rose et al. (2019) also suggested that spring inputs of freshwater and nutrients into Barataria Bay from the Mississippi River stimulate primary and secondary production in the spring and summer. Higher than average nutrient inputs likely contribute to seasonal increases in high biomass, low trophic level species such as shrimps and crabs, and small planktivorous fish species such as bay anchovy and gulf menhaden. These species groups are important to inshore fisheries and serve an important ecological role, as they facilitate energy transfer to higher trophic level consumers and predators. Environmental changes, or changes in the supply of nutrients, therefore have the potential to alter the seasonal production of these high biomass, low trophic level consumer groups, such as shrimp, anchovy, and gulf menhaden. Spring and early summer operations of the Future with Project have the potential to show the largest responses in the food web in and around the diversion outfall transition feature. The changes in the abundance of phytoplankton, phytobenthos, and detritus predicted under this action may result in changes to high biomass prey species (for example juvenile brown shrimp, crabs, and small forage fish).

Biomass within the Barataria Basin food web is lower in the higher trophic levels, and predatory fish abundance is unlikely to be food-limited (Rose et al. 2019). Numerous and redundant food web connections may reduce the impact of severe food limitation for predators even if important prey groups are disturbed or eliminated because many of the species are opportunistic, trophic generalists that are likely to shift their target prey items. However, individual species or groups of similar species in the food web can still be affected (some being reduced), and resiliency depends on the type (where it impacts the food web and how), magnitude, duration, and repetitiveness of the disturbance. A large-magnitude disturbance that impacts phytoplankton, phytobenthos, and detritus and occurs over a prolonged period and repeatedly over years—as would be the case under the Future with Project—could have large implications on the food web. However, it is likely that the food web, having numerous and redundant web connections that involve lower trophic levels, could adjust for a disturbance that impacts only a portion of the low trophic level species. Therefore, even if minor to moderate changes in the lower trophic level biomass is detected under prolonged operation of the Future With Project, a detectable response in a predator's response to these food web changes may be difficult to discern.

With increased salinity and water levels, and more open water in Barataria Bay, some general shift from the existing species assemblages and relative abundance of fauna throughout the basin is expected. The system will likely shift to support more coastal and marine species (for example, snappers and mackerels) and away from more freshwater fauna (for example, bass, sunfish, and catfish) with salinity encroachment continuing into the estuary. Unless the converted open waters remain shallow enough to support SAV establishment and growth in place of the lost marsh, the production of shrimp, crab, and estuarine fishes like minnows, killifish, pinfish, seatrout, croaker, and drum that rely on vegetated habitats in the estuary, particularly as juveniles, will decline (LaPeyre and Gordon 2012, Castellanos and Rozas 2001, Ault et al. 1998, Minello et al. 1989, Browder et al. 1989, Turner et al. 1988). This shift in species assemblage and lost production would be a major, permanent and indirect impact of the Future Without Project.

Effects on the Food Web

The following information is a summary of the key findings on existing food web dynamics in Barataria Basin and how the structure of the food web may or may not be resilient to change. Both the EwE and CASM models support a conclusion that detritus serves as an important part of the base of the Barataria Basin food web (Rose et al. 2019; Figure 6.5.8-1**Error! Reference source not found.**). Detritus can be generated in many ways in a food web. It can come from marsh plants and remain in the system for weeks to months before being consumed or slowly decaying. It can also come from phytoplankton, which is rapidly produced, and what is not consumed becomes detritus. Because there are multiple sources of detrital material, there is a buffering effect for disturbance at higher trophic levels. For example, the presence of marsh habitat will provide detrital material even when changes in light, nutrients, or other factors may limit primary production and reduce the generation of detritus from phytoplankton sources. Several key species in Barataria Basin (e.g., Penaeid shrimp, blue crab) depend on detrital food sources and may be more protected from potential food web disturbances if there is a persistence of freshwater sources or an adjacent marsh production of detritus, even if there is a reduction in production and decay of the phytoplankton in Barataria Basin.

Rose et al. (2019) also report on a comparison of EwE model results that predict primary productivity between high-flow (June) events and low-flow (October) events. The results of this analysis indicated that the food web responds positively to spring peaks in primary productivity from high-flow events (Rose et al. 2019). The model results describe a pathway that makes efficient use of primary production that then supports a high biomass of other species. For example, the response of Penaeid shrimp, bay anchovy, and Gulf menhaden is positively correlated to spring phytoplankton blooms. The model results also indicate that the food web is stable, even under conditions of low or high salinity, based on the lack of variability in biomass in years with extreme conditions.

Both the EwE and CASM models agreed that the Barataria Bay food web is bottom-up controlled and relatively truncated (Rose et al. 2019). For example, the average trophic pathways do not have many levels (i.e., there are relatively few steps to get from detritus to adult red drum). This indicates that the food web is highly responsive to changes in environmental conditions (as described in section 6.7 in terms of the changes in Habitat Suitability Index (HSI) but is also based on a low-trophic structure with high turnover rates. In other words, there is not much predator biomass compared to other forms of energy, and the food web is built from species that have short life cycles (e.g., phytoplankton, zooplanktons, forage species). Therefore, the response of the food web can be rapid, the food web is composed of species with high growth rates (1 to 2 years) that concentrate energy quickly, and the food web is resilient to disturbance. The models also agreed that fish population was not limited by the amount of food availability, but rather by high rates of mortality from recreational and commercial fishing, which again emphasizes the bottom-up structure of the food web.

Finally, the Barataria Basin food web has many potential pathways to transfer energy (Rose et al. 2019). The system does not depend on one species or group of species to support the food web, but rather contains many generalist feeders that are able to utilize several different food sources. This is another indication that the Barataria Basin food web may be resilient to disturbance because of the redundancy in energy pathways. Compared to other estuaries, the Barataria Basin appears to have a more diverse set of energy transfer pathways. For example, adjacent to the diversion outflow, phytoplankton production is predicted to decline because of the increase in suspended sediments and a decrease in light availability. In areas that experience a decrease in phytoplankton from diversion operations, the aquatic community may increase its reliance on a detrital food base from marsh habitat, and thus be buffered from diversion impacts on one part of the food web. In the mid- and lower basin, phytoplankton production is expected to increase due to an increase in nutrients. If phytoplankton production exceeds consumption, the excess phytoplankton may contribute to detritus and enter the food web through that pathway.

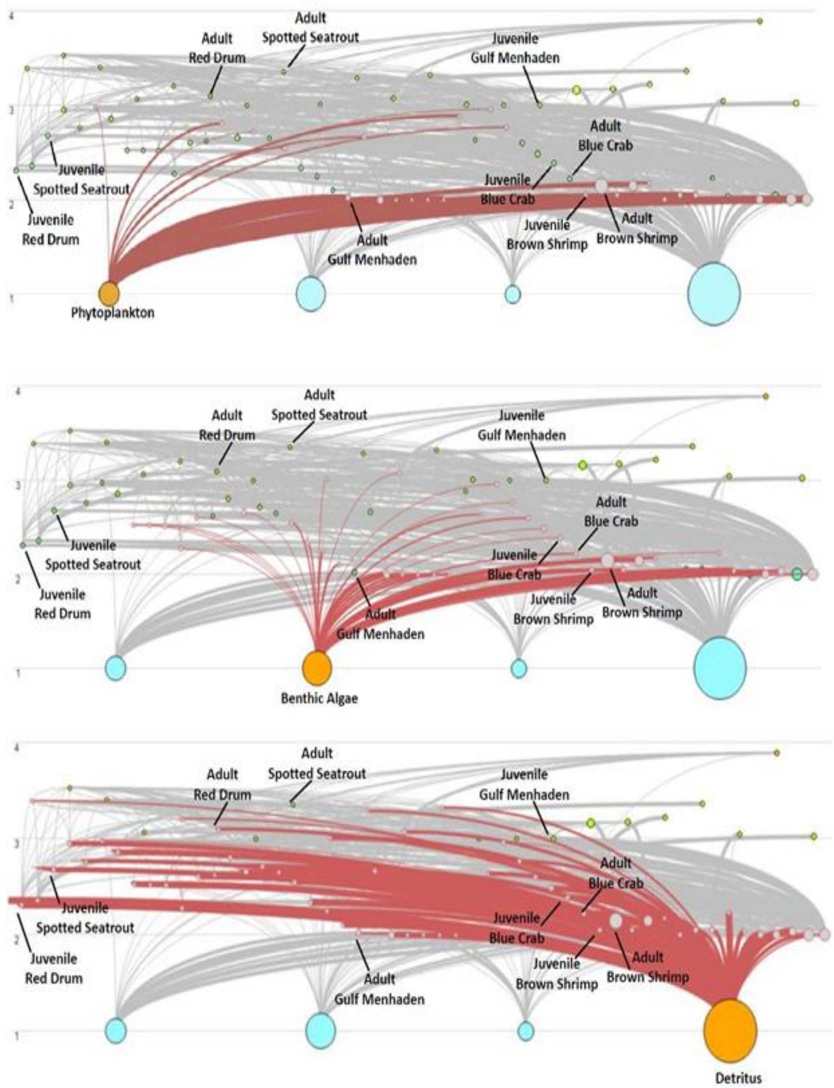


Figure 6.5.8-1. Energy Flow Diagrams from the Ecopath Base Model used in the Ecosim Calibration Simulation.
Source: Rose et al. 2019. Note that each line represents a food chain pathway in the model.

6.6 Project Effects to EFH

6.6.1 Estuarine Water Column Associated Habitat

Construction Effects

Construction will have potential temporary effects to turbidity and suspended sediments (Section 6.4.1). Turbidity in estuarine and coastal waters can have complex impacts to a wide range of organisms (Hirsch et al. 1978, Wilver et al. 2005). Increases in TSS reduce light penetration and therefore can potentially reduce primary productivity and phytoplankton production (Wiber and Clark 2001). Any reduction in productivity is expected to be localized and associated with the dredging, sediment placement, and piling installation activities. The duration would be comparable to the construction duration, with sediment disturbances which are anticipated to last about 2 months. Studies of increased turbidity indicate that adverse impacts to plankton communities are localized and of short duration (Armstrong et al. 1987, Vaiela 1995).

Increased turbidity can also reduce feeding efficiency, alter reproduction, and degrade habitat for juvenile and adult fish (Clarke and Wiber 2000).

Most or all of the dredged material will be used at BUP sites to establish or restore estuarine marsh habitat (Section 6.4.2). The ecological function of marsh habitat provides support to aquatic life in the region.

Operation and Maintenance Effects

The operation of the diversion will affect the water column throughout mid- and lower Barataria Basin. These effects are associated with the releases of fresh water, nutrients, and sediment from the Mississippi River into Barataria Basin. Effects of the diversion operations are variable through time because freshwater discharges from the diversion will be controlled by Mississippi River flow conditions.

Previous studies have investigated the impacts of salinity shifts on fish assemblages and biomass. For example, catch data for red drum and seatrout within the area of influence of the Caernarvon freshwater diversion showed an increase in the catch of these species post-operation including in areas with low salinity (LDNR 2003a, LDNR 2003b). Red drum were caught both below and above salinities of 5 ppt, while spotted seatrout were caught more frequently above 5 ppt. Furthermore, finfish biomass increased by 62% post-operation; though this increase could in part be due to increased biomass of freshwater species (LDNR 2001, LDNR 2003). In contrast, an analysis of fisheries-independent monitoring data showed no strong indication of changes in the abundance or distribution of 5 fishery species in Breton Sound from the Caernarvon diversion (Sable and Villarrubia 2011). Fishery-independent data collected to monitor the impacts of Davis Pond Freshwater Diversion found mixed results

(Plitsch 2014). For example, the CPUE for red drum and spotted seatrout was variable, but relatively stable before and after the diversion opening. Since the diversion opening, the Plitsch (2014) report shows red drum CPUE increased steadily for gillnets and electrofishing but decreased slightly in trammel nets and creel surveys. Similarly, there was an increase in spotted seatrout CPUE in gillnets and creel surveys, but a slight decrease in trammel nets and electrofishing. The Vermilion-Cote Blanche Bay system, which has a similar faunal assemblage as the Barataria Basin, received large pulses of freshwater in mid-summer 2015, January 2016, August 2016, and August 2017 due to high discharge events from the Atchafalaya and Vermillion Rivers. Seine and trawl data collected between 2015 and 2017 indicated that while some species were temporarily displaced or had delayed recruitment, these impacts were short-term with catch levels returning to average levels within the 2-year study (CPRA 2019).

Olsen (2019) notes that higher estuarine salinities are typically correlated with decreasing species diversity, and fresher estuaries correlate with a more diverse and even species assemblage. Many species present within the Barataria Basin have optimum salinity ranges that include salinities down to 0 ppt, and tolerance ranges that infer a certain level of adaptability to salinity regime shifts. Estuarine species will often use areas of very low salinity as predation refuge and can often adapt to salinity variability through osmoregulation or relocation, although both tactics require energy expenditure which could otherwise be used for growth. Therefore, these species (or species life stages) are not expected to be significantly negatively affected by altered salinity regimes and major, permanent, and beneficial impacts on species with lower salinity preferences may occur as saltwater intrusion into the Barataria Basin is curtailed. Species for which altered salinities are outside of the optimal range (for example, brown shrimp and seatrout) may experience moderate, adverse, and sporadic (temporary) impacts associated with areas predicted to experience significant drops in salinity while the diversion complex is open. However, as suggested by de Mutsert et al. (2012), this is expected to result in a movement of species to more suitable habitats (such as towards Grand Isle). However, while species presence and abundance may be influenced by salinity, these characteristics are ultimately driven by a more complex interaction of abiotic factors (such as a change in bioenergetics as a species is exposed to suboptimal conditions) and biotic factors. As noted by Olsen (2019), organisms are directly impacted by physical drivers such as salinity, but are also directly and indirectly affected by the interaction of salinity on other ecosystem features such as competition and predation.

Input of riverine water into Barataria Basin will also affect water temperatures as river water tends to be cooler than water in Barataria Basin. Although temperature differentials would quickly decrease as the inflowing river waters mix into the bay, and the effects of the colder waters would decrease with distance from the outfall, the potential for faunal stress and mortality may increase during initial opening of the diversion each year, as well as in areas near the outfall during the winter. The overall direct effects of decreased average temperatures and acute temperature changes on faunal populations at these discrete locations and time periods would likely be minor and adverse, although permanent and recurring during the Project life.

In the Future Without Project, the main drivers of change in Barataria Basin would be temperature and salinity. Water quality in the basin is predicted to experience warmer temperatures as future temperatures are anticipated to rise, and increased salinity as the intrusion of Gulf waters increases with SLR. Without the project, suspended sediments and contaminants from the Mississippi River would not be conveyed into the basin.

6.6.2 Estuarine Soft Bottoms and Sand/Shell Bottoms

Construction Effects

The proposed Project would alter the benthic habitat through dredging in the outfall area, and through sediment placement in the beneficial use sites. Excavation removes and buries benthic organisms. Dredging and sediment placement may cause ecological damage to the benthos by physical disturbance to benthic species and habitats; exposure of sediment, potentially including anoxic areas; and an increase in the amount of suspended sediment in the water column (Montagna et al. 1998). Dredging removes much of the benthic ecosystem within the upper portion of the seabed and can result in dramatic reductions in species richness, population levels, and overall biomass within the dredge footprint (Newell et al. 1998).

Following the impacts associated with dredging and the removal of substrate, ecological recovery occurs through natural ecological processes including vertical migration of buried organisms, immigration of postlarval organisms from adjacent areas, larval recruitment from the water column, and sediments slumping from the edges of the dredged area (Bolam and Rees 2003, Newell et al. 1998). The action area is not frequently dredged, with much of the outfall area representing areas that have never been dredged. Therefore, the dredging activity may facilitate a short-term transition from a relatively late-successional ecological community to a community dominated by opportunistic species that are tolerant of a wide range of conditions (Bolam and Rees 2003, Newell et al. 1998).

Areas affected by the BUP of dredged material are expected to transition from shallow estuarine mud bottoms to marsh habitats. These habitats will no longer support much of the benthic production associated with shallow mud and sand bottoms.

Operation and Maintenance Effects

Operation of the diversion will result in changes to estuarine and mud bottom areas due to deposition of sediments and changes in salinity. Deposition of sediments in the outfall area is predicted to occur over time. Figure 6.6.2-1 shows the areas where sediment deposition is predicted to create land and where land loss is predicted due to operation of the Future With Project compared to the Future Without Project after 50 years. Throughout the basin, outside of the outfall area, mud and soft bottom habitat will continue to deepen in response to SLR in both the Future With Project and Future Without Project scenarios.

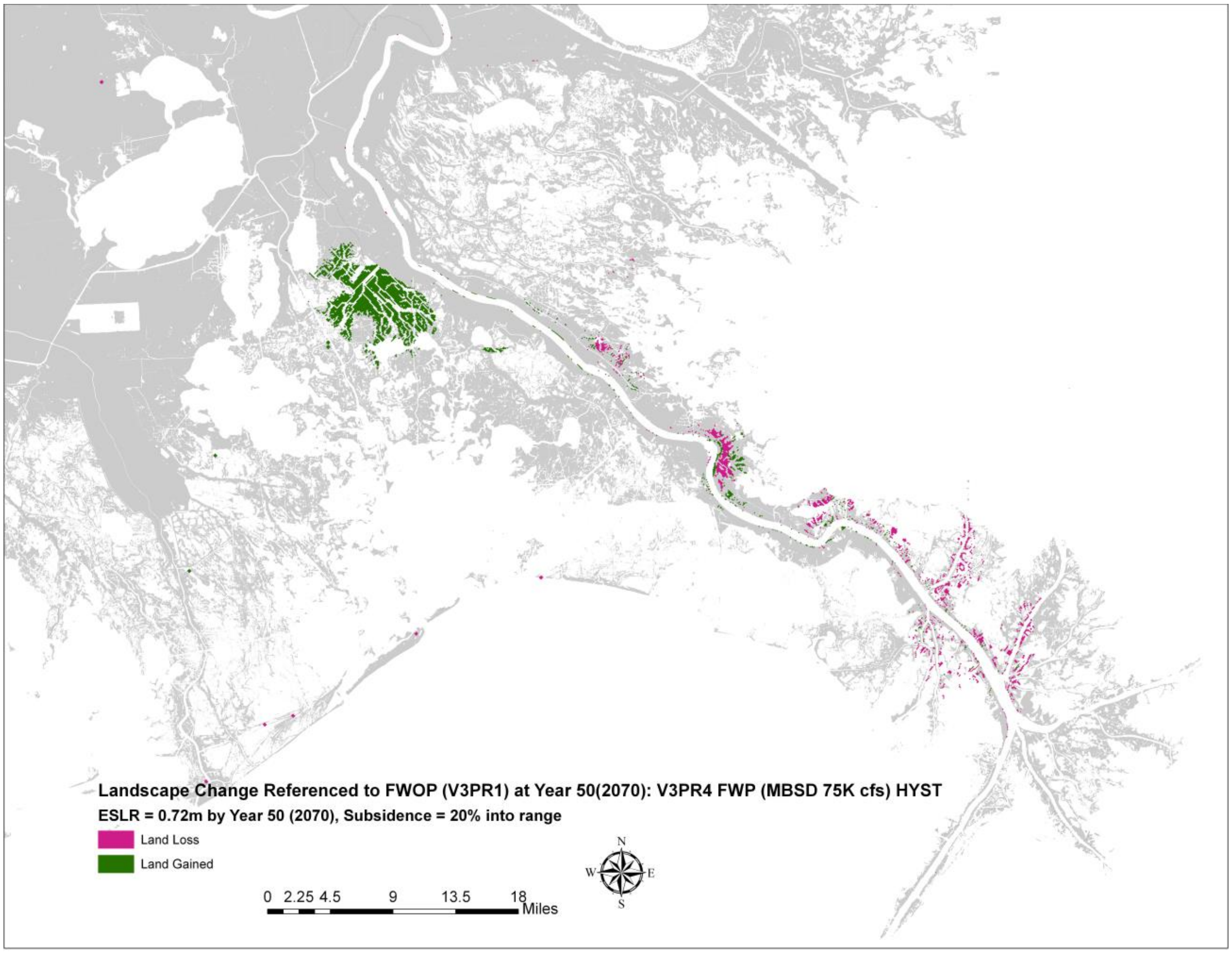


Figure 6.6.2-1. Land Gain and Loss due to the Future With Project (PR4) Compared to the Future Without Project (PR1) after 50 Years from Delft3D Modeling.

In addition to sediment deposition that leads to land formation above MLLW, there will be sediment deposition on soft bottoms adjacent to these areas, which will cause soft bottom habitat to become shallower as a result of the Future With Project scenario. This process is likely to cause deltaic processes in the outfall vicinity. In addition to the sand fraction (> 63 microns), the coarse silts (32-63 microns) are also important to the efficiency of re-establishing deltaic land building processes. The coarse silt fraction of Mississippi River sediment and the very fine sand fraction (63-125 microns) are able to settle quickly in still water environments like the outfall area in Barataria Basin. In addition, the 32-63-micron size increment represents the largest total volume (by weight) of sediment that is transported into the Basin (Allison 2011, Allison et al. 2014). Thompson (1951, 1955) studied the effects of increasing sedimentation in Atchafalaya Bay and the adjacent continental shelf. In Atchafalaya Bay ‘‘prodelta’’ muds buried oyster reefs in the bay and the formed of low-angle clinoform deposits on the inner shelf. Delta formation does not proceed evenly as large flood events transport substantial quantities of sediment that can create rapid subaerial land formation.

In most areas beyond the areas where land gain is predicted, deposition is expected to be gradual with sediment accretion over the 50-year life of the Project. Operation of the Project is expected to result in deposition of sediment throughout the outfall area, which will help offset rates at which water bottoms deepen. While burial of some benthic habitats may occur, recovery of benthic macroinvertebrates following burial is typically rapid (recovery within months) (VanDerWal et al. 2011, Wiber et al. 2006, Wiber and Clarke 2001). The species which recolonize this area will be those that are tolerant of the lower salinities generated by diversion operation, however the areas near the outfall where sediment deposition will be occurring have average salinities between 0 and 3 ppt. The rapid recovery and minimal salinity change near the outfall suggest that there would be limited long-term impacts from the Future With Project on benthic organisms due to sediment deposition. Deposition is likely to be episodic and may lead to cycles of burial and recovery in some areas and may shift communities to those more tolerant of the new sediment deposition patterns. Outside the areas near the outfall where sediment deposition is highest, deposition patterns would be similar to current conditions and therefore cause in negligible changes to mud and sand bottom communities.

The operation of the diversion would result in minimal decreases in dissolved oxygen with levels typically staying above 6.0 mg/L, within the tolerance range of most organisms. However, the model is not designed to capture episodic low DO events that may occur in isolated locations such as canals. In these areas if DO levels are low and remain low for sufficient duration some episodic mortality of species sensitive to low DO levels.

As described in section 6.5.1, salinity will also change with freshwater from the diversion causing fresher conditions in Barataria Basin when the diversion is operating above base flow. An evaluation of the invertebrate communities in Lake Pontchartrain following the 1996 Bonne Carré Spillway opening showed that a community of oligohaline taxa survived during the freshwater period, however dominance changed between species and in some locations species composition changed (Brammer et al. 2007). Sites closer to the spillway showed much greater change compared to sites further from the freshwater input. It is anticipated that mud and sand bottom communities will shift to species tolerant of the new salinity ranges similar to the existing communities present in the Basin, albeit in altered locations based on the new spatial patterns of salinity. These communities, ranging from fresh to marine, all provide essential resources to higher trophic level organisms.

6.6.3 Estuarine Emergent Marsh and Submerged Aquatic Vegetation (SAV)

Construction Effects

Construction of the Project will result in losses of wetlands within and along the margins of the outfall area where dredging will remove wetland habitats or create deeper habitats adjacent to existing wetlands. The construction activity proposes to use dredged sediments to support and create wetlands in the BUP areas.

Operation and Maintenance Effects

The Project is predicted to create a net increase of about 13,400 acres of emergent habitat, defined by mudflats and emergent vegetated areas, by the year 2070 compared to the Future Without Project in Barataria Basin. Without the Project, the Barataria Basin is predicted to have continued emergent habitat loss declining from an estimated 298,270 acres of mudflats and vegetated wetland area in 2030 to about 52,077 in 2070. With the Project, the total amount of emergent habitat area in 2070 is estimated to be approximately 65,477 acres. There are differences in the characteristics of the created and retained emergent vegetated habitats, with the wetland area maintained or created by the Project being mostly intermediate salinity marsh, while without the Project most of the marsh retained would be brackish. Overall, aquatic vegetation (excluding SAV) is projected to decline within the action area, with and without the project. However, under the Future with Project, approximately 9,790 acres more habitat is created or retained than in the Future without Project (Table 6.5.3-2 above).

The sediment diversion may function to not only build new land but also to increase the elevation of existing marshes (Carle et al. 2015). Areas in which bottom elevations increase may result in a shift from fully SAV such as hydrilla and Najas, to floating-leaved species such as pondweed (*Potamogeton nodosus*) and water lotus (*Nelumbo lutea*), as described for the Wax Lake Outlet following the 2011 Mississippi River flood (Carle et al. 2015). These emerging wetlands would provide additional value for fish and wildlife, as demonstrated by the recovery of fish nursery capacity (Thompson and Deegan 1983) and a much greater density of nekton in vegetated areas of freshwater tidal wetlands in the Atchafalaya River Delta when compared to unvegetated (Castellanos and Rozas 2001). Increased emergent marsh vegetation would also provide important edge habitat for fish and invertebrates with respect to feeding, reproduction, and refuge (Peterson and Turner 1994, Castellanos and Rozas 2001). Studies have shown that there is a strong trophic link between infauna and nekton near the marsh edge that contributes to high fishery productivity in Gulf Coast marshes (Whaley and Minello 2002).

Submerged aquatic vegetation is also positively affected by the Project. SAV in the action area is projected to increase overtime in both with and without the Project. However, in the Future with Project, approximately 1,500 additional acres of SAV (about 2%) are projected to be retained or created compared to the Future without Project. In agreement with Delft 3D model prediction trends, percent submerged aquatic vegetation (SAV) were developed by using changes in turbidity, water depth, exposure, and salinity, obtained from the Delft 3D model, combined with the premises developed through the SAV Likelihood of Occurrence Model (or SLOO) model, predicting a net increase of at least 2% (1,500 acres) of SAV in the fresh/intermediate portion of the Project area at the end of the Project life (DeMarco et al. 2018, USFWS 2020). Hillmann et al. (2016b) indicated that fresher marshes of the Barataria Basin, on average, had higher species richness and biomass of SAV when compared to intermediate, brackish, and saline sites; saline sites had the lowest species richness and biomass of SAV. Therefore, the decrease in average salinity in the basin may result in increased total biomass of SAV over time, when compared to the Future Without Project.

6.6.4 Oyster Reef

Construction Effects

Construction is not anticipated to have any effects on oyster reefs because none occur within the Project construction footprint.

Operation and Maintenance Effects

Operation of the diversion will affect water quality conditions throughout central and lower Barataria Basin. The water quality changes will result in indirect effects to oysters due to changes in temperature, salinity, and suspended sediments. The effects to oysters from the Project are analyzed in detail in Appendix B.

6.7 Project Effects to Federally Managed Species

Several federally managed fish and shellfish species and their EFH are known to occur within the action area. These include 2 shrimp species, red drum, 2 coastal migratory pelagic fish species, 7 reef fish species, and 9 highly migratory fish species. The proposed action will result in evolving effects on EFH that are likely to directly and indirectly affect some of these species. Project effects on federally managed species are evaluated using 2 methods: model-based analysis of predicted near-term, intermediate-term, and long-term effects on HSIs for 3 indicator species, white shrimp, brown shrimp, and red drum combined with an review of the scientific literature and comparisons to estuarine systems with similar conditions; and a qualitative analysis of predicted effects on other fish species based on comparison of modeled changes in habitat conditions over similar time periods to species-specific life history requirements based on the scientific literature.

Model-Based Analytical Approach

Where HSIs were generated for specific species (e.g., brown shrimp, white shrimp and red drum), the potential Project effects were evaluated at 3 time-periods:

1) a near-term analysis (2020-2029) that focuses on the initial decade of diversion operations, representing a time when the diversion is operating but there are minimal landscape changes;

2) a mid-term analysis (2050-2059) when the area of wetlands created by the diversion are predicted to be at a peak; and

3) a long-term analysis (2070) that focuses on the end of the modeled 50-year operational period for the Project, when the impacts of SLR are the greatest.

The analysis considered multiple life stages including larval recruitment and juvenile growth before subadults migrate out of the estuary. Published literature and other available data were used to evaluate the potential impacts of the Project on multiple life-stages. In general, these analyses assume that diversion operations are expected to be operating above base flows (5,000 cfs) and frequently approaching peak flows (75,000 cfs) between December and July each year, with base flows typically occurring during between August and November when the head differential between the river and the basin permits base flow to occur.

6.7.1 Overview of Species Water Quality Tolerances

This section focuses on representative Barataria Basin nekton species for which HSI analyses are available, as well as oysters. The greatest potential for negative effects are for those species and life stages with the greatest sensitivities to freshwater riverine inputs and decreased salinity associated with operation of the diversion under the Future With Project (**Error! Reference**

source not found.6.7.1-1). Detailed discussions of potential Project operation impacts on individual aquatic species are provided below in Sections 6.7.2 – 6.7.10.

Table 6.7.1-1. Summary of Water Quality Tolerances and Optimal Ranges for Representative Barataria Basin Species

Life Stage*	Salinity Tolerance (ppt)	Optimal Salinity (ppt)	Temperature Tolerance (°C)	Optimal Temperature (°C)	DO Tolerance (mg/L)	Optimal Land/Depth (m)	HSI Model (n = no; y = yes)	Data Sources
Blue Crab								
Eggs	22.0–32.6	22.0–28.0	-	19.0–29.0	> 1.0**	Pelagic	N	1
Larvae	5.0–40.0	20.0–31.1	-	24.0–31.0	> 1.0**	-	N	1
Juveniles	0.0–60.0	1.0-20.0 (early) 7.0-20.0 (late)	3.0–35.0	12.0-25.0 (early) 18.0-33.0 (late)	> 1.0	demersal estuarine	Y	1,12
Adults	0.0–37.0	24.0–37.0	3.0–35.0	18.0-33.0	> 1.0	demersal estuarine	N	1
Brown Shrimp								
Larvae	2.0–40.0	24.0–36.0	12.6–30.6	28.0–30.0	> 1.0	0.0–82.0	N	2,3
Juveniles	0.0–45.0	10.0–20.0	7.0–35.0***	18.0–32.0	> 1.0	-	y (small)	2,3
Subadults	0.9–30.8	10.0-25.0	18.0–29.0	18.0–29.0	>1.0	1.0–18.0	N	2,3,12
White Shrimp								
Eggs	27.0 - 35.0	-	-	-	> 1.0**	9.0–34.0	N	2,4
Larvae	0.4–37.4	-	12.6–32.5	18.0–32.5	> 1.0**	0.0–82.0	N	2,4
Postlarvae	0.4–37.0	27.0–35.0	12.6–32.5	18.0–32.5	> 1.0	<1.0	N	2,4
Juveniles	5.0–26.0	< 10.0	9.0–33.0	15.0–33.0	> 1.5	1.0–30.0	Y	2,4
Adults	0.1–45.3	27.0–40.0	10.0–37.0	< 18.0	> 2.0	< 27.0	N	2,4
Spawning Adults	-	27.0–35.0	-	-	> 1.0	9.0–34.0	N	2,4
Gulf Menhaden								
Larvae	2.0–30.0	25.0–29.0	2.5–35.5	12.0–30.0	> 3.0	-	N	5
Juveniles	5.0–30.0	5.0–10.0	-	20.0-27.0	> 3.0	-	Y	5,12
Adults	0.0–67.0	20.0–29.0	-	20.0-32.0	> 3.0	1.8–14.6 (spring/ summer) 7.3–87.8 (fall/winter)	N	5
Spotted Sea Trout								
Eggs	5.0–45.0	15.0–35.0	-	23.0–32.7	> 2.0	-	N	6
Larvae	8.0–40.0	20.0–35.0	5.0–36.0	20.0–30.0	> 2.0	-	N	6
Juveniles	0.0–48.0	8.0–25.0	5.0–36.0	20.0–30.0	> 2.0	0.2–2.2	Y	6
Adults	0.2–75.0	18.0–32.0	4.0–33.0	15.0–27.0	> 2.0	-	N	6
Spawning Adults	-	-	-	21.0–34.0	> 2.0	3.0–50.0	N	6
Largemouth Bass								
Eggs	-	-	13.0–26.0	15.6–21.0	> 1.0**	-	N	7
Larvae	0.0–6.0	0.0–1.6	15.0–32.0	27.0–30.0	> 1.0**	-	N	7

Life Stage*	Salinity Tolerance (ppt)	Optimal Salinity (ppt)	Temperature Tolerance (°C)	Optimal Temperature (°C)	DO Tolerance (mg/L)	Optimal Land/Depth (m)	HSI Model (n = no; y = yes)	Data Sources
Juveniles	0.0–6.0	0.0–1.6	15.0–32.0	27.0–30.0	> 1.0**	-	Y	7
Adults	0.5–24.0	0.5–5.0	15.0–36.0	24.0–30.0	> 1.0**	1.0–6.0 (summer) > 6.0 (winter)	N	7
Spawning Adults	-	-	13.0–26.0	15.6–21.0	> 1.0**	0.15–7.5	N	7
Bay Anchovy								
Eggs	-	30.0–37.0	-	22.0–32.0	> 3.5	-	N	8
Larvae	0.0–80.0	3.0–7.0	5.0–40.0	22.0–32.0	> 3.5	-	N	8
Juveniles	0.0–80.0	3.0–10.0	5.0–40.0	-	> 1.5	1.2–2.5	Y	8
Adults	0.0–80.0	6.0–15.0	-	8.0–32.0	> 1.5	1.0–2.5	N	8
Spawning Adults	-	30.0–37.0	-	≥ 20	> 1.5	< 20.0	N	8
Atlantic Croaker								
Eggs	0.0–70.0	-	-	-	> 1.0**	-	N	9
Larvae	0.0–70.0	-	-	-	> 1.0**	-	N	9
Juveniles	0.0–70.0	0.0-10.0 (early) 0.0-20.0 (late)	0.0–36.0	15.0-25.0 (early) 17.0-25.0 (late)	> 1.0**	-	Y	9,12
Adults	0.0–70.0	0.0-25.0	-	17.0-28.0	> 1.0**	-	N	9,12
Red Drum								
Eggs	10.0–40.0	-	20.0–30.0	-	> 1.0**	20.0–30.0	N	2,10
Larvae	8.0–36.4	-	18.3–31.0	25.0–30.0	> 1.0**	-	N	2,10
Postlarvae	8.0–36.4	< 30.0	18.3–31.0	-	> 1.0**	-	N	2,10
Early Juveniles	0.0–45.0	20.0–40.0	5.0–32.2	16.0-28.0	> 1.0**	0.0–3.0	N	2,10,12
Late Juveniles	0.0–45.0	20.0–40.0	5.0–30.0	18.0-28.0	> 1.0**	0.0–5.0	N	2,10,12
Adults	0.0–45.0	20.0–40.0	2.0–33.0	18.0-28.0	> 1.0**	1.0–70.0	N	2,10,12
Southern Flounder								
Juveniles	0.0–35.0	19.6–30.0	2.0–35.0	16.0–30.0	> 3.7	-	Y	11
Adults	0.0–60.0	5.0–20.0	5.0–34.9	14.0–34.9	> 4.0	-	Y	11

Tolerance range = identifies the range where the organism is able to survive in natural or laboratory settings.
Optimal range = identifies the range where the organism is not experiencing consequential stress, and where maximal growth, abundance, or activity occurs.
Only life stages present in the action area are reported.
** Unreported DO tolerance assumed to be above hypoxia concentrations.
*** Juvenile brown shrimp burrow between 7.0 and 18.0°C.
Sources: [1]O'Connell et al., 2017c; [2]GMFMC, 2016; [3]O'Connell et al., 2017a; [4]O'Connell et al., 2017b; [5]Sable et al. 2017a, [6]Sable., 2017b; [7]Hijuelos et al., 2017; [8]Sable et al., 2017c; [9]Diaz and Onuf, 1985; [10]Buckley, 1984; [11]Enge and Mulholland, 1985; [12]Dynamic Solutions 2016

6.7.2 White Shrimp

Near-Term (2020 – 2029)

The only life stages for white shrimp found within the Barataria Basin are postlarvae, juveniles, and subadults. Because larval white shrimp and adults are found offshore, the Future With Project is not expected to impact those life stages. White shrimp postlarvae emigrate into the lower estuary from late spring to late summer (Turner and Brody 1983). This is the period of time diversion flows typically would be decreasing or have returned to a baseflow condition. Based on an analysis of 50 years of historic stage data on the Mississippi River, the Project would likely be flowing at base flow approximately 33% of the time in June, 58% of the time in July, and more than 90% of the time during August and September.

Migration of white shrimp postlarvae into Barataria Basin is unlikely to be adversely affected by the outflow of freshwater from diversion operations. Even at high discharge rates, flow velocity and direction are changed very little at the barrier islands including at Barataria and Bastian Passes (Section 6.5.8). However, the Project does have the potential to impact recruitment of white shrimp into portions of the estuary near the outfall location where flows in channels may be unidirectional flowing away from the diversion when the diversion is operating at or above 20,000 cfs. Flood tides and bi-directional flow are present in these channels when the Project is operating at base flow, suggesting that while movement of white shrimp postlarvae into these areas may be impeded to a minor degree during moderate and high diversion flows (above 20,000 cfs), movements into and throughout the basin are expected to occur during baseflow. Therefore, the potential for temporary minor impacts to movement in the mid- and upper Barataria Basin is most likely during the early (June) immigration peak and unlikely during the September immigration peak. During June, the Project is expected to operate above base flow 20 days per month, whereas during the August to October period, such operations are expected an average of less than 3 days per month. Though potential flow impacts from diversion operation are considered, similar systems (such as Vermilion Bay, Sabine Lake, and the Mississippi River Delta) suggest that larvae are able to recruit and sustain viable populations and that Project impacts on white shrimp due to flow would be negligible (Lindquist 2019).

White shrimp are more euryhaline than brown shrimp. They are able to adapt to a wide range of salinity conditions and are tolerant of more freshwater conditions. Turner and Brody (1983) defined optimal conditions for white shrimp as between 1 ppt and 15 ppt for the summer months. As such, even if the diversion was still in maximum operation during the summer months, the reduction in salinity across Barataria Basin associated with diversion operations likely would maintain suitable habitat conditions for white shrimp for most of the basin. However, in portions of the mid-basin close to the diversion outfall, salinity reductions may negatively impact white shrimp. In Vermilion Bay, collection of recently recruited postlarvae and early juveniles from September to November were generally highest at stations where average salinity ranged from 3 ppt to 12 ppt, and were lower at stations higher up in the bay where salinity ranged from 1 ppt to 6 ppt (Lindquist 2019).

The HSI analysis for white shrimp incorporates 3 variables: mean salinity and water temperature for the months of June through November, and percent of each polygon composed of wetlands. Under the Future With Project, the HSI output for white shrimp during the near-term decreases by less than 0.1 for all but 3 polygons in the upper, mid, and lower basins (for the remaining 3 polygons, there was no change in HSI score compared to the Future Without Project) (Figure 6.7.1-1). The magnitude of the decrease for white shrimp is smaller than the magnitude of decrease for brown shrimp because the Project is not predicted to operate at peak flow as frequently during white shrimp peak abundance periods because white shrimp have higher suitability indices at low salinities than brown shrimp. While the white shrimp HSI includes the percent of land as an important variable, during the near-term period of analysis there is insufficient difference in wetland acreage between the Future With Project and the Future Without Project to offset minor reductions in suitability caused by decreases in salinity with diversion operations.

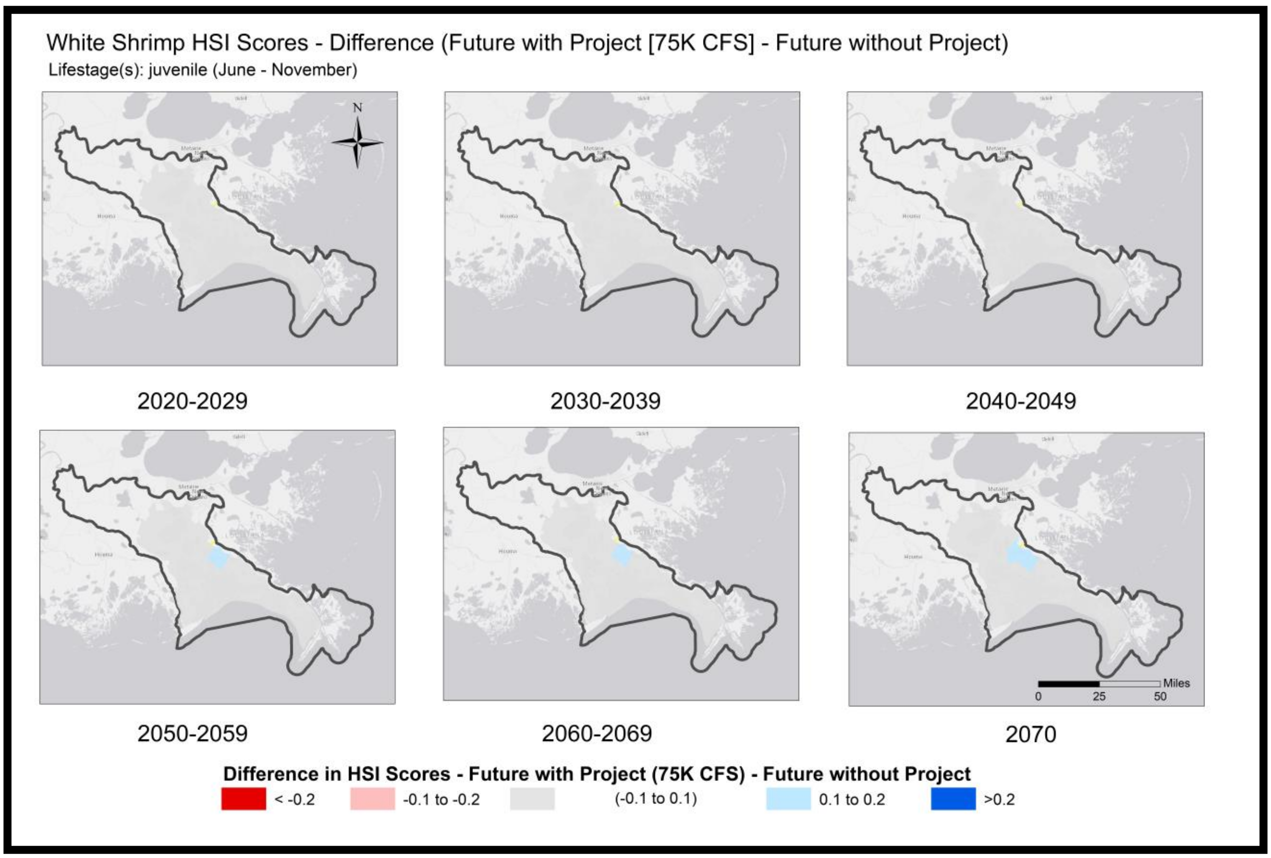


Figure 6.7.1-1: White Shrimp HSI Scores Comparing Future With and Without Project

Reports of the effects of freshwater input on finfish and shellfish in Vermilion Bay (Lindquist 2019) and in Breton Sound (deMutsert and Cowan 2012) suggest white shrimp production should benefit in the near term from the Project. Lindquist (2019) reported juveniles and subadults white shrimp were caught in high numbers across the Vermilion-Cote Blanche system and that average catches of white shrimp in the Vermilion Bay system were 6 times to 20 times higher than average catches in Barataria Basin, a system less impacted by freshwater introduction (Lindquist 2019). deMutsert and Cowan (2012) reported greater abundance of white shrimp in the Breton Sound estuary after implementation of the Caernarvon Freshwater Diversion as compared to a control area.

During the near-term time period, nutrient addition to the Barataria Basin caused by diversion operations should help improve primary productivity supportive of the aquatic food web. This increase in nutrients should increase phytoplankton and zooplankton populations, as well as the production of detritus and algae supportive of juvenile to subadult white shrimp growth. However, during the near-term period, food availability likely would not be limiting; therefore, increased food availability may not benefit white shrimp abundance or growth. Therefore, it is unlikely the operation of the Project would benefit or adversely impact white shrimp abundance in the near term.

Mid-Term (2050 – 2059)

By the end of the fourth decade of operation of the Project, water quality impacts will be similar to the Near-Term period. Salinity reductions would continue to decrease suitability for juvenile white shrimp in portions of the mid-basin closest to the outfall site during periods the diversion is operating above base flows. Potential impacts to white shrimp recruitment into the estuary would be similar to the near-term period of analysis.

However, the benefits of the diversion in protecting habitat supportive of the juvenile white shrimp food web is greatest during this time period. Specifically, during the fourth decade of analysis, modeling predicts more than 17,000 acres of marsh (10% more) with operation of the Project compared to the Future Without Project scenario (Table 5.2-2). Much of the increased acreage of marsh will be tidal intermediate marshes near the diversion where land building and reduced land loss effects are anticipated. Direct use of the newly created areas by white shrimp may be limited by lower salinity conditions during diversion operations; however, indirect benefits to white shrimp would still occur through export of prey to the larger basin ecosystem.

Given white shrimp juveniles benefit from the presence of marsh, and the mid-term period has the greatest net acreage of marsh resulting from operation of the Project, this is the time period when the diversion is likely to have the greatest overall net benefit on white shrimp abundance and biomass. During the 2050 to 2059 period of analysis, the difference in white shrimp HSI scores between the Future With Project and Future Without Project diminishes slightly for the mid and lower basins, going from -0.04 to 0.00 for the mid-basin and -0.03 to -0.02 for the lower basin. Additionally, the 2 polygons closest to the diversion outfall location (8 and 12) show an increase in HSI score for the Future With Project compared to the Future Without Project (Figure 6.7.1-1). This switch to positive projections using the HSI is based on the net increase in wetland acreage under the Future With Project compared to the Future Without Project.

As noted previously, the HSI scores are intended to reflect habitat suitability, but do not explicitly incorporate changes in the white shrimp food web. By 2050–2059, diversion operations will have maintained marsh supportive of juvenile and subadult white shrimp and provided nutrients expected to enhance primary and secondary productivity supportive of the white shrimp food web. Given many of the primary food items for white shrimp are most abundant in marsh habitats (Hollweg et al., in review), or produced by marsh habitats (i.e. detritus) then the creation and maintenance of marsh habitat under the Future With Project may benefit white shrimp abundance and biomass compared to the Future Without Project in the mid-term.

It should be noted that even in the Future Without Project, the acreage of wetlands in Barataria Basin is predicted to be reduced by approximately 30% by 2050–2059, compared to 2020. This reduction in habitat is anticipated to result in an overall reduction in white shrimp over time, for both the Future With Project and the Future Without Project scenarios Turner (1977). Because the Future With Project is anticipated to cause some accelerated loss of wetlands in the Birdfoot Delta, minor impacts to white shrimp habitat are expected during the mid-term period of analysis.

Long-Term (2070)

As noted previously, by the end of the modeled 50-year operational period for the Project, Delft3D modeling results project that almost 80% of the marsh present at the initiation of the Project will have been lost to relative SLR and erosion. Compared to the Future Without Project scenario, approximately 20% of the marsh remaining after 50 years is attributed to the operation of the diversion. As with the mid-term period of analysis, the Trustees expect that benefits to white shrimp from creating and maintaining wetlands and associated primary productivity would be greater than the impacts of salinity reductions on white shrimp abundance.

Operation of the Project during peak white shrimp immigration periods, while unlikely, should not reduce recruitment through tidal passes into Barataria Basin. However, if occurring, operations above base flow could have a minor influence on immigration to wetlands adjacent to the outfall. As wetlands are lost over time in areas farther from the diversion outfall, tidal channels and waterbodies are expected to widen and current velocities during high-discharge periods should decrease. If discharge flows have the potential to impact recruitment during the near-term, such impacts are projected to decrease where wetland loss is occurring by 2070.

For 2070, the difference in HSI scores between the Future With Project and the Future Without Project changes minimally in most polygons, as compared to the mid-term period of analysis. Some polygons experience minor increases (i.e., become less negative or more positive), and some decrease slightly (Figure 6.7.1-1). During the long-term period of record, HSI values for mid-basin polygons actually increased slightly (by an average of 0.1) as compared to the same polygons for the Future Without Project, although the lower basin polygons remained an average of 0.02 HSI lower with the Future With Project as compared to Future Without Project. The polygons nearest the outfall experienced the largest increases in HSI during the long-term period of analysis as these polygons maintained marsh acreage as compared to the Future Without Project. Because of the overall land loss in the basin by 2070, the Trustees expect that white shrimp abundance and biomass would be significantly reduced in the future as compared to current conditions under both the Future With Project and the Future Without Project scenarios. Because the Project is anticipated to cause some accelerated loss of wetlands in the Birdfoot Delta, neutral to minor negative impacts to white shrimp habitat are expected to that area during the long-term period of analysis.

Synthesis

In the near-term, habitat suitability for white shrimp may decrease very slightly due to decreases in salinity, however data from Vermilion Bay suggest broad tolerance of white shrimp for decreased salinity therefore this change is unlikely to reduce overall abundance. Long-term operation of the diversion will increase the suitability of polygons closest to the diversion for white shrimp, while resulting in neutral to minor decreases in suitability in other locations. Additionally, given the predicted timing of high diversion flows, white shrimp recruitment to wetlands and waterbodies throughout the Barataria Basin is unlikely to be negatively impacted. While in the Future without Project, major negative effects are anticipated due to habitat loss, the Future with Project is anticipated to have neutral to minor beneficial effects to white shrimp.

Overall, suitability of Barataria Basin for white shrimp under the Future With Project is expected to be better than that under the Future Without Project scenario, primarily because of the maintenance of more vegetative marsh habitat, as well as increased primary productivity, and SAV, under the Future With Project scenario resulting in a neutral to minor beneficial impact to white shrimp abundance. However, it is expected that in the long term, white shrimp abundance will ultimately decrease over time in the both the Future with Project and the Future without Project because of the loss of wetlands to SLR. Because operation of the Project is expected to cause minor wetland loss in the Birdfoot Delta, neutral to minor adverse effects to white shrimp are expected in the Birdfoot Delta from the Project.

6.7.3 Brown Shrimp

Near-Term (2020 – 2029)

Adult brown shrimp are found off-shore where spawning occurs; thus the Project is not expected to directly affect spawning adults or early larval life-stages that also are found off-shore. Migration of brown shrimp postlarvae into Barataria Basin is unlikely to be adversely affected by the outflow of freshwater from diversion operations. These freshwater outflows are expected to influence currents and circulation in the Basin, with effects diminishing with distance away from the outfall. The extent to which the recruitment of brown shrimp postlarvae to Barataria Basin should not be impacted by the Project.

However, the Project does have the potential to impact the recruitment of brown shrimp postlarvae into portions of the estuary closest to the outfall location. Channels near the outfall location could have unidirectional outflow when the diversion is operating at midflow levels and higher (>20,000 cfs). For these areas, flood tides return and tidal signatures are similar between Future With Project and Future Without Project scenarios when the diversion is operating at base flows. As such, operation of the diversion above base flows could impede the movement of brown shrimp postlarvae to wetlands and waterbodies north of Wilkinson Canal and east of the Barataria Bay Waterway. Brown shrimp postlarvae should be able to physically access such areas when operations return to base flow. The conclusions provided above are based on the analysis of tidal impacts undertaken by The Water Institute of the Gulf (TWI) which focused on locations with the highest likelihood of increased current velocities. There are many locations and other possible pathways that may still allow for recruitment to the central and eastern portions of the mid-basin. During base flow and higher level flows, salinities in these areas should be sufficiently low as to limit use of these areas by brown shrimp postlarvae. The prevention of immigration due to direction and velocity of tidal transport would just constitute an additional reason brown shrimp productivity in the areas closest to the outfall location would be adversely impacted by the Project.

Model outputs suggest operation of the diversion above base flow could have some impact on brown shrimp postlarval movement to wetlands and water bodies in that portion of Barataria Basin south of Wilkinson Canal and north of Barataria Bay in close proximity to the Barataria Bay Waterway. During periods of greater than base flow conditions, there is a tidal signature and bi-directional flow in these channels should be able to occur on a daily basis. However, the duration of flood tide events appears reduced with diversion operations as compared to without and ebb tide velocities are greater. This suggests brown shrimp postlarvae would have a reduced amount of time to recruit into those portions of Barataria Bay during periods when the diversion is operating above base flow and would have to move out of the main channel and into channel margins or other areas of refugia to avoid being displaced by faster than baseline ebb tides. The conclusions provided above are based on the analysis of tidal impacts undertaken by TWI which focused on locations with the highest likelihood of increased current velocities. Outside of the areas of projected maximum flow velocities, there are many other locations and pathways (e.g., channel margins, vegetated shallows, etc>) where current velocities may be unaffected by diversion operations, and recruitment to the central and eastern portions of the mid-basin would be unaffected. As with wetlands and waterbodies closer to the diversion outfall, the impacts of reductions in salinity already would limit use of this area by brown shrimp postlarvae. Therefore, the reductions in the potential of postlarval brown shrimp to access this area of the Barataria Basin may constitute an additional reason brown shrimp productivity in this area would be reduced by operation of the Project.

Predicted average flow conditions based on the 50-year historic hydrograph used in the Delft3D model indicate during the months of January through June, when postlarvae are carried into the estuary, the diversion would be operating at maximum flow for an average of 3.5 days/month (12% of days) within that time period, and above baseflow (below maximum) for an average of 20 days/month (66% of days) within the same time period. In Vermilion Bay, brown shrimp will recruit into the Bay even when river flows are high and salinities are low (Lindquist 2019), although these shrimp can experience reduced growth rates and are less available for commercial harvest (B. Carter, LDWF, personal communication).

Project-induced low salinity and decreased temperatures in the mid and lower basin may also reduce growth rates of juveniles and subadults within the basin. Saoud and Davis (2003) found that juvenile brown shrimp survival rates are similar across salinities from 2 ppt to 25 ppt, however biomass and weight gain decreased substantially at salinities below 4 ppt.

Reductions in salinity associated with the first decade of diversion operations are anticipated to adversely affect juvenile brown shrimp by reducing the quality of their habitat within the mid and lower basin as compared to the Future Without Project (Figure 6.7.2-1). Initial negative impacts occur when diversion operations cause water quality conditions in the mid and lower basin to remain below the optimal salinity range of 10 ppt to 20 ppt for juveniles. There are no anticipated near-term Project impacts to brown shrimp habitat within the upper basin or Birdfoot Delta because the diversion is not anticipated to change salinity or vegetation conditions in these areas.

The modeled decrease in HSI between Future With Project and Future Without Project scenarios exceeded 15% for most polygons during the near-term in the mid- and lower basins (Figure 6.7.2-1). Specifically, the average and maximum decrease in HSI score across polygons in the mid-basin for are 0.13 and 0.21, respectively, while the average and maximum decrease in HSI scores across polygons in the lower basin are 0.16 and 0.24, respectively. This reduction in HSI results from expected reductions in salinity downstream of the diversion as a result of diversion operations. These HSI results suggest that diversion operations would have negative impacts on conditions supportive of small juvenile brown shrimp survival and growth.

These conclusions from the HSI analysis are supported by an examination of LDWF data on nekton abundance in Vermilion Bay, which receives riverine flows from the Atchafalaya River (Lindquist 2019). In Vermilion Bay, juvenile brown shrimp abundance was lower in areas most influenced by river inputs, and abundance generally was higher with distance from such influence (Lindquist 2019). However, a study of the effects of the Caernarvon Freshwater Diversion on nekton in Breton Sound (a smaller 8,000 cfs diversion in a system with greater tidal exchange) did not find that the diversion reduced brown shrimp biomass across the estuary (deMutsert and Cowan 2012). Taken together, these studies (deMutsert and Cowan 2012, Lindquist 2019) suggest that brown shrimp distribution may be sensitive to the amount of freshwater inflow and area of dispersion. Fry et al. (2003) found that juvenile brown shrimp arriving in estuaries from offshore waters continue movement through sub-optimal habitats but stay in an area once optimal habitat is reached. Thus, when Mississippi river conditions are low and the diversion is reduced to base flow, salinities and water temperatures are predicted to return to background levels in the fall (except in the polygons immediately adjacent to the diversion), and brown shrimp, if present, would be able to expand their range into the mid-basin.

Brown shrimp present in the Barataria Basin may be displaced to the portion of the lower basin near the barrier islands, where average spring salinities are predicted by the Delft3D model to remain around 5 ppt during periods when the diversion is flowing to maximum capacity. Brown shrimp may be better able to use the mid- and lower basin when the diversion is operating at base flow. Similarly, Rozas et al. (2005) reported operation of the Caernarvon Freshwater Diversion displaced brown shrimp to areas lower in the Breton Sound Basin, but that the species returned to upper basin areas when diversion operations ceased.

The HSI does not consider the availability of food for brown shrimp – the model assumes that food is not a limiting factor. If food is limiting for brown shrimp, an enhancement of the food web from nutrient and freshwater additions could benefit brown shrimp. If food is not limiting, as assumed by the HSI model, then these enhancements to the food web will not affect shrimp abundance or productivity. During the near-term, food availability likely is not limited. During later years, as wetlands become less plentiful, the availability of detritus will decrease and food availability may become limited.

Overall, in the near-term, it is expected that brown shrimp habitat suitability in the Barataria estuary will decrease with operation of the Project, given the potential effects to brown shrimp from freshwater flows and decreased salinity at suppressing areas of marsh habitat with optimal range of conditions.

Mid-Term (2050 – 2059)

By the end of the fourth decade of operation of the Project, salinity reductions would continue to decrease suitability for juvenile brown shrimp in the mid-basin and portions of the lower basin during periods of maximum diversion discharge. Potential impacts to brown shrimp recruitment into the estuary, and to those areas most closely located near the diversion outfall, would be the same as for the near-term period of analysis, as would potential impacts to growth rates of juveniles and subadults.

However, the benefits of the diversion in protecting habitat supportive of the juvenile brown shrimp food web is greatest during this time period. Specifically, during the fourth decade of analysis, modeling predicts more than 17,000 acres of marsh (10% more) with operation of the diversion compared to the Future Without Project scenario. Much of the increased acreage of marsh will be tidal freshwater marshes near the diversion where land building and reduced land loss effects are anticipated. Direct use of the newly created areas by brown shrimp may be limited by lower salinity conditions during diversion operations, however indirect benefits to brown shrimp would still occur through export of prey to the larger basin ecosystem.

For small juvenile brown shrimp, HSI results support the expected benefits of maintaining marsh on brown shrimp. Specifically, during the 2050–2059 period of analysis (decade 4), the difference in brown shrimp HSI scores between Future With Project and Future Without Project diminishes for those polygons that are predicted to be most negatively impacted by diversion operations in the near-term period of analysis. For 2050–2059, the average and maximum decreases in HSI scores across polygons in the mid-basin for Future With Project compared to Future Without Project are 0.09 and 0.19, respectively, while the average and maximum decreases in HSI scores across polygons in the lower basin are 0.10 and 0.18, respectively. These HSI scores reflect the benefit provided by the maintenance of marsh habitat supportive of brown shrimp production – noting that even when HSI scores indicate suitable habitats, there may be times when water quality conditions (salinity or temperature) limit use of this habitat by brown shrimp. There are no anticipated mid-term Project impacts to brown shrimp habitat within the upper basin or Birdfoot Delta.

As noted previously, the HSI scores are intended to reflect habitat suitability, but do not explicitly incorporate changes in the brown shrimp food web. By 2050–2059, diversion operations will have maintained marsh supportive of juvenile brown shrimp and provided nutrients expected to enhance primary and secondary productivity supportive of the brown shrimp food web. Given many of the primary food items for brown shrimp are most abundant in marsh habitats (Hollweg et. al, in review), then the creation and maintenance of marsh habitat under the Future With Project may benefit brown shrimp abundance and biomass compared to the Future Without Project in the mid-term because the increase in marsh habitat is expected to result in an increase in available food.

However, as also noted above for the near-term analysis, juvenile brown shrimp may relocate away from areas affected by freshwater discharge when the diversion is open above base-flow. The potential benefit of increased food availability also assumes that brown shrimp are able to recruit successfully into the estuary. As noted above, much of the increased acreage of marsh will be tidal freshwater marshes near the diversion where direct use of the habitat by brown shrimp may be limited. Although, it should be noted that even with operation of the diversion, the acreage of wetlands in Barataria Basin is predicted to be reduced by approximately 30% by 2050–2059, compared to 2020. This reduction in habitat is anticipated, as predicted by Turner (1977), to result in an overall reduction in brown shrimp over time, for both Future With Project and the Future Without Project scenarios. Because the Project is anticipated to cause some accelerated loss of wetlands in the Birdfoot Delta, minor impacts to brown shrimp habitat are expected to that area during the mid-term period of analysis.

Long-Term (2070)

By the end of the modeled 50-year operational period for the Project, Delft3D modeling results predict that almost 80% of the marsh present at the initiation of the Project will have been lost to relative sea level rise and erosion. Compared to the Future Without Project scenario, approximately 20% of the marsh remaining in Barataria Basin after 50 years will be tidal freshwater marshes near the diversion that are attributed to the operation of the Project. Even with operation of the Project, the acreage of wetlands in Barataria Basin is predicted to be reduced by more than 80% by 2070, compared to 2020. This reduction in habitat is anticipated, as predicted by Turner (1977), to result in an overall reduction in brown shrimp over time, for both The Future With Project and the Future Without Project scenarios. Differences in brown shrimp HSI scores between the 2 scenarios narrow even further by 2070, compared to the earlier time periods. For 2070, the average and maximum decreases in HSI score across polygons in the mid-basin for The Future With Project compared to the Future Without Project are 0.05 and 0.11, respectively, while the average and maximum decreases in HSI scores across polygons in the lower basin are 0.06 and 0.10, respectively. This increasing similarity in HSI values results from more similar salinities between the 2 scenarios over time, as well as increased vegetation cover under Future With Project. Because the Project is anticipated to cause some accelerated loss of wetlands in the Birdfoot Delta, minor impacts to brown shrimp habitat are expected to that area during the long-term periods of analysis. However, any potential impacts to brown shrimp recruitment into areas adjacent to the outfall would be the same as for the near-term period of analysis, as would potential impacts to growth rates of juveniles and subadults. As wetlands are lost over time in areas farther from the diversion outfall, tidal channels and waterbodies are expected to widen and current velocities during high-discharge periods should decrease. If discharge flows have the potential to impact recruitment during the near-term, such impacts are projected to decrease where wetland loss is occurring. There are no anticipated long-term Project impacts to brown shrimp habitat within the upper basin or Birdfoot Delta. Because of the overall land loss in the basin by 2070, it is not expected brown shrimp abundance and biomass would be significantly reduced in the future compared to current conditions under both the Future With Project and Future Without Project scenarios.

Synthesis

Across the 3 time periods, the implementation of the Project would result in reductions of habitat quality for brown shrimp. Operation of the diversion, especially when the diversion is running at maximum capacity, would likely preclude use of the mid-basin near the diversion by brown shrimp and decrease, but not eliminate, the suitability of the lower portions of the Barataria Basin for small juvenile brown shrimp. Operation of the diversion could also affect brown shrimp recruitment into portions of the estuary closest to the diversion outfall and could negatively affect growth rates which would result in an overall loss of brown shrimp biomass. No impacts to brown shrimp habitat are expected in the upper basin or Birdfoot Delta. In the near-term, habitat suitability for brown shrimp juveniles in Future With Project is expected to decrease in the mid and lower basin regions as compared to the Future Without Project scenario. In the long-term, habitat suitability for brown shrimp juveniles in Future With Project is expected to be only slightly decreased in the mid and lower basin regions as compared to the Future Without Project scenario. These negative impacts in the mid- and lower basin will be greatest closer to the diversion outflow and in the near-term. Although brown shrimp abundance in Barataria Basin is expected to decrease greatly in the future both with and without operation of the Project as wetlands supportive of brown shrimp productivity are lost, the Future with Project is projected to have major negative effects to brown shrimp.

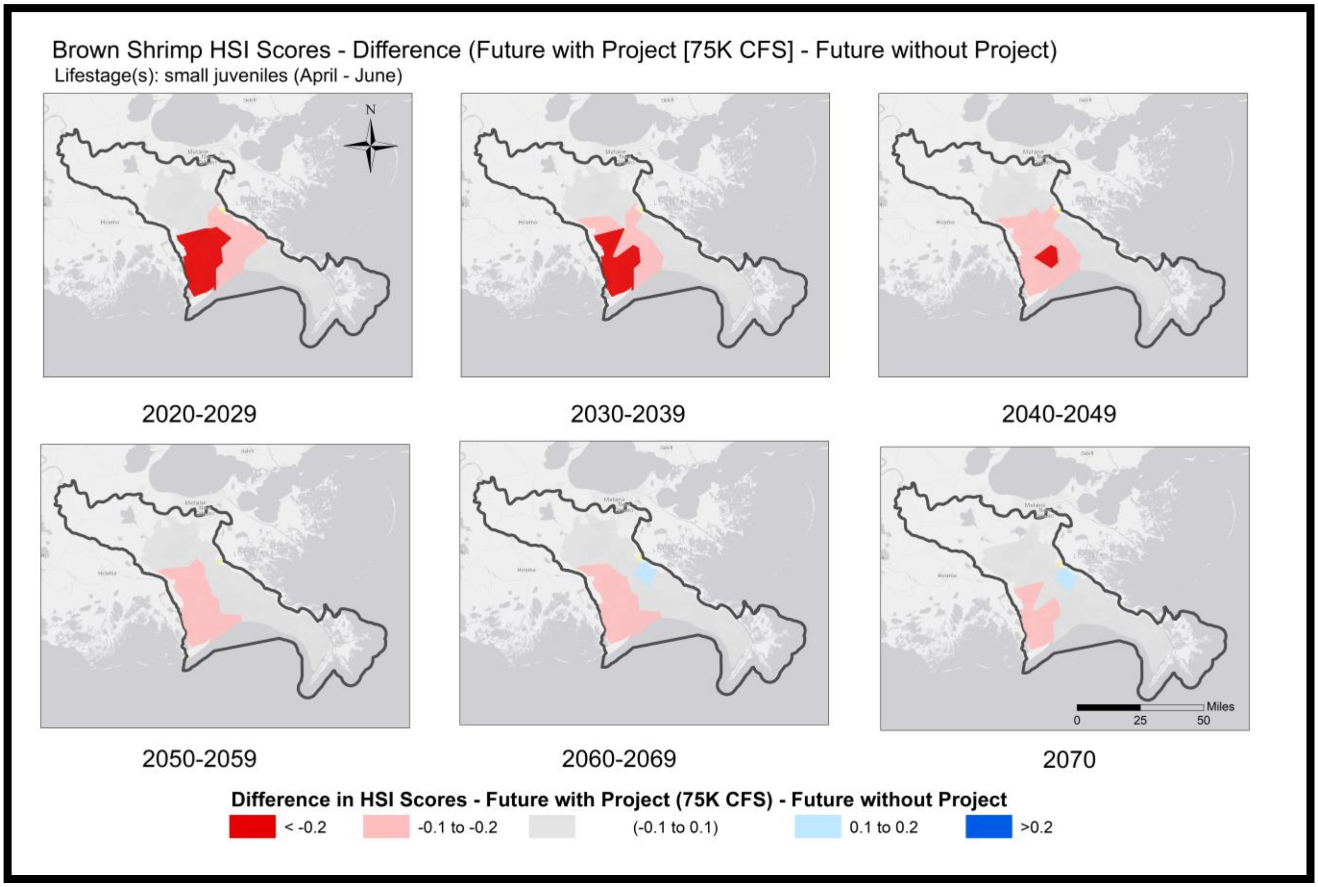


Figure 6.7.2-1. Brown Shrimp HSI Scores Comparing Future With and Without Project

6.7.4 Red Drum

Near-Term (2020 – 2029)

Because red drum spawning activity occurs offshore, and eggs and larval life stages are found primarily offshore, the Project is not expected to directly affect spawning adults, eggs, or early larval life-stages. Salinity appears to be an important factor in egg hatching and larval survival for the first 24 hours after egg hatching, with higher mortality in freshwater (Buckley 1984). Because red drum spawn offshore, outside of Barataria Basin and the Project area, eggs and larvae less than 24 hours old are not anticipated to be exposed to salinity decreases associated with diversion operation. In the unlikely event that young larvae are transported into Barataria Basin when the diversion is flowing and low salinity water is present near the barrier islands, then larvae could be subject to higher mortality.

Migration of red drum postlarvae into Barataria Basin is unlikely to be adversely affected by the outflow of freshwater from diversion operations. The analysis summarized in Section 6.5.8 shows that even at high discharge rates, flow velocity and direction are changed very little in both Barataria and Bastian Passes. Therefore, the recruitment of red drum postlarvae into Barataria Basin should not be impacted by the Project if it were to be flowing in excess of base flow during immigration periods.

Model outputs of water velocity suggest operation of the Project above base flow could have some impact on red drum postlarvae movement to wetlands and water bodies in that portion of Barataria Basin south of Wilkinson Canal and north of Barataria Bay near Barataria Bay Waterway. During periods of greater than base flow conditions, there is a tidal signature, and bi-directional flow in these channels should be able to occur on a daily basis. However, the duration of flood tide events appears reduced with diversion operations as compared to the Future without Project and ebb tide velocities are greater. This suggests red drum postlarvae would have a reduced amount of time to recruit into those portions of Barataria Bay during periods when the diversion is operating above base flow and would have to move out of the main channel and into channel margins or other areas of refugia to avoid being displaced by faster than normal ebb tides. The potential for such an impact is unlikely given that red drum postlarvae are generally present in the Barataria Basin during the fall and winter when diversion outflows are generally expected to be at base levels. There are many locations and other possible pathways where tidal patterns may be unaffected by diversion operations and recruitment to the central and eastern portions of the mid-basin would be unaffected even when the diversion is flowing above base flow.

Young red drum are euryhaline and have been captured at salinities ranging from 0 ppt to 50 ppt and water temperatures from 13 °C to 30 °C (NOAA 1992, GMFMC 2016); there is even potential to rear postlarval red drum in inland freshwater aquaculture systems (Vela et al. 2018). Studies of red drum survival in freshwater suggest that juveniles (57 days old) have comparable survival and food conversion efficiencies in both fresh and saltwater (35 ppt) (Crocker 1981). However, red drum do expend energy to maintain osmoregulation, and the metabolic cost increases as salinity decreases—for example, a salinity decrease from 10 ppt to 1 ppt results in a metabolic cost increase of 10% (Wakeman and Wohlschlag 1983).

Red drum juveniles and sub-adults also have broad salinity and temperature tolerances (Buckley 1984, NOAA 1992, GMFMC 2016). Wakeman and Wohlschlag (1983) report that red drum can adapt rapidly to changing salinities as low as 1 ppt, and juvenile and adult red drum can tolerate temperatures ranging from 5 °C to 30 °C (NOAA 1992, GMFMC 2016). Thus, even when the Project diversion flows are running at full capacity, it is unlikely that the diversion would result in conditions outside of the tolerance of red drum juveniles and sub-adults. However, optimal salinities for red drum juveniles and adults reported in the literature range from 20 ppt to 40 ppt. Outside of this optimal range, individuals are expected to incur slightly higher metabolic costs to maintain osmoregulation which may reduce fitness. Thus, red drum, particularly as larger adults, would most likely prefer habitats with higher salinity, such as the southern lower basin, barrier islands, and Birdfoot Delta, although these areas are not predicted to be in the optimal salinity range even under the Future Without Project condition. Reductions in salinity caused by Project operations would impose a metabolic cost on red drum, as indicated above.

Near-term freshwater additions to the basin are anticipated to shift saline and brackish marsh habitats to brackish and intermediate marsh habitats composed of more freshwater-tolerant species. With this transition, there is potential for reductions in prey biomass during initial high flow periods and as the estuary transitions to freshwater and brackish marsh habitats. As Barataria Basin supports a complex, multi-branched detrital-based food web, significant impacts to prey availability are not anticipated because detrital energy sources may compensate for any turbidity driven loss of phytobenthos (Rose et al. 2019). The introduction of freshwater flow from the diversion may cause changes in the composition of prey items; however, red drum, as opportunistic predators, are anticipated to be able to feed on a diverse array of available prey resources.

Operation during the Future With Project scenario is not expected to appreciably impact marsh availability in the near-term; however, prey resources from the river (e.g., shad and other riverine fish species) delivered through the diversion may represent foraging resources to red drum. deMutsert and Cowan (2012) reported that operation of the Caernarvon Freshwater Diversion appeared to increase red drum biomass per individual because of increases in food abundance associated with the diversion resulting from increased secondary productivity stimulated by increased nutrients and primary productivity. The authors further suggested that increases in biomass per individual could result in increased survival and spawning success for red drum. Similar increases in prey abundance are anticipated in Barataria Basin when the Project is operational. However, for red drum to have an overall benefit from operation of the

Project, the increase in prey abundance associated with the diversion would need to offset the metabolic costs to red drum of existing in lower salinity water. Although this potential tradeoff is difficult to quantify, the status of red drum as opportunistic predators with broad salinity tolerance suggest that operation of the Project would be likely to increase both biomass per individual and abundance of red drum as compared to the Future Without Project due to likely increased prey abundance.

Mid-Term (2050 – 2059)

During the mid-term period of analysis, operation of the Project is expected to have similar effects on red drum as during the near-term period of analysis, including benefits of increased prey abundance and impacts of higher metabolic costs associated with fresher conditions. By 2050, the diversion is predicted to account for the creation and maintenance of more than 17,000 acres of wetlands primarily in mid-Barataria. Red drum are opportunistic predators that are known to occupy and make extensive forays into freshwater systems; they are expected to use available prey resources in a range of salinities down to and including 0 ppt. The marsh created and sustained by the diversion will directly or indirectly benefit the productivity of red drum prey species like Penaeid shrimp, blue crab, and smaller finfish. The diversion also will provide nutrients that may benefit the aquatic food web and SAV cover. However, the nutrients and contaminants introduced into Barataria Basin by the diversion could also impact red drum and its prey if higher nutrients led to areas of decreased oxygen availability (particularly in locations with limited circulation such as canals) or contaminant levels increased. Fish tissue sampling conducted at Davis Pond 6 years after the diversion opened found statistically higher values for nickel, selenium, total aliphatic hydrocarbons, total organochlorines, total DDT, DDE, and PCBs in post-diversion samples compared to pre-diversion samples (Jenkins et al. 2011), although, for example, the maximum concentration of PCBs detected (0.29 ppm) was well below the mean total PCBs in fish tissue in a national study (1.898 ppm) (USEPA 1992).

Operation of the Project during peak red drum postlarval immigration periods, while unlikely, should not reduce recruitment through tidal passes into Barataria Basin. Operation above base flow is unlikely to occur during periods that postlarval red drum are abundant in the action area, but if this occurs it could reduce immigration to wetlands in central and eastern portions of the mid-basin. As wetlands are lost over time in areas farther from the diversion outfall, tidal channels and waterbodies are expected to widen and current velocities during high discharge periods should decrease. If discharge flows have the potential to impact recruitment during the near-term, such impacts, while likely, should decrease where wetland loss is occurring during the mid-term periods of analysis. In areas close to the diversion outfall, recruitment impacts from high discharge periods are unlikely to change over time.

Given the above factors, it is anticipated that the Project would benefit red drum abundance and biomass during the mid-term period of project analysis as compared to Future Without

Project, despite the potential higher metabolic costs of lower salinity and potential impacts of higher nutrients and contaminants. Because the Project is anticipated to cause some accelerated loss of wetlands in the Birdfoot Delta, minor impacts to red drum habitat are expected to that area during the mid-term period of analysis.

Long-Term (2070)

By the end of the 50-year period of analysis, red drum abundance is expected to remain higher under the Future With Project scenario compared to the Future Without Project scenario. Operation of the diversion would continue to provide basic components to the aquatic food web, and diversion operations will continue to be responsible for the creation and maintenance of more than 10,000 acres of wetlands. The marsh will directly or indirectly benefit the productivity of red drum prey species like Penaeid shrimp, blue crab, and smaller finfish; and the diversion will provide nutrients that would benefit the aquatic food web and SAV cover. Given these factors, the Trustees expect that the Project would provide an overall benefit to red drum abundance and biomass for as long as the diversion continues to operate, despite the potential higher metabolic costs of lower salinity and the potential impacts of nutrients or contaminants. In general, the benefits to red drum are likely to be greater during periods when the diversion is running at base flow conditions or below, and red drum can seek out more favorable, higher salinity habitats. Because the Project is anticipated to cause some accelerated loss of wetlands in the Birdfoot Delta, minor reductions in red drum habitat are expected to that area during the long-term period of analysis.

Synthesis

Across the 3 time periods, the implementation of the Project would result in moderate positive effects to red drum. Neutral to minor negative effects could result from an increase in habitat area that is near the low end of red drum salinity tolerance, particularly from December to the following July when the diversion is more likely to be operating above baseflow. In general, however, environmental conditions are expected to improve for most life stages of red drum under Future With Project compared to the Future Without Project scenario as the diversion would create and maintain marsh and SAV habitat, increasing primary production and prey abundance. Red drum in Barataria Basin are currently regularly using areas that are measured as below optimal salinity conditions according to the HSIs. If red drum have increased metabolic costs associated with further reductions of salinity, differences are expected to minor.. Overall, the suitability of the Barataria Basin for red drum under Future With Project is expected to increase as compared to the Future Without Project scenario due to increased availability of prey items. Minor reductions in red drum habitat due to the Project are expected in the Birdfoot delta, where the Project is expected to cause some accelerated wetland loss.

6.7.5 Coastal Migratory Pelagic Fish

The Gulf of Mexico coastal migratory pelagic fish complex includes 3 species that are known or likely to occur within or near the action area. These are king mackerel and cobia. These species are associated primarily with pelagic marine habitats but each may use portions of the action area to varying degrees during specific life stages. Potential direct and/or indirect effects due to changes in estuarine dynamics caused by the Project are described by species below.

King Mackerel

King mackerel are most commonly found in coastal marine habitats with salinities greater than 32 ppt and are only rarely found in estuaries. Adults are generally found in mid-water over reefs and other hard bottomed features in areas less than 80 meters deep. These types of habitat features are not present in the action area. Within the action area, adults are found in the water column in nearshore areas. In contrast, early juveniles are commonly found in shallow marine waters (less than 9 meters deep), conditions which are present seaward of the barrier islands at the mouth of the Barataria Basin. Planktonic king mackerel larvae are commonly found in the north central and northwestern gulf outside of the action area at water depths of more than 35 meters, where they enjoy enhanced growth rates from high productivity associated with the Mississippi River plume. These habitat preferences indicate that these life stages are likely present along in marine habitats on the outer boundary of the action area. The distribution of suitable marine habitats for adult and juvenile king mackerel, as determined by the location of estuarine fronts and the outer bound of the river plume, may shift as a result of the Project, but the proposed action would not significantly alter the overall quantity and availability of suitable marine habitat. Juveniles occur in the vicinity between May and October, suggesting that individuals arriving early months would be the only ones to experience effects from the diversion operating above base flows. The project would periodically reduce salinity in Barataria Bay but these effects would not substantially reduce overall habitat availability for this species. In contrast, increased food web productivity (as discussed in Section 6.5.9) in the action area would increase prey availability for this species including schooling fish a such as Bay Anchovy, Menhaden and penaeid shrimp relative to the Future Without Project. The effects of the Project on king mackerel EFH are expected to be neutral.

Cobia

Cobia are a pelagic marine species that are primarily found as juveniles and adults in open waters in proximity to hard substrates. However, cobia are known to spawn in saline coastal bays and estuaries and larvae are commonly observed in estuarine habitats with salinities greater than 18.9 ppt. The Project would decrease salinity in Barataria Bay in most months of the year, although these effects would only be pronounced during diversion operations in winter and spring when cobia are less likely to be present. In contrast, salinity would increase in Bastian Bay and associated estuary habitats near the mouth of the Birdfoot Delta during those same periods. Salinity effects would decrease as diversion flows drop to baseflow levels by early summer, reaching negligible levels from early July through September. This suggests that habitat suitability for cobia spawning and rearing during spring could be affected in the early part of the year but these effects would diminish during the summer and fall spawning peaks. These diversion effects would be offset over time by advancing sea level rise such that the saline habitats in Barataria Bay and adjacent coastal shelf are likely to remain suitable for cobia spawning and rearing, although this area is also influenced by Mississippi River flow interactions. Therefore, the Project is not likely to significantly reduce the quality and quantity of EFH for this species.

6.7.6 Reef Fish

The Gulf of Mexico reef fish complex includes 2 species that may occur in marine waters within the action area boundary: the gray snapper and lane snapper.

6.7.7 Lane Snapper

Lane snapper have relatively specific temperature (15.0 °C and 27.5 °C) and salinity (19 ppt and 35 ppt) requirements (Springer and Woodburn 1960) that likely limit species distribution Barataria Basin to the more marine habitats in Barataria Bay and coastal passes between barrier islands and nearshore environments outside the barrier islands. Studies of feeding habits of juvenile lane snapper suggest that decapods (shrimp), amphipods, and fish, primarily anchovies, are the primary prey items (Franks and Vanderkooy 1999). Changes in salinity may reduce the proportion of Barataria Basin that will be used by lane snapper as nursery areas, however juveniles are most common in the late summer to early fall when the diversion is operating at base flow. Therefore, changes in salinity from the Project are less likely to affect juveniles in the southern portions of the basin. Some prey items are predicted to respond positively to influence of the Project; however, brown shrimp may be negatively affected by the Project. Declines in shrimp may be offset by potential increases in blue crab or other prey items. Delft 3D modeling suggests that conditions for another preferred prey item, bay anchovy, would likely recover from near-term habitat effects and would increase in abundance over the long-term relative to the Future Without Project. Collectively, the combined habitat effects of the Future With Project to lane snapper and their EFH are expected to be minor negative relative to the Future Without Project.

6.7.8 Gray Snapper

Adult gray snapper are found throughout the Gulf in estuarine, nearshore, and offshore marine habitats, associated with hard bottom, soft bottom, reef, sand/shell, bank/shoal, and emergent marsh habitats. Juvenile gray snapper are regularly found in inshore waters including estuaries, often found in seagrass beds and over mud bottoms (GMFMC 2016). Juvenile gray snapper are found in waters between 13 °C and 32.5 °C (Springer and Woodburn 1960). Juveniles and adults can tolerate a wide range of salinities between 1 ppt and 35 ppt (Starck 1970, Serrano et al. 2011).

Based on the presence of suitable salinity and temperature conditions and abundant prey availability, juvenile gray snappers are likely present throughout much of the lower Barataria Basin. Gray snappers are tolerant of a broad range of salinity conditions making them relatively insensitive to the salinity effects of the Project and therefore likely to continue to use Barataria Basin habitats. However, the abundance and distribution of some prey species may change in response to changes in estuarine dynamics. Gray snapper have similar feeding habitats to lane snapper; however, anchovy may be a greater proportion of their diet compared to lane snapper (Francks and Vanderkooy 1999). Some prey items are predicted to respond positively to influence of the Project; however, brown shrimp, a preferred prey item, are predicted to be negatively affected by the Project. Other prey items, including bay anchovy, are predicted to have neutral or minor beneficial responses to the project. These findings suggest that the Future With Project could have minor negative effects on adult gray snapper relative to the Future Without Project.

6.7.9 Highly Migratory Species

Members of the highly migratory species complex known or likely to occur in the action area and vicinity include 6 shark species, 2 billfish, and Atlantic yellowfin tuna. The predicted effects of the proposed action on these species and EFH are described by species grouping below.

Sharks

There is little information about the distribution of shark species in and near Barataria Basin. Limited catch data (LDWF, unpublished data) indicates that the abundance of sharks in the area are as follows, from most abundant to least: bull shark, blacktip and Atlantic sharpnose shark, spinner shark, finetooth shark, bonnethead shark, and scalloped hammerhead shark. These patterns follow habitat use expectations for each species as bull sharks are recognized as using a diversity of habitats with salinities ranging from 15 ppt to 33 ppt (NMFS 2006). All of these shark species use habitats from shoreline to depths of 25 meters to 200 meters during neonate or juvenile life stages. These neonate juvenile life stages may be associated with muddy bottoms and seagrass beds (NMFS 2006). Apart from bull sharks, these species tend to be found in salinities of 20 or higher.

Temperature, salinity, and DO conditions can affect the physiology of sharks by affecting metabolism, osmotic balance, or acid-base status. Decreasing salinities as a result of diversion operations may reduce the area of Barataria Basin used by shark species. Much of the current habitat use is likely in the lower portions of Barataria Basin and juveniles and subadults. Catch data indicates sharks are caught in areas near the barrier island passes and Birdfoot Delta (LDWF, unpublished data). Bull sharks experience a stress response associated with metabolic and respiratory acidosis at the low end of their salinity tolerances or the high end of their temperature tolerances (Hyatt et al. 2018). The impact from low salinity had less impact than high water temperatures; however, there may also be synergistic effects in cases where hyposalinity and high temperatures co-occur. Since the Project is expected to introduce relatively cool water from the Mississippi River into Barataria Basin, the periods of Project-induced low salinity are not expected to co-occur with high temperatures in most years. Furthermore, while studies indicate rapid transitions from saltwater to brackish water may generate stress responses including metabolic alkalosis, when slowly acclimated to brackish water there may be minimal stress response in some fish species (Gaumet et al. 1994).

In addition to metabolic effects, sharks are likely to be influenced by the availability of SAV and prey items. As described in Section 6.6.3, the Project is expected to result in greater acreage of estuarine wetlands and SAV, which may provide nursery habitats for neonate and juvenile sharks including bull sharks which use low salinity habitats. Other shark species are likely to continue to use the lower Barataria Basin in the vicinity of the barrier islands. However, these habitats are expected to form in portions of Barataria Basin that will have relatively fresh water, which may limit their use by sharks. Sharks consume a wide diversity of prey items, and responses of potential prey items to the Project are diverse. Sharks are known to travel large distances, occasionally through unfavorable habitats, in pursuit of prey items. Therefore, it is likely that sharks will continue to use Barataria Basin for feeding opportunities resulting in a neutral effect on this EFH species from the Project.

Yellowfin Tuna

Yellowfin tuna are a wide-ranging, pelagic, predatory fish species found in tropical, subtropical and temperate ocean waters around the globe. Research on primary habitat associations indicates this species tolerant of and may prefer relatively low oxygen waters (< 0.2 mmol/L), although salinity conditions were of limited value for predicting distribution compared with other tuna species (Arrizabalaga et al. 2015). Larval yellowfin tuna are known to associate with the frontal edge of the Mississippi River plume during summer (June to September), with maximal growth observed at salinities of 31 ppt and temperatures of 29 °C (Lang et al. 1994). Available information suggests that yellowfin may opportunistically use the plume front for spawning and larval development. The location of the front varies seasonally and annually depending on Mississippi River discharge, and yellowfin tuna appear to adjust habitat use accordingly. The Project would redirect a portion of Mississippi River outflow to the Barataria Basin, primarily during high discharge conditions. This could minimally influence the location of the frontal zone of the plume, but it would not significantly affect the oceanographic processes that form productive habitats along the plume edge or the current and upwelling features that provide incubation and larval rearing habitat. The frontal plume will continue to occur in similar areas to the existing plume and will continue to have similar temperature and salinity conditions. Given the ability of yellowfin tuna to adapt to existing patterns of seasonal and interannual variability, the Project would not be expected measurably affect EFH for this species.

Sailfish

Sailfish are highly migratory species that are most common in the open ocean. Sailfish spawning occurs in suitable habitats throughout the northern Gulf of Mexico. Planktonic eggs and larvae and early juvenile life stages of sailfish are found in association with the Gulf Loop Current, seasonal current eddies, and frontal upwelling south of the Mississippi River delta (Rooker et al. 2012). These habitats are outside of the action area. However, highly mobile adults and juveniles could periodically occur near or within the outermost bounds of the action area in pursuit of prey, particularly in high productivity areas along the frontal edge of the Mississippi River plume. The Project would redirect a portion of Mississippi River outflow to the Barataria Basin, primarily during high discharge conditions. This could theoretically influence the location of the frontal zone, but it would not significantly affect the oceanographic processes that form productive habitats along the plume edge or the current and upwelling features that provide incubation and larval rearing habitat. Moreover, the location of front varies seasonally and annually depending on Mississippi River discharge under existing conditions, and sailfish are able to adjust their habitat use accordingly. These factors indicate that the Project would not significantly affect EFH for these species.

6.7.10 Prey Items and Food Web

Bay Anchovy

Historic fishery-independent catches of nekton in Louisiana suggest that Bay anchovy are likely the most abundant species, comprising an average of 47.5% of the catch (Chesney et al. 2000). Across the 3 time-periods, the implementation of the Project would result in no injurious negative effects to bay anchovy. High flows through the diversion during spring and summer could impact bay anchovy spawning activity during a portion of their known nearly year-round spawning period. Such impacts to spawning could reduce their overall abundance in the Barataria Basin in the near term. Operation of the diversion will result in neutral or very minimal changes to the calculated habitat suitability values for bay anchovy, across all locations and time-periods (average differences in HSI scores are less than 0.1 in all polygons). During the mid-term and long-term period of analysis, it is believed bay anchovy abundance will increase as compared to the Future Without Project. This increase is based on higher quantities of marsh acreage with the Project compared to the Future Without Project and increased primary productivity supportive of the bay anchovy food web. Such increases are expected to more than offset seasonal adverse impacts to spawning activity and immigration to a small portion of the basin. Overall, neutral to minor beneficial effects to bay anchovy are anticipated in Barataria Basin due to the project.

In the Birdfoot Delta, bay anchovy abundance will likely decrease in both the future both with the Future With Project and the Future Without Project due to the local wetland loss expected to occur. Due to the induced loss of wetlands in the Birdfoot Delta caused by the operation of the Project, neutral to minor negative effects to bay anchovy in the Birdfoot Delta would occur.

Gulf Menhaden

Across the 3 time-periods, the implementation of the Project would not result in impacts to Gulf menhaden. Operation of the diversion will result in neutral or very minimal changes to the calculated habitat suitability values for Gulf menhaden, across all locations and time periods. Three polygons show increases greater than 0.1 during the initial decades of operations and 1 polygon shows a slight decrease during 1 time. While operation Project may impair recruitment of Gulf menhaden postlarvae to portions of the Barataria Basin in close proximity to the outfall location, such impacts are expected to be localized and short in duration.

Overall, the Project is expected to provide moderate benefits to Gulf menhaden as compared to the Future Without Project by maintaining primary productivity supportive of their food web. While it is operating, the diversion is expected to provide benefits to Gulf menhaden by reducing salinity, supporting primary productivity and associated food web benefits, and creating and maintaining marsh habitat. It is predicted that Gulf menhaden abundance and biomass would be reduced in the future compared to current conditions under both the Future With and Future Without Project scenarios. The Project is not expected to have measurable effects to Gulf menhaden in the Birdfoot Delta because the Project should not affect conditions in the delta that are strongly correlated with their abundance.

Atlantic Croaker

Across the 3 time periods, the implementation of the Project would result in no measurable effect to Atlantic croaker. Operation of the Project will result in lower HSIs in most polygons in the near-term due to increases in water depth caused by diversion flows. During the mid-term and long-term periods of analysis, operation of the Project is expected to result in positive increases in HSI in the polygons closest to the diversion outfall due to sediment input maintaining shallow water conditions in those areas.

Overall, the Project is expected to provide benefits to Atlantic croaker by the maintenance of some vegetative habitat supportive of the Atlantic croaker food web and by decreasing water temperatures in portions of the mid and lower basin during postlarval, juvenile and subadult life stages. There should be greater abundance of Atlantic croaker during the mid-term and long-term periods of analysis. During the near-term, Atlantic croaker abundance with the Project should be similar to the Future Without Project. However, even with the Project, it is likely Atlantic croaker abundance will be somewhat decreased in the future compared to current conditions as habitat supportive of their food web decreases significantly over time. Because operation of the Project is expected to cause minor wetland loss in the Birdfoot Delta, negligible negative effects to Atlantic croaker is expected in the Birdfoot Delta.

Spotted Sea Trout

Across the 3 time periods, the implementation of the Project would result in some negative impacts to spotted sea trout. High flows through the diversion in the summer and fall could impact spotted sea trout spawning and early life-stages, but this time period is when high flows are least likely (diversion was predicted to operate above base-flow 24% of the days between June and November, based on Delft modeling). Additionally, flows above base could impact recruitment of larvae and juveniles into wetlands and waterbodies in the central and eastern portions of the mid-basin. In the near-term, habitat suitability for spotted seatrout juveniles is expected to be nearly equivalent between the Future With and Future Without Projects scenarios because of the broad salinity tolerance of juveniles. While spotted sea trout have been collected in salinities as low as 0.2 ppt (Perret 1971), spotted sea trout in low salinity conditions require more energy to maintain osmoregulation. Wohlschlag and Wakeman (1978) found that metabolic rates at low salinities (below 10 ppt) were double rates at the optimal salinities. This is a far greater metabolic cost than other euryhaline species in Barataria Basin, such as red drum. Therefore, spotted sea trout are anticipated to have declines in use of Barataria Basin and may have lower biomass. In addition, minor negative impacts could result if increased nutrients or contaminants decrease habitat quality for spotted seatrout and its prey. Long-term operation of the diversion will increase the suitability of polygons closest to the diversion for spotted sea trout juveniles, while resulting in little change in other locations. Maintenance of primary productivity and vegetated habitats in the mid-basin will increase spotted seatrout prey availability throughout the Barataria Basin over that expected without the Project. Adult spotted seatrout may relocate away from areas of the basin affected by the diversion discharge. Overall, suitability of Barataria Basin for spotted seatrout under the Future With Project is expected to decrease compared to that under the Future Without Project scenario.

Southern Flounder

In the near-term, operation of the Project is expected to result in neutral to minor negative effects to southern flounder in Barataria Basin. Minor negative effects due to temporary shifts in prey composition and distribution are possible, especially around the outfall area in early years while freshwater marsh areas establish. Throughout the Project's lifespan, minor negative effects are possible due to suboptimal salinity affecting early postlarvae southern flounder; however, later life history stages are not anticipated to be affected. In the long-term, compared to the Future Without Project, southern flounder are expected to also experience benefits under the Future With Project because of the creation and preservation of nursery and foraging habitat within the Barataria Basin, in addition to support of the food web by diversion operations. Overall, southern flounder in Barataria Basin are expected to experience neutral to minor negative impacts due to the Project.

Because the Project is anticipated to cause some accelerated loss of wetlands in the Birdfoot Delta, minor negative impacts to southern flounder habitat are expected to that area during the long-term period of analysis.

6.8 Cumulative Effects

Cumulative effects assessments consider the impact on the environment from the incremental impact from the proposed action added to other past, present and reasonably foreseeable future actions. Cumulative effects can result from actions that do not have an effect as individual actions, but when considered as a set of actions results in a potential impact. Federal actions unrelated to the proposed action are not considered in this section because they require separate consultation pursuant to MSA. Most activities in the area are occurring in aquatic habitats that will require and be subject to federal permitting and will not be included in the cumulative effects analysis. Potential pathways of cumulative effects are described in the following sections.

6.8.1 Past, Present, and Ongoing Actions and Trends

The following past, present, and ongoing actions and trends were identified as impacting the project area resources and were included in baseline of the analysis of Project impacts. They are described below:

- **Levees and channelization of the Mississippi River**: These actions have caused major, adverse, permanent impacts on the Barataria Basin by altering natural sediment transport from the river into the basin, removing the source of sediment and fresh water that built and maintained wetlands and marshes. As a result, the basin is suffering from significant coastal habitat loss (USGS 2015, CPRA 2012). Without the Project, this reduced input of sediment due to Mississippi River levees would continue to cause major wetland loss in the Barataria Basin.

- **Subsidence and sea-level rise**: These ongoing trends continue to be a primary cause of major, adverse, permanent impacts on Barataria Basin wetland and land loss by increasing flooding frequency and duration, marsh vegetation break-up, and erosion (BTNEP 2010, Couvillion et al. 2017). Subsidence and sea-level rise were factored into the baseline conditions and Project alternatives over the 50-year period of analysis for all resources. The SLR value simulated for all model runs was an increase of 2.2 feet (0.7 meter) by 2070 compared to year 2020 sea levels, or 4.9 feet (1.5 meters) by year 2100.

- **Storm and hurricane events**: These ongoing major, adverse events will continue to cause loss of life, major economic damages, and outmigration of residents and businesses. They also convert wetlands to open water from erosion when large storm surges bring salt water inland (Day et al. 2007).

- **Canals dredged in the Barataria Basin for navigation and oil and gas development**: Canals and channels in the basin provide a conduit for saltwater intrusion and obstruct the natural hydrology and sheet flow of water across and through marsh, causing marsh loss and impoundment (Cowan et al. 1988 from Boesch et al. 1994, Swenson and Turner 1987).

- **2010 DWH oil spill**: This major disaster was the direct cause of a minimum of 850 miles of shoreline oiling in coastal Louisiana, with the most widespread oiling occurring in Barataria Bay salt marshes (DWHNRDAT 2016). The consequences of the spill included major adverse impacts on aquatic resources, including marsh vegetation, intertidal biota (for example, fiddler crabs), and shoreline erosion (Zengel et al. 2015). This catastrophic event is the basis of the purpose and need of the MBSD Project which is to help restore habitat and ecosystem services injured by the DWH oil spill. The impacts of the DWH oil spill are captured in the baseline conditions of the Project area.

- **Shoreline and marsh restoration projects**: the Delft3D Basinwide Model incorporates past or recently completed restoration projects into the baseline conditions of Project-area topography, bed elevations, hydrology, water quality, and wetland conditions.

- **Rivers and diversions**: Within the Delft3D Basinwide Model, numerous rivers are applied at the model boundary. The rivers carry freshwater, sediments, and nutrients into the model domain. Additionally, the model incorporates the impacts of the following natural and man-made diversions that allow Mississippi River water to leave: the Davis Pond Freshwater Diversion (see more information about this diversion below), the Bonnet Carré Spillway, the Caernarvon Freshwater Diversion, Mardi Gras Pass, the West Point A La Hache Siphon, and various passes in the Birdfoot Delta. Ongoing operations and influences of rivers and diversions were incorporated into the Delft 3D Basinwide Model baseline conditions and 50-year projections for hydrology, hydrodynamics, water quality, vegetation/wetlands, and other resources in the Project area.

- **Davis Pond Freshwater Diversion**: Ongoing operations and influences of this diversion were incorporated into the Delft 3D Basinwide Model baseline conditions and 50-year projections for the MBSD and the FWOP. This diversion operates at a minimum of 1,000 cfs flow with the capacity to divert up to 10,650 cfs of water from the Mississippi River at RM 118 ABH (approximately 15 miles upriver from New Orleans). The diversion introduces freshwater, sediments, and nutrients into the marshes of the northern Barataria Basin.

6.8.2 Reasonably Foreseeable Future Projects

The following 3 projects are reasonably certain to occur within the timeframe and general area of the proposed Project and will not involve or require federal permits or actions. These 3 projects are considered in the cumulative effects analysis and are described below.

These included the following types of projects:

- municipal;
- major industrial development; and
- recreation.

Table 6.8.2-1 lists each project considered in the cumulative effects analysis, its distance from the MBSD Project, and the resources that each would potentially impact. None of these 3 reasonably foreseeable projects assessed were incorporated into the Delft3D Basinwide Model, as they all occur upland and would not impact areas large enough to be captured in the Delft3D Basinwide Model resolution.

Table 6.8.2-1. Reasonably Foreseeable Future Projects Considered in the Cumulative Effects Analysis

Project Name/ Proponent	Project Type	Closest Distance to Project Location	Description and Status	Estimated Construction Timing	Resources with Potential Cumulative Effects
Braithwaite Methanol Plant/CCI Port Nickel LLC	Major Industrial	13.0 miles	Methanol manufacturing facility with 5,000-metric ton daily production capacity (1.8 million tons per annum) of feedstock natural gas from an unspecified connection. The schedule for the construction is unknown. Air permit received from LDEQ in December 2019.	2020 – 2023	Commercial Fisheries
Bayou Segnette State Park Improvements/ CPRA	Recreational Use	19.1 miles	Infrastructure improvements in Bayou Segnette State Park in Jefferson Parish, including upgrades to an existing boating area to improve access, upgrades to a playground to comply with ADA requirements, and repairs to road and parking areas damaged by repeated flooding.	2020	Commercial Fisheries
Pumping Capacity Improvements Phase I/ LDEQ/CPRA & Fresh Water District	Municipal	67.5 miles	Construction of a pump station on the Mississippi River at Donaldsonville in Ascension Parish with a minimum pumping capacity of 1,000 cfs alongside the existing 500-cfs pump station, thereby tripling the capacity for fresh water entering Bayou Lafourche to combat saltwater intrusion and provide fresh drinking water to over 300,000 residents in Assumption, Ascension, Lafourche, and Terrebonne Parishes.	Unavailable	Aquatic Resources, ESA Species; Commercial Fisheries, Marine Mammals

6.8.3 Potential Cumulative Effects on Each Resource

None of the foreseeable projects have the potential to contribute to cumulative effects on federally managed species and EFH within the Project action area; therefore, there are no anticipated cumulative effects during construction or operations of the MBSD Project. The potential projects and impacts pathways for cumulative effects are described below.

Aquatic Resources

Potential impacts from the upland foreseeable project of the Pumping Capacity Improvements Phase I/ LDEQ/CPRA & Fresh Water District are expected to be minor and highly localized, and would not contribute to cumulative effects to aquatic resources during construction or operations of the MBSD Project.

Commercial Fisheries

None of the foreseeable projects have the potential to contribute to cumulative effects to commercial fisheries in the Mississippi River or Barataria Basin areas of the Project action area. The 3 upland foreseeable projects are small enough in scale and spread out enough that they are not likely to create traffic disruptions, or disrupt commercial fishing activities.

Potential minor positive impacts by the Bayou Segnette State Park Improvements/ CPRA are possible through increased water access as a result of the project, but the impact to commercial fisheries within the Project action area would be discountable. Potential impacts from the upland foreseeable project of the Pumping Capacity Improvements Phase I/ LDEQ/CPRA & Fresh Water District are expected to be minor and highly localized, and would not contribute to cumulative effects to aquatic resources or commercial fisheries during construction or operations of the MBSD Project. Therefore, there are no anticipated cumulative effects from underwater noise levels during construction or operations of the MBSD Project.

7.0 DIFFERENCES BETWEEN PROJECT ALTERNATIVES

The MBSD Project development includes evaluation of several alternatives, with the Future With Project being the 75,000 cfs diversion with no terraces. Alternatives represent variations in the maximum capacity of the diversion (between 50,000 and 150,000 cfs) and whether terraces are constructed in the outfall area to influence sediment distribution and deposition.

There are minor differences in construction effects, with all alternatives requiring the same construction activities in the same general areas. The 50,000 cfs diversion alternative is predicted to require slightly less dredging and a slightly smaller outfall footprint, while the 150,000 cfs diversion alternative is predicted to require more dredging and an incrementally larger dredging footprint. These differences are minor and result in the same overall effects and effect determinations.

The Project alternatives affect the maximum capacity of the diversion operations and therefore the maximum volume of water and sediment that can be delivered to the Barataria Basin both instantaneously and over time during operation of the Project. Since the alternatives all rely on Mississippi River flow to control flow rates up to 50,000, 75,000, and 150,000 cfs, the differences are limited to the peak flows. All diversion alternatives have the same flow conditions below 50,000 cfs. Therefore, differences occur during peak flows of the Mississippi River when its flows are above 425,000 cfs. Diversion alternatives affect the total amount of land created and the amount of wetland and SAV occurring at each time interval (Table 7.0-1). Salinity and other water quality parameters follow similar overall patterns across the alternatives, with the larger diversions creating greater magnitudes of difference during periods of peak flow (December through July).

Table 7.0-1. Summary of Differences in Habitat Type by Alternative (Acres)

Alternative	Habitat Type	Year 0 (2020)	Year 10 (2030)	Year 20 (2040)	Year 30 (2050)	Year 40 (2060)	Year 50 (2070)
Future Without Project	Fresh/Intermediate Marsh	278,055	263,687	228,245	189,581	130,898	66,381
	Brackish Marsh	80,959	73,209	55,621	29,069	11,971	6,350
	Saline Marsh	70,929	44,901	28,651	16,296	6,965	6,453
	Total	429,943	381,797	312,517	234,946	149,834	79,184
Future With Project (75k CFS)	Fresh/Intermediate Marsh	313,966	304,900	273,224	219,903	153,202	79,511
	Brackish Marsh	68,624	57,923	34,025	20,450	5,801	3,218
	Saline Marsh	47,377	23,056	16,530	11,305	7,333	6,248
	Total	429,967	385,879	323,779	251,658	166,336	88,977
50 k CFS	Fresh/Intermediate Marsh	309,601	301,435	266,289	212,207	147,253	75,839
	Brackish Marsh	69,371	58,367	37,785	22,520	6,693	3,589
	Saline Marsh	50,993	24,968	17,571	12,006	6,074	6,275
	Total	429,965	384,770	321,645	246,733	160,020	85,703
150 k CFS	Fresh/Intermediate Marsh	321,519	313,943	288,838	238,687	170,834	96,058
	Brackish Marsh	66,785	55,254	26,795	14,860	2,962	1,887
	Saline Marsh	41,420	18,476	15,442	10,978	4,788	4,341
	Total	429,724	387,673	331,075	264,525	178,584	102,286

8.0 CONCLUSIONS EFH EFFECT DETERMINATIONS

Federally managed species evaluated in this EFH Assessment use the estuarine and Gulf habitat in and adjacent to the action area during a portion of their life for spawning, food, development, and/or protection (GMFMC 2004). The Project was analyzed to determine potential impacts to EFH and federally managed species.

During construction, dredging activities are expected to temporarily affect EFH by disturbing bottom sediments and increasing turbidity in the water column near the dredging activity. These activities can have adverse effects on federally managed species. Effects from dredging in the sediment removal area are expected to be temporary; however, habitats affected by beneficial use placement of dredged sediments are expected to transition from aquatic to wetland habitat for many years or permanently.

During the operations of the MBSD, the Project is expected to have direct impacts on EFH due to the introduction of freshwater flow and sediment laden water from the Mississippi River into Barataria Basin. As a result, much of the action area will experience reduced salinities and changes in other metrics of water quality including nutrient levels and minor changes to dissolved oxygen. These water quality parameters will affect the suitability of habitat in Barataria Basin to support fishery species, with the effects varying from species to species.

Indirect impacts of the Project include beneficial effects to acreage of SAV and emergent marshes. Over the 50-year project time horizon, the resulting distribution of SAV and emergent marshes will be higher in the Future With the Project compared to the Future Without Project. Negative indirect impacts of the Project include conversion of oyster reef and sand/shell habitat to soft bottom habitat.

This assessment found that federal managed species use estuarine and Gulf habitats in and adjacent to the action area. The Project will have direct and indirect negative impacts to EFH in the action area (Table 8.0-1). The Project will also convert certain types of EFH from one category to another (e.g., water column to emergent marsh; oyster reef to soft bottom; brackish marsh to intermediate marsh, etc.). The Project will also result in beneficial impacts to EFH through the restoration and maintenance of riverine deltaic processes, including sediment delivery and marsh creation, that have been absent due to major anthropogenic modifications of the system over the last century. The project will have neutral effects to most managed species, with brown shrimp having negative effects, and white shrimp having positive effects (Table 8.0-2).

Table 8.0-1: Summary of Project Effects to EFH

Essential Fish Habitat	Summary
Emergent marshes (tidal wetlands, salt marshes, tidal creeks, rivers/streams)	- Emergent marsh acreage predicted to increase by 13,151 acres by 2070. - Marsh type shifts towards intermediate salinity.
Submerged Aquatic Vegetation (SAV; seagrasses, benthic algae)	- Net predicted increase of 2% (1,500 acres) of fresh/intermediate SAV by 2070 - SAV species shift towards fresh/intermediate salinity.
Soft bottom (mud, clay, silt)	- Dredging impacts approximately 700 acres of soft bottom habitat during construction. - Approximately 20,714 acres of habitat that would otherwise be soft bottom habitat converted to emergent marsh or SAV habitat. - Salinity decreases as a result of the project as described in section 6.5.1 may cause changes in habitat use.
Sand/shell bottom (sand, shell)	- Some existing sand/shell habitat may receive sediment and become soft bottom habitat or emergent marsh habitat.
Oyster reefs	- Freshwater conditions may reduce oyster survival, reproduction and/or growth rates. - Oyster growing conditions predicted to decline in portion of Barataria Bay as described in section 6.6.4. - Future habitat improvements in lower Barataria Bay may create new habitat for oysters.
Water Column Associated (WCA; pelagic, planktonic, coastal pelagic)	- As described in section 6.6.1, conditions in the water column and associated species may shift as water conditions shift towards fresher, cooler, higher nutrient conditions associated with water from the diversion.

Table 8.0-2: Summary of Project Effects to Managed Species

Managed Fisheries	Effect to Managed Species	Summary
Coastal Migratory Pelagic Fish		
King Mackerel (*Scomberomorus cavalla*	Neutral	Primary habitat is along front between estuarine and marine habitats. This front may shift, however will continue to exist.
Cobia (*Rachycentron canadum*)	Neutral	
Red Drum		
Red Drum (*Sciaenops ocellatus*)	Moderate Positive	Increased prey items from marsh and SAV habitat created by the Project.
Reef Fish		
Gray Snapper (*Lutjanus griseus*)	Minor Negative	Distribution may be limited to more saline portions of Barataria Basin. Some preferred prey items expected to decrease.
Lane Snapper (*Lutjanus synagris*)	Minor Negative	
Shrimp		
Brown Shrimp (*Farfantepenaeus aztecus*)	Negative	Reduced habitat quality for brown shrimp during diversion operations due to salinity reductions
White Shrimp (*Litopenaeus setiferus*)	Neutral to Minor Positive	Population ability to recruit and sustain is not expected to be affected by changes to salinity and flow. Potential for increased habitat quality due to wetland created by the Project
Highly Migratory Species		
Blacktip Shark	Neutral	Distribution not expected to be affected by changes in salinity. Prey resources are expected to be available throughout Barataria basin
Bull Shark	Neutral	
Finetooth Shark	Neutral	
Scalloped Hammerhead Shark	Neutral	
Atlantic Sharpnose Shark	Neutral	
Spinner Shark	Neutral	
Sailfish (*Istiophorus platypterus*)	Neutral	Associated with Mississippi River plume where no effects are expected
Atlantic Yellowfin Tuna (*Thunnus albacares*)	Neutral	Associated with Mississippi River plume where no effects are expected

9.0 REFERENCES

Adamack A.T., C.A. Stow, D.M. Mason, L.P. Rozas, T.J. Minello. 2012. Predicting the effects of freshwater diversions on juvenile brown shrimp growth and production: a Bayesian-based approach. Mar Ecol Prog Ser 444:155-173. https://doi.org/10.3354/meps09431

Adamack, A.T., K.A. Rose, and C.F. Cerco. 2017. Simulating the effects of nutrient loading rates and hypoxia on Bay Anchovy in Chesapeake Bay using coupled hydrodynamic, water quality, and individual-based fish models In Modeling Coastal Hypoxia. Justic, D., K. A. Rose, R. D. Hetland, and K. Fennel (eds.). Springer.

Ahrenholz, D.W. 1991. Population Biology and Life History of the North American Menhadens, Brevoortia spp. Marine Fisheries Review, 53(4), pp. 3-19.

Alleman, L.K. and M.W. Hester. 2011. Reproductive Ecology of Black Mangrove (Avicennia germinans) Along the Louisiana Coast: Propagule Production Cycles, Dispersal Limitations, and Establishment Elevations. Estuaries and Coasts 34: 1068. https://doi.org/10.1007/s12237-011-9404-8

Allen, D.M, J. Judson, J. Harold, and T.J Costello. 1980. Postlarval Shrimp (Penaeus) in the Florida Keys: Species, Size, and Seasonal Abundance. Bulletin of Marine Science, Volume 30, Number 1.

Arnold, E.L., J.R. Thompson. 1958. Offshore Spawning of the Striped Mullet, Mugil cephalus, in the Gulf of Mexico. Copeia, Vol. 1958, No. 2, pp. 130-132.

Baker, A., P. Gonzalez, R.I.G. Morrison, and B.A. Harrington. 2013. Red Knot (Calidris canutus), version 2.0. In The Birds of North America (P. G. Rodewald, editor). Cornell Lab of Ornithology, Ithaca, New York, USA. Available at: https://doi.org/10.2173/bna.563. Cornell University 2015.

Banks, P., Berrigan, M., Choudhury, A., Craig, L., Diaz, D., Kern, F., King, J., Marshall, M., Robinson, L., Steimle, F., Takacs, R., and Wikfors, G. 2007. Status review of the Eastern Oyster (Crassostrea virginica) NOAA Technical Memo NMFS F/SPO-88, Northeast Regional Office. Report to the National Marine Fisheries Service.

Baxter, K.N., and Renfro, W.C. 1968. Seasonal occurrence and size distribution of postlarval brown and white shrimp near Galveston, Texas, with notes on species identification. Fishery Bulletin, 66(1), 149–158.

Beardsley, G. L., Jr., N. R. Merrett and W. J. Richards. 1975. Synopsis of the biology of the sailfish Istiophorus platypterus (Shaw and Nodder, 1791). Pages 95-120 in: Shomura, R. S. and F. Williams. eds. Proceedings of the International Billfish Symposium Kailua-Kona, Hawaii, 9-12 August 1972. Part 3. Species Synopses. NOAA Tech. Rep. NMFS SSRF-675. 159 p.

Beck, M.W., K.L. Heck, K.W. Able, D.L. Childers, D.B. Eggleston, B.M. Gillanders, B. Halpern, C.G. Hays, K. Hoshino and R.J. Orth. 2001. The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates: a better understanding of the habitats that serve as nurseries for marine species and the factors that create site-specific variability in nursery quality will improve conservation and management of these areas. Bioscience, 51(8), 633-641.

Benson, N.G. 1982. Life history requirements of selected finfish and shellfish in Mississippi Sound and adjacent areas. U.S. Fish Wildlife Service Biol., Rep., FWS OBS-81/51, 97p.

Bernardi, G., and D.A. Powers. 1995. Phylogenetic Relationships among Nine Species from the Genus Fundulus (Cyprinodontiformes, Fundulidae) Inferred from Sequences of the Cytochrome b Gene. American Society of Ichthyologists and Herpetologists, Vol. 1995, No. 2, p. 469-473. DOI: 10.2307/1446912

Biber, P.D., E.A. Irlandi. 2006. Temporal and spatial dynamics of macroalgal communities along an anthropogenic salinity gradient in Biscayne Bay (Florida, USA). Aquatic Botany, 85(1), 65-77.

Blair, W.F., A.P. Blair, P. Brodkorb, F.R. Cagle, and G.A. Moore. 1968. Vertebrates of the United States, 2nd edition. McGraw-Hill, Inc., New York, 616 p.

Blanchet, H., M. Van Hoose, L. McEachron, B. Muller, J. Warren, J. Gill, T. Waldrop, J. Waller, C. Adams, R. B. Ditton, D. Shively, and S. VanderKooy. 2001. The spotted seatrout fishery of the Gulf of Mexico, United States: a regional management plan. S. VanderKooy, editor. Gulf States Marine Fisheries Commission, Publication Number 87, Ocean Springs, Mississippi.

Boesch, D.F., Josselyn, M.N., Mehta, A.J., Morris, J.T., Nuttle, W.K., Simenstad, C.A. and D.J. Swift. 1994. Scientific assessment of coastal wetland loss, restoration and management in Louisiana. Journal of Coastal Research, pp.i-103.

Brammer, A.J., Z. Rodriguez del Rey, E. A. Spalding, and M. A. Poirrier. 2007. Effects of the 1997 Bonnet Carré Spillway Opening on Infaunal Macroinvertebrates in Lake Pontchartrain, Louisiana. Journal of Coastal Research: Volume 23, Issue 5: pp. 1292 – 1303.

Breuer, J.P. 1957. An ecological survey of Baffin and Alazan Bays, Texas. Publ. Institute of Marine Science, University of Texas 4(2): 134-155.

Broadhead, G.C. 1953. Investigations of the black mullet, Mugil cephalus L. in northwest Florida. Fla. Board Cons. Mar. Res. Lab. Tech. Ser. No. 7, 34 p.

Broadhead, G.C. 1958. Growth of the black mullet (Mugil cephalus L.) in west and northwest Florida. Fla. Board Cons. Mar. Res. Lab. Tech. Ser. No. 25, 31 p.

Brown, S. S., G. R. Gaston, C. F. Rakocinski, and R. W. Heard. 2000. Macrobenthic trophic structure responses to environmental factors and sediment contaminants in northern Gulf of Mexico estuaries. Estuaries 23:411–424.

BTNEP (Barataria Terrebonne National Estuary Program). 2010. Shedding Light on Our Estuary & Our Economy: Environmental Indicators in the Barataria-Terrebonne Estuary System 2010. Thibodaux, LA. 36 pp.

Bush A, K.N. Holland. 2002. Food limitation in a nursery area: estimates of daily ration in juvenile scalloped hammerheads, Sphyrna lewini (Griffith and Smith, 1834) in Kane'ohe Bay, Sphyrna lewini (Griffith and Smith, 1834) in Ka¯ne'ohe Bay, O'ahu, Hawai'i. J Exp Mar Biol Ecol 278:157–178.

Callihan, J.L. 2011. Spatial ecology of adudlt spotted seatrout, Cynoscion nebulosus, in Louisiana coastal waters" (2011). LSU Doctoral Dissertations. 941. https://digitalcommons.lsu.edu/gradschool_dissertations/941.

Callihan, J.L., J. Cowan, and M.D. Harbison. 2013. Sex Differences in Residency of Adult Spotted Seatrout in a Louisiana Estuary. Marine and Coastal Fisheries Dynamics Management and Ecosystem Science, Vol. 5.

Camp, G.S. 1985. A survey of the distribution and migration of fishes in Tampa Bay. In Proc. Tampa Bay Area Sci. Info. Symp., p. 393-425.

Carle, M.V., Sasser, C.E., and H.H. Roberts. 2015. Accretion and vegetation community change in the Wax Lake Delta following the historic 2011 Mississippi River flood. Journal of Coastal Research, 31(3), pp.569-587.Carr, W.E.S., and C.A. Adams. 1973. Food habits of juvenile marine fishes occupying seagrass beds in the estuarine zone near Crystal River, Florida. Trans. American Fisheries Society. 102: 511-540.

Castellanos, D.L. and L.P. Rozas. 2001. Nekton use of submerged aquatic vegetation, marsh, and shallow unvegetated bottom in the Atchafalaya River delta, a Louisiana tidal freshwater ecosystem. Estuaries, Vol. 24, Issue 2, pg:184-197.

Castro, J.I. 1983. The sharks of North American waters. Texas A&M University Press, xii, 180 pp.

Cech, Jr., J.J., and D.E. Wohlschlag. 1982. Seasonal Patterns of Respiration, Gill Ventilation, and Hematological Characteristics in the Striped Mullet, Mugil Cephalus L. Bulletin of Marine Science, Vol. 32, No. 1, pp. 130-138. University of Miami.

Chabreck, R. 1972. Vegetation, water, and soil characteristics of the Louisiana coastal region. La. Agri. Exp. Sta., AEA Inform. Ser. No. 25, Baton Rouge, LA.

Chao, L.N and J.A. Musick. 1977. Life history, feeding habits, and functional morphology of the juvenile sciaenid fishes in the York River Estuary. Fishery Bulletin 75: 657–702.

Chavez, F.P., J. Ryan, S.E. Lluch-Cota, and M. N˜iquen. 2003. From Anchovies to Sardines and Back: Multidecadal Change in the Pacific Ocean. Science, Vol. 299.

Chesney, E.J. 2008. Foraging behavior of bay anchovy larvae, Anchoa mitchilli. Journal of Experimental Marine Biology and Ecology, Vol. 362, Issue 2, p. 117-124.

Christmas, J.Y., and D.J. Etzold. 1977. The shrimp fishery of the Gulf of Mexico United States; a regional management plan. Gulf Coast Res. Lab. Tech. Rep. Ser. No. 2(1), 125 p.

Christmas, J.Y., and R.S. Walker. 1973. Estuarine vertebrates, Mississippi. Cooperative Gulf of Mexico Estuarine Inventory and Study Mississippi, p. 320-434. Gulf Coast Research Laboratory, Ocean Springs, MS.

Christmas, J.Y., J.T. McBee, R.S. Waller, and F.C. Sutter, III. 1982. Habitat suitability models: gulf menhaden. U.S. Department of Interior, Fish and Wildlife Service, FWS/OBS 82/10.23. 23 pp.

Coen, L.D., K.L. Heck, Jr., and L.G. Abele. 1981. Experiments on competition and predation among shrimps of seagrass meadows. Ecology 62: 1484-1493.

Collette, B.B. and C.E. Nauen. 1983. FAO species catalogue. Vol. 2. Scombrids of the world. An annotated and illustrated catalogue of tunas, mackerels, bonitos and related species known to date. FAO Fish. Synop., (125) Vol 2: 137 p.

Collins, M.R. 1985. Species Profiles. Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (South Florida). Striped Mullet. Florida Cooperative Fish and Wildlife Research Unit, Gainesville.

Compagno, L.J.V. 1984. Sharks of the World. An annotated and illustrated catalogue of shark species to date. Part II (Carcharhiniformes). FAO Fisheries Synopsis, FAO, Rome.

Conner, J.C., and F.M. Truesdale. 1972. Ecological implications of a freshwater impoundment in a low salinity marsh. Pages 259-276 in Robert H. Chabreck, ed. Proceedings of the Coastal Marsh and Estuary Management Symposium, Louisiana State University, Baton Rouge.

Conner, W.H. and J. W. Day, Jr. (eds). 1987. The ecology of Barataria Basin, Louisiana: an estuarine profile. U.S. Fish and Wildlife Service Biological Report 87 (7.13). 165 pp.

Cook, H.L., and M.J. Lindner. 1970. Synopsis of biological data on the white shrimp Penaeus setiferus (Linnaeus) 1767. FAO Fisheries Report, No. 4, Issue 57, p. 1439-1468.

Courtney, L.A., and J.A. Couch. 1984. Usefulness of Cyprinodon variegatus and Fundulus grandis in carcinogenicity testing: advantages and special problems. Natl. Cancer Inst. Monogra. 65: 83-96.

Couvillion, B.R., Beck, Holly, Schoolmaster, Donald, and Fischer, Michelle, 2017, Land area change in coastal Louisiana 1932 to 2016: U.S. Geological Survey Scientific Investigations Map 3381, 16 p. pamphlet, https://doi.org/10.3133/sim3381.

Cowan, J. H. and R. S. Birdsong. 1985. Seasonal occurrence of larval and juvenile fishes in a Virginia Atlantic coast estuary with emphasis on drums (Family Sciaenidae). Estuaries 8(1): 48–59.

Cowan, J.H., Turner, R.E. and Cahoon, D.R., 1988. Marsh management plans in practice: do they work in coastal Louisiana, USA?. Environmental Management, 12(1), pp.37-53.

Cowan, J.H., and R.F. Shaw. 1988. The distribution, abundance, and transport of larval sciaenids collected during winter and early spring from the continental shelf waters off West Louisiana. Fisheries Bulletin, vol. 86, no. 1, p. 129-142.

Cowan, J.H., Jr., R.F. Shaw, and J.G. Ditty. 1989. Occurrence, age and growth of two morphological types of sand seatrout (Cynoscion arenarisus) larvae in the winter and early spring coastal waters off west Louisiana. Contrib. Mar. Sci. 31: 39-50.

CPRA (Coastal Protection and Restoration Authority). 2016. Development of the CASM for evaluation of fish community impacts for the Mississippi River Delta Management study: Model setup, calibration and validation for existing conditions (Technical) (p. 102). Baton Rouge, LA: Coastal Protection and Restoration Authority. Retrieved from ftp://ftp.coastal.la.gov/CIAP%20Deliverables/MR%20Delta%20Management%20Strategic%20Planning/Mississippi%20River%20Delta%20Management%20Study/c%20Fish%20and%20Shellfish%20Community%20Models/MRDM%20CASM%20Final%20Report.pdf

Craig, A., E.N. Powell, R.R. Fay, and J.M. Brooks. Distribution of Perkinsus marinus in Gulf Coast Oyster Populations. Estuaries, vol. 12, No. 2, pp. 82-91.

Danker, S.A. 1979. A food habit study of the spotted seatrout, Cynoscion nebulosus, in Mississippi Sound and adjacent areas. M.S. Thesis. Mississippi State University, Mississippi State. 45 pp.

Darcy, G.H. 1985. Synopsis of biological data on the pinfish, Lagodon rhomboides (Pisces:Sparidae). NOAA Tech. Rep. NMFS No. 23, 32 p.

Darnell, R.M. 1958. Food habits of fishes and larger invertebrates of Lake Pontchartrain, Louisiana, and estuarine community. Publ. Inst. Mar. Sci. University of Texas. 5: 353-416.

Day, J.W., D.F. Boesch, E.J. Clairain, G.P. Kemp, S.B. Laska, W.J. Mitsch, K. Orth, H. Mashriqui, D. J. Reed, L. Shabman, C.A. Simenstad, B.J. Streever, R.R. Twilley, C.C. Watson, J.T. Wells, and D.F. Whigham. 2007. Restoration of the Mississippi delta: lessons from hurricanes Katrina and Rita. Science 315:1679–1684.

Deegan, L.A. 1990. Effects of estuarine environmental conditions on population dynamics of young-of-the-year gulf menhaden. Marine Ecology Progress Series, Vol. 68, p. 195-205.

DeMarco, K., Couvillion, B., Brown, S., & La Peyre, M. (2018). Submerged aquatic vegetation mapping in coastal Louisiana through development of a spatial likelihood occurrence (SLOO) model. Aquatic Botany, 151, 87-97.

DHNRDAT (Deepwater Horizon Natural Resource Damage Assessment Trustees). 2016. Deepwater Horizon oil spill: Final Programmatic Damage Assessment and Restoration Plan and Final Programmatic Environmental Impact Statement. Available: http://www.gulfspillrestoration.noaa.gov/restoration-planning/gulf-plan. Viewed: April 11, 2019.

Diener, R.A., A. Inglis, and G.B. Adams. 1974. Stomach contents of fishes from Clear Lake and tributary waters, a Texas estuarine area. Contrib. Mar. Sci.18:7-17.

Ditty, J.G. and R.F. Shaw. 1996. Spatial and temporal distribution of larval striped mullet (Mugil cephalus) and white mullet (M. curema, family: Mugilidae) in the northern Gulf of Mexico, with notes on mountain mullet, Agonostomus monticola. Bull. Mar. Sci. 59(2):271-288.

Drymon, J.M., Ajemian, M.J., and S.P. Powers. 2014. Distribution and Dynamic Habitat Use of Young Bull Sharks Carcharhinus leucas in a Highly Stratified Northern Gulf of Mexico Estuary. PLoS ONE 9(5): e97124. doi:10.1371/journal.pone.0097124

Duggins, C.F., Jr., K.G. Relyea, and A.A. Karlin. 1989. Biochemical systematics in southeastern populations of Fundulus heteroclitus and Fundulus grandis. Northeast Gulf Sci. 10(2): 95-102.

DWH NRDA Trustees. 2016. Final Programmatic Damage Assessment and Restoration Plan and Final Programmatic Environmental Impact Statement. Retrieved from http://www.gulfspillrestoration.noaa.gov/restoration-planning/gulf-plan

Dynamic Solutions. 2012. Delta Ecological Model for Use in the Delta EFDC Hydrodynamic Model. Final Report submitted to the Sacramento District, US Army Corps of Engineers, for the CalFed/Delta Islands and Levees Feasibility Study Hydrodynamic Models of the Sacramento - San Joaquin Delta.

Ernst, V.V., and J.M. Neff. 1977. The effects of the water-soluble fractions of No. 2 fuel oil on the early development of the estuarine fish, Fundulus grandis. Environ. Pollut. 14: 25-35.

FGDC (Federal Geographic Data Committee). 2013. Classification of wetlands and deepwater habitats of the United States. Second Edition. Wetlands Subcommittee, Federal Data Committee and U.S. Fish and Wildlife Service, Publication FGDC-STD-004-2013, Washington, D.C.

Finucane, J.H., L. Collins and L.E. Barger. 1978. Spawning of the Striped Mullet, Mugil cephalus, in the Northwestern Gulf of Mexico. Northeast Gulf Science 2 (2). Retrieved from https://aquila.usm.edu/goms/vol2/iss2/11

Fischer, W. 1978. FAO Species Identification Sheets for Fishery Purposes, Western Central Atlantic (Fishing Area 31), Volume IV. Food and Agriculture Organization of the United Nations, Rome.

Fitzhugh, G.R., L.B. Crowder, and J.P. Monaghan, Jr. 1996. Mechanisms contributing to variable growth in juvenile southern flounder (Paralichthys lethostigma). Can. J. Fish. Aquat. Sci. 53: 1964-1973.

Fonseca, M. and S.S. Bell. 1998. Influence of Physical Setting on Seagrass Landscapes Near Beaufort, North Carolina, USA. Marine Ecology Progress Series, 171: 109-121.

Fontenot, Jr., B.J., H.E. Rogillio. 1970. A study of estuarine spotfishes in the Biloxi Marsh complex, Louisiana. Louis. Wild Life Fish. Comm., Dingell-Johnson Project, F-8 Completion Report, 172 p.

Franks, J.S. 1970. An investigation of the fish population within the inland waters of Horn Island, Mississippi, a barrier island in the northern Gulf of Mexico. Gulf Res. Rep. 3(1): 3-104.

GMFMC (Gulf of Mexico Fishery Management Council). 1981. Final Environmental Impact Statement and Fisheries Management Plan for the Reef Fish Resources of the Gulf of Mexico. GMFMC, Tampa, FL. August 1981.

GMFMC. 2004. Final Environmental Impact Statement for the Generic Essential Fish Habitat Amendment to the following fishery management plans of the Gulf of Mexico (GOM): Shrimp Fishery of the Gulf of Mexico, Red Drum Fishery of the Gulf of Mexico, Reef Fish Fishery of the Gulf of Mexico, Stone Crab Fishery of the Gulf of Mexico, Coral and Coral Reef fishery of the Gulf of Mexico, Spiny Lobster Fishery of the Gulf of Mexico and South Atlantic, Coastal Migratory Pelagic Resources of the Gulf of Mexico and South Atlantic. GMFMC, Tampa, Florida. 118 p

GFMFC. 2016. Final Report 5-Year Review of Essential Fish Habitat Requirements, Gulf of Mexico Fishery Management Council, 510 pages. Available at: http://gulfcouncil.org/wp-content/uploads/EFH-5-Year-Revew-plus-App-A-and-B_Final_12-2016.pdf.

Grabowski, J.H., A.R. Hughes, D.L. Kimbro, and M.A. Dolan. 2005. How habitat setting influences restored oyster reef communities. Ecology. 86: 1926-1935.

Greeley, M.S. Jr., R. Macgregor, III. 1983. Annual and Semilunar Reproductive Cycles of the Gulf Killifish, Fundulus grandis, on the Alabama Gulf Coast. Copeia, Vol. 1983, No. 3, pp. 711-718.

Gunter, G. 1945. Studies on marine fishes of Texas. Publ. Inst. Marine Sciences, University of Texas 1(1): 1-190.

Gunter, G. 1950. Distributions and abundance of fishes on the Aransas National Wildlife Refuge, with life history notes. Publication of the Institute of Marine Science, University of Texas 1(2):89-101.

Gunter, G. 1967. Vertebrates in hypersaline waters. Contrib. Mar. Sci. 12: 230-241.

Harrington, R.W., Jr., and E.S. Harrington. 1961. Food selection among fishes invading a high subtropical salt marsh: from onset of flooding through the progress of a mosquito brood. Ecology 45(4):646-666.

Hazin, F., A. Fischer and M. Broadhurst. 2001. Aspects of reproductive biology of the scalloped hammerhead shark, Sphyrna lewini, off northeastern Brazil. Environ. Biol. Fishes 61: 151159.

Hein, S., and J. Shepard. 1986. Spawning peak of red drum in southeast Louisiana. Louisiana Department of Wildlife and Fisheries, Tech. Bull. No. 40, p. 65-68.

Heist, E.J., J. Musick, and J.E. Graves. 1996. Mitochondrial DNA Diversity and Divergence Among Sharpnose Sharks, Rhizoprionodon Terraenovae, From The Gulf Of Mexico And Mid-Atlantic Bight." VIMS Articles. 590.https://scholarworks.wm.edu/vimsarticles/590

Hellier, T.R., Jr. 1962 and E.S. Harrington. 1962. Fish production and biomass studies in relation to photosynthesis in the Laguna Madre of Texas. Publ. Ins. Marine Sciences, University of Texas. 8:1-22.

Helser, T.E. R.E. Condrey, and J.P. Geaghan. 1993. Spotted Seatrout Distribution in Four Coastal Louisiana Estuaries. American Fisheries Society, Vol. 122, Issue 1, pp. 99-111.

Henley, D.E., and D.G. Rauschuber. 1981. Freshwater needs of fish and wildlife resources in the Nueces-Corpus Christi Bay area, Texas: a literature synthesis. U.S. Fish and Wildlife Service Biol. Rep. FWS/OBS-80/10, 410 p.

Hettler, W.F. Jr. 1989. Food habits of juveniles of spotted seatrout and gray snapper in western Florida Bay. Bull Mar. Sci. 44(1):155–162.

Hiatt, R.W. 1944. Food chains and the food cycle in Hawaiian fish ponds. The food and feeding habits of mullet (Mugil cephalus), milkfish (Chanos), and the ten-pounder (Elops machnata). Trans. American Fisheries Society. 74: 250-280.

Hillmann, E.R., K. DeMarco, and M. K. LaPeyre. 2016a. Establishing a baseline of estuarine submerged aquatic vegetation resources across salinity zones within coastal areas of the northern Gulf of Mexico. Journal of the Southeastern Association of Fish and Wildlife Agencies 3: 25-32.

Hillmann, E.R., DeMarco, K.E., Nyman, A.J., La Peyre, M.K. 2016b. Environmental drivers of seasonal variability in coastal marsh pond SAV communities along a salinity gradient in Barataria basin, Louisiana, U.S.A. State of the Coast, June 2016, New Orleans, LA. Presentation Abstract. (IPDS-070897).

Hillmann, E., K. DeMarco, and M. La Peyre. 2017. Submerged aquatic vegetation and environmental data along a salinity gradient in Barataria Bay, Louisiana (2015): U.S. Geological Survey Data Release. Available at: https://doi.org/10.5066/F7M61HG4.

Hoese, H.D. and R.H. Moore. 1977. Fishes of the Gulf of Mexico. Texas A&M University Press, College Station, TX, 327 p.

Honig, A., Supan, J. and Peyre, M.L., 2015. Population ecology of the gulf ribbed mussel across a salinity gradient: recruitment, growth and density. Ecosphere, 6(11), pp.1-13.

Houde, E.D., and Zastrow, C.E. 1991. Bay anchovy. In Funderburk, S.L., Jordan, S.J., Mihursky, J.A., and Riley, D. (eds.) Bay Anchovy. Chesapeake Bay Program, Annapolis, MD, pp. 8–14.

Humphries, A.T., La Peyre, M.K., Kimball, M.E., Rozas, L.P. 2011. Testing the effect of habitat structure and complexity on nekton assemblages using experimental oyster reefs. J. Exp. Marine Biol. Ecol. 402, 172–179.

Hunt, M., P. Doering. 2013. Salinity Preferences and Nursery Habitat Considerations for Blue Crab (Callinectes sapidus), Bull Shark (Carcharhinus leucas), and Smalltooth Sawfish (Pristis pectinate) in the Caloosahatchee Estuary. South Florida Water Management District. Technical publication WR-2013-001. https://www.sfwmd.gov/sites/default/files/documents/salinity_pref_nursery_wr-2013-001.pdf

Idyll, C.P. and D. de Sylva. 1963. Synopsis of biological data on yellowfin tuna Thunnus albacares (Bonnaterre) 1788 (Western Atlantic). Pages 771-777 in: H. Rosa Jr. ed. Proceedings of the World Scientific Meeting on the Biology of Tunas and Related Species. FAO Fisheries Reports No. 6 (2).

Jenni, D.A. 1969. A study of the ecology of four species of herons during the breeding season at Lake Alice, Alachua County, Florida. Ecol. Monogr. 39(3): 245-270.

Johnson, G.D. 1978. Development of Fishes of the Mid-Atlantic Bight: an Atlas of Egg, Larval and Juvenile Stages, Volume IV, Carangidae through Ephippidae. U.S. Fish Wild. Biol. Serv. Biol. Rep. FWS/OBS-78/12, 314 p.

Johnson, D.R., and W. Seaman, Jr. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (south Florida) - spotted seatrout. U.S. Fish Wildl. Serv. Bioi. Rep. 82(11.43). U.S. Army Corps of Engineers, TR EL-82-4, 18 p.

Kelley, J.R., Jr. 1965. A taxonomic survey of the fishes of the Delta National Wildlife Refuge with emphasis upon distribution and abundance. M.S. Thesis La. State University, Baton Rouge. 133 p.

Kemp, R.J. 1949. Report on stomach analysis from June 1, 1949 through August 31, 1949. Ann. Report. Tex. Game, Fish, Oyster Comm., p. 100-127.

Kemp, P. F., S. Y. Newell, and C. S. Hopkinson. 1990. Importance of grazing on the salt-marsh grass Spartina alterniflora to nitrogen turnover in a macrofauanal consumer, Littorina irrorata, and to decomposition of standing-dead Spartina. Marine Biology 104(2): 311-319.

Kilby, J.D. 1949. A preliminary report on the young striped mullet (Mugil cephalus Linnaeus) in two Gulf coastal areas of Florida. Q.J. Fla. Acad. Sci. 11: 7-23.

Killam, K.A., R.J. Hochberg, and E.C. Rzemien. 1992. Synthesis of basic life histories of Tampa Bay Species. Tampa Bay National Estuary Program, Tech. Pub. No. 10-92, 155 p.

Klima, E.F., Baxter, K.N., and Patella, F.J. 1982. A review of the offshore shrimp fishery and the 1981 Texas closure. Marine Fisheries Review, 44, 16–30.

Kimmerer W.J. 2002. Effects of freshwater flow on abundance of estuarine organisms: physical effects or trophic linkages? Mar Ecol Progr Ser 243: 39-55.

Kimmerer, W. 2004. Open water processes of the San Francisco Estuary: from physical forcing to biological responses. San Francisco Estuary and Watershed Science 2(1).

Kimmerer, W.J., and J.K. Thompson. 2014. Phytoplankton growth balanced by clam and zooplankton grazing and net transport into the low-salinity zone of the San Francisco Estuary. Estuaries and Coasts 37: 1202-1218.

King, B.D., III. 1971. Study of Migratory patterns in fish and shellfish through a natural pass. Tex. Parks Wildl. Dept. Tech. Ser. No. 9, 54 p.

Kloth, T.C. 1970. Size related metabolic responses of the pinfish, Lagodon rhomboides, to grouping salinity variations, and sublethal petrochemical pollution. M.S. thesis, Univ. Texas, Austin, TX, 118 p.

Koch, E.W. 2001. Beyond light: physical, geological, and geochemical parameters as possible submersed aquatic vegetation habitat requirements. Estuaries, 24(1), pp.1-17.

Kushlan, J.A., and T.E. Lodge. 1974. Ecological and distributional notes on the freshwater fish of southern Florida. Fla. Sci. 37(2): 110-128.

La Peyre, M.K., B. Gossman, and J.F. La Peyre. 2009. Defining optimal freshwater flow for oyster production: Effects of freshet rate and magnitude of change and duration on eastern oysters and Perkinsus marinus infection. Estuaries and Coasts 32: 522–534.

La Peyre, M.K., B.S. Eberline, T.M. Soniat, and J.F. La Peyre. 2013. Differences in extreme low salinity timing and duration differentially affect eastern oyster (Crassostrea virginica) size class growth and mortality in Breton Sound, LA. Estuarine, Coastal and Shelf Science 135: 146–157.

La Peyre, M.K., A.T. Humphries, S.M. Casa, J.F. La Peyre. 2014. Temporal variation in development of ecosystem services from oyster reef restoration. Ecological Engineering 63: 34-44.

La Peyre, M. K., K. Serra, T. A. Joyner, and A. Humphries. 2015. Assessing shoreline exposure and oyster habitat suitability maximizes potential success for sustainable shoreline protection using restored oyster reefs. October 6, 2015, PeerJ, volume 3, DOI: 10.7717/peerj.1317.

Lassuy, D.R. 1983. Species Profiles: Life Histories and Environmental Requirements (Gulf of Mexico) – Spotted Seatrout.

Lee, D.S., C.R. Gilbert, C.H. Hocutt, R.E. Jenkins, D.E. McAllister, and J.R. Stauffere, Jr. 1980. Atlas of North American Freshwater Fishes. N.C. Biological Survey. Publication No. 1980-12. N.C. St. Museum of Natural History, Raleigh, N.C, 867 p.

Lessa, R., R.C. Menni and F. Lucena. 1998. Biological observations on Sphyrna lewini and S. tudes (Chondrichthyes, Sphyrnidae) from northern Brazil. Life and Environment 48: 203-213.

Levine, S.J. 1980. Gut contents of forty-four Lake Pontchartrain, Louisiana, fish species. In Stone, J.H. (ed.), Environmental analysis of Lake Pontchartrain, Louisiana, its surrounding wetlands, and selected land uses, Vol. II, p. 899-1030. Center for Wetland Resources, Louisiana St. Univ., Baton Rouge, LA.

Lin, Q., Mendelssohn, I.A., Graham, S.A., Hou, A., Fleeger, J.W., & Deis, D.R. 2016. Response of salt marshes to oiling from the Deepwater Horizon spill: Implications for plant growth, soil surface-erosion, and shoreline stability. Science of the Total Environment, 557, 369-377.

Lowe, M.R., T. Sehlinger, T. . Soniat, and M.K. La Peyre. 2017. Interactive effects of water temperature and salinity on growth and mortality of eastern oyster, Crassostrea virginica: a meta-analysis using 40 years of monitoring data. J. Shellfish Res. 36:683–697.

LDFW (Louisiana Department of Wildlife and Fisheries). 2005. Conservation Habitats and Species Assessments. Ch. 4 In LDFW Louisiana Comprehensive Wildlife Conservation Strategy.

LDWF. 2014 Oyster Stock Assessment of the Public Oyster Areas of Louisiana: Public Oyster Seed Grounds and Seed Reservations. Oyster Data Report Series No. 20. Baton Rouge, LA. 87 pp.

LDWF. 2015a. Waterbody Management Plan Series: Barataria Basin – Lake History & Management Issues. Louisiana Department of Wildlife & Fisheries. Baton Rouge, LA. 45 pp. Available at: http://www.wlf.louisiana.gov/sites/default/files/pdf/document/39504-barataria-basin-2015/barataria_basin_mp-a_2015.pdf

LDWF. 2015b. Louisiana Shrimp Fishery Management Plan. Louisiana Department of Wildlife and Fisheries, Office of Fisheries. Baton Rouge, LA. 158p.

Manooch, C.S. III. 1984. Fishermans' Guide to the Fishes of the Southeastern United States. North Carolina State Museum of Natural History, Raleigh, NC, 362 p.

Marcus, N.H., and F. Boero. 1998. Minireview: The importance of benthic-pelagic coupling and the forgotten role of life cycles in coastal aquatic systems. The American Society of Limnology and Oceanography, Inc., 43(5), 1998, 763-768.

Marotz, B.L. 1984. Seasonal movements of penaeid shrimp, Atlantic croaker, and gulf menhaden through three marshland migration routes surrounding Calcasieu Lake in southwestern Louisiana. M.S. thesis. Louisiana St. Univ., Baton Rouge, LA 192 p.

Martin, F.D., and G.E. Drewry. 1978. Development of fishes of the Mid-Atlantic Bight-an atlas of egg, larval, and juvenile stages, Vol. VI, Stromateidae through Ogcocephalidae. U.S. Fish Wildl. Serv. Biol. Rep. FWS/OBS-78/12, 416 p.

May, L.N., Jr. 1977. The effects of oil recovery operations on the biology and ecology of killifishes in a Louisiana salt marsh. M.S. thesis, Louisiana St. Univ., Baton Rouge, LA, 80 p.

McFarlane, R.B., and R.J. Livingston. 1983. Effects of acidified water on the locomotor behavior of the gulf killifish, Fundulus grandis: a time series approach. Arch. Env. Contam. Toxicol. 12: 163-168.

McMichael, R.H. Jr. and K.M. Peters. 1989. Early life histories of spotted seatrout, Cynoscion nebulosus (Pisces: Sciaenidae) in Tampa Bay, Florida. Estuaries 12(2):98–110.

Melancon E.T. Soniat, V. Cheramie, R. Dugas, J. Barras, and M. Lagarde. 1998. Oyster resource zones of the Barataria and Terrebonne estuaries of Louisiana. Journal of Shellfish Research. 17:1143–1148.

Mercer, L.P. 1984. A biological and fisheries profile of spotted seatrout, Cynoscion nebulosus. North Carolina Dept. Nat. Res. Comm. Dev., Spec. Sci. Rep. No. 40, 87p.

Mercer, L.P. 1989. Fishery management plan for spot (Leiostomus xanthurus). North Carolina Dept. Nat. Res. Comm. Devel. Spec. Sci. Pub. No. 49, 81 p.

Miles, D.W. 1949. A study of the food habits of the fishes of the Aransas Bay area, M.S. thesis, Univ. Houston, Houston, TX, 70 p.

Miller, L.S., J. La Peyre and M. La Peyre. 2017. Suitability of oyster restoration sites along the Louisiana coast: examining site and stock X interaction. J. Shellfish Res. 36: 1-11.

Miller, L.S., J. La Peyre, and M. La Peyre. 2017. Suitability of oyster restoration sites along the Louisiana coast: examining site and stock 3site interaction. J. Shellfish Res. 36:1–11.

Millikin, M.R., and A.B. Williams. 1984. Synopsis of biological data on the blue crab, Callinectes sapidus Rathbun. NOAA Tech. Rep. NMFS, 1(4).

Minello, T.J. 1999. Nekton densities in shallow estuarine habitats of Texas and Louisiana and the identification of essential fish habitat.

Minello, T.J., R.J. Zimmerman, and E.X. Martinez. 1989. Mortality of young brown shrimp Penaeus aztecus in estuarine nurseries. Transactions of the American Fisheries Society 118: 693– 708.

Minello, T.J., Zimmerman, R.J. and Barrick, P.A., 1990. Experimental studies on selection for vegetative structure by penaeid shrimp. NOAA Technical Memorandum NMFS-SEFC-237, 30 p.

Mitsch, W.J. and J.G. Gosselink. 2000. Wetlands (third edition). John Wiley & Sons, New York. 920 pp.

Mitsch W.J., B. Bernal, A.M. Nahlik, U. Mander, L. Zhang, C.J. Anderson, S.E. Jørgensen, and H. Brix. 2012. Wetlands, carbon, and climate change. Research Article i: Landscape Ecol, DOI

10.1007/s10980-012-9758-8. Received: 3 December 2011 / Accepted: 7 May 2012. Springer Science+Business Media B.V. 2012.

Moffet, A.W., L.W. McEachron, and J.G. Kay. 1979. Observations on the biology of the sand seatrout (Cynoscion arenarius) in Galveston and Trinity Bays, Texas. Contrib. Mar. Sci. 22: 163-172.

Montague, C.L., S.M. Bunker, E.B. Haines, M.L. Pace, and R.L. Wetzel. 1981. Aquatic macroconsumers. In The Ecology of a Salt Marsh by Pomeroy, L. R., Wiegert, R. G. (eds.). Springer-Verlag: New York. pp 69–85.

Moore, R.H. 1974. General ecology, distribution, and relative abundance of Mugil cephalus and Mugil curema on the south Texas coast. Contrib. Mar. Sci. 15: 241-255.

Morton, T. 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Mid-Atlantic) – bay anchovy. U.S. Fish Wildl. Serv. Biol. Rep. 82. 13 pp.

Muncy, R.J. 1984. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (south Atlantic): white shrimp. U.S. Fish and Wildl. Serv. FWS/OBS-82/11.27. U.S. Army Corps of Engineers, TR EL-82-4. 19 pp.

Murphy, M.D., and R.G. Taylor. 1994. Age, growth, and mortality of spotted seatrout in Florida waters. Trans. American Fisheries Society. 123: 482-497.

Murphy, M.D. 2011. An assessment of the status of spotted seatrout in Florida waters through 2009. Florida Fish and Wildlife Conservation Commission IHR 2011-002. 53 p.

Murray, J., H. Roman, and J.J. Westerink. 2015. Technical Memorandum. Development of Oyster Larval Transport Analysis (ADCIRC). DWH Oyster NRDA Technical Working Group Report.

Nakamura, I. 1985. FAO Species Catalogue. Vol. 5. Billfishes of the world. An annotated and illustrated catalogue of marlins, sailfishes, spearfishes and swordfishes known to date. FAO Fish Synop., (125) Vol. 5: 65 p.

NRC (National Research Council) 1994. An Assessment of Atlantic Bluefin Tuna. National Academy Press. Washington D.C., 144 pp.

Nelson, D.M. (Editor). 1992. Distribution and abundance of fishes and invertebrates in Gulf of Mexico estuaries, Volume I: data summaries, ELMR Report Number 10 NOAA/NOS/Strategic Environmental Assessments Division, Rockville, MD. 273 p.

Nelson, D.M. E.A. Irlandi, L.R. Settle, M.E. Monaco, and L.C. Clements. 1991. Distribution and abundance of fishes and invertebrates in southeast estuaries. ELMR Rep. No. 9. NOAA/NOS SEA Div., Silver Spring, MD, 167 p.

Nelson, D.M. M.E. Monaco, C.D. Williams, T.E. Czapla, M.E. Pattillo, L. Coston-Clements, L.R. Settle, and E.A. Irlandi. 1992. Distribution and abundance of fishes and invertebrates in Gulf of Mexico estuaries, Vol. 1: Data summaries. ELMR Rep. No. 10. NOAA/NOS SEA Div., Rockville, MD, 273 p.

Newell, R. C., L.J. Seiderer, and D.R. Hitchcock. 1998. The impact of dredging works in coastal waters: a review of the sensitivity to disturbance and subsequent recovery of biological resources on the sea bed. Oceanography and Marine Biology: An Annual Review 36.1 (1998): 127-178.

Newell, R.I.E., T. R. Fisher, R.R. Holyoke, and J.C. Cornwell. 2005. Influence of eastern oysters on nitrogen and phosphorus regeneration in Chesapeake Bay, USA. Pages 93–120 in R. Dame and S. Olenin, editors. The comparative roles of suspension feeders in ecosystems. NATO Science Series IV: Earth and Environmental Sciences. Volume 47. Springer, Amsterdam, The Netherlands.

Nicholson, W.R. 1978. Gulf Menhaden, Brevoortia patronus, Purse Seine Fishery: Catch, Fishing Activity, and Age and Size Composition, 1964-73. NOAA Technical Report NMFS SSRF-722.

Nieland, D., G. Thomas, and C. Wilson. 2002. Age, Growth, and Reproduction of Spotted Seatrout in Barataria Bay, Louisiana. Transactions of The American Fisheries Society, Vol. 131, p. 245-259.

NMFS (National Marine Fisheries Service). 2006a. Final Consolidated Atlantic Highly Migratory Species Fishery Management Plan. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Office of Sustainable Fisheries, Highly Migratory Species Management Division, Silver Spring, MD. Public Document. pp. 1600.

NMFS. 2006b. SEDAR 11 Stock Assessment Report: Large coastal Shark Complex, Blacktip and Sandbar Shark.

NMFS. 2009. Final amendment 1 to the 2006 consolidated Atlantic highly migratory species fishery management plan, essential fish habitat. U.S. Department of Commerce, NOAA, Office of Sustainable Fisheries, Highly Migratory Species Management Division, Silver Spring, MD, USA, 395 p

NMFS. 2018. Fisheries of the United States, 2017. U.S. Department of Commerce, NOAA Current Fishery Statistics No. 2017 Available at: https://www.fisheries.noaa.gov/feature-story/fisheries-united-states-2017

NOAA (National Oceanographic and Atmospheric Administration). 1985. Gulf of Mexico Coastal and Ocean Zones Strategic Assessment: Data Atlas. NOAA NOS Strategic Assessment Branch, Rockville, MD.

NOAA). 1997. Distribution and Abundance of Fishes and Invertebrates in Gulf of Mexico Estuaries Volume II: Species Life History Summaries. ELMR Report Number 11. August 1997.

NOAA. 2016. Regional Use of the Habitat Area of Particular Concern (HAPC) Designation. Prepared by the Fisheries Leadership & Sustainability Forum for the Mid-Atlantic Fishery Management Council. 69 p.

NOAA. 2019. NOAA Fisheries Southeast Overview. https://www.fisheries.noaa.gov/region/southeast

O'Connell, A.M., Hijuelos, A.C., Sable, S.E., and Geaghan, J.P. 2017a. 2017 Coastal Master Plan: C3-13 – Brown Shrimp, Farfantepenaeus aztecus, Habitat Suitability Index Model. Version II. (pp. 1-34). Baton Rouge, Louisiana: Coastal Protection and Restoration Authority.

O'Connell, A.M., A.C. Hijuelos, S.E. Sable, and J.P. Geaghan. 2017b. 2017 Coastal Master Plan: Attachment C3-14: White Shrimp, Litopenaeus setiferus, Habitat Suitability Index Model. Version Final. (pp. 1-32). Baton Rouge, Louisiana: Coastal Protection and Restoration Authority.

O'Connell, A.M., A.C. Hijuelos, S.E. Sable, and J.P. Geaghan. 2017c. 2017 Coastal Master Plan Modeling: Attachment C3-11: Blue Crab, Callinectes sapidus, Habitat Suitability Index Model. Version Final. (pp. 1-26). Baton Rouge, Louisiana: Coastal Protection and Restoration Authority.

Odum, W.E. 1971. Pathways of energy flow in a south Florida estuary. Univ. Miami Sea GrantTech. Bull. No. 7, 162 p.

Oesterling, M.L., and G.L. Evink. 1977. Relationship between Florida's blue crab population and Apalachicola Bay. Fla. Mar. Res. Publ. 26: 101-121.

Orth, R.J., and K.L. Heck, Jr. 1980. Structural components of eelgrass (Zostera marina) meadows in the Lower Chesapeake Bay – fishes. Estuaries 3: 278-288.

Overstreet, R.M. and R.W. Heard. 1982. Food Contents of Six Commercial Fishes from Mississippi Sound. Gulf Research Reports 7 (2): 137-149. Retrieved from http://aquila.usm.edu/gcr/vol7/iss2/5

Parker, J.C. 1971. The biology of the spot, Leiostomus xanthurus Lacepede, and Atlantic coraker, Micropogon undulates (Linnaeus), in two Gulf of Mexico nursery areas. Tex. A&M Univ. Sea Grant Coll. TAMU-SG 71-210. 182 pp.

Pattillo, M.E., T.E. Czapla, D.M. Nelson, and M.E. Monaco. 1997. Distribution and abundance of fishes and invertebrates in Gulf of Mexico estuaries, Volume II: Species life history summaries. ELMR Rep. No. 11. NOAA/NOS Strategic Environmental Assessments Division, Silver Spring, MD. 377 p.

Perret, W.S., W.R. Latapie, J.F. Pollard, W.R. Mock, G.B. Adkins, W.J. Gaidry, and C.J. White. 1971. Fishes and invertebrates collected in trawl and seine samples in Louisiana estuaries. In: Cooperative Gulf of Mexico estuarine inventory and study, Louisiana. Louis. Wildl. Fish. Comm., New Orleans, LA, p. 41-105.

Perret, W.S., J.E. Weaver, R.O. Williams, P.L. Johansen, T.D. Mcilwain, R.C. Rulifson, and W.M. Tatum. 1980. Fishery profiles of red drum and spotted seatrout. Gulf States Mar. Fish. Comm. Rep. 6.

Perry, J.A. 1970. A study of the bottom fish population in the offshore waters of Mississippi by trawl survey. M.S. thesis, Univ. Mississippi, Jackson, MS, 112 p.

Perry, H.M., C.K. Eleuterius, C.B. Trigg, and J.R. Warren. 1995. Settlement patterns of Calfinectes sapidus megalopae in Mississippi Sound: 1991, 1992. Bull. Mar. Sci. 57(3):821-833.

Perschbacher, P.W., and K. Strawn. 1986. Feeding selectivity and standing stocks of Fundulus grandis in an artificial, brackishwater pond, with comments on Cyprinodon variegatus. Contrib. Mar. Sci. 18: 257-261.

Perschbacher, P.W., D.V. Aldrich, and K. Strawn. 1990. Survival and growth of the early stages of gulf killifish in various salinities. Progressive Fish-Culturist 52: 109-111.

Peters, K.M. and R.H. McMichael, Jr. 1987. Early life history of the red drum Sciaenops ocellatus (Pisces: Sciaenidae) in Tampa Bay, Florida. Estuaries 10:92–107.

Peterson, G.W. 1986. Distribution, habitat preferences, and relative abundance of juvenile spotted seatrout and red drum in the Caminada Bay estuary, Louisiana. M.S. thesis, Louisiana St. Univ., Baton Rouge, LA, 96 p.

Philomena, A.L. 1983. The Distribution of Macrobenthos in Barataria Basin, Louisiana. LSU Historical Dissertations and Theses. 8217. https://digitalcommons.lsu.edu/gradschool_disstheses/8217.

Piazza, B.P., P.D. Banks, and M.K. La Peyre. 2005. The potential for created oyster shellreefs as a sustainable shoreline protection strategy in Louisiana. Restoration Ecol. 13, 499–506.

Pinckney, J.L., H.W. Paerl, and M.B. Harrington. 1999. Responses of the phytoplankton community growth rate to nutrient pulses in variable estuarine environments. J. Phycol. , 35, 1455–1463.

Post, J. 1998. The life history of the sailfish, Istiophorus platypterus. University of Miami, Masters thesis, May 1998. Rosentiel School of Marine and Atmospheric Science.

Powell, A.D., and F.J. Schwartz. 1977. Distribution of paralichthid flounders (Bothidae: Paralichthys) in North Carolina estuaries. Chesapeake Science 18(4)334-339

Powers, S.P. and S.B. Scyphers. 2015. Estimating injury to nearshore fauna resulting from the Deepwater Horizon oil spill. (NS_TR.17). DWH Shoreline NRDA Technical Working Group Report.

Powers, S.P., C.L. Hightower, J.M. Drymon, and M.W. Johnson. 2012. Age composition and distribution of red drum (Sciaenops ocellatus) in offshore waters of the north central Gulf of Mexico: an evaluation of a stock under a federal harvest moratorium. Fish. Bull. 110:283-292.

Powers, S.P., Rouhani, S., Baker, M.C., Roman, H., Murray, J., Grabowski, J.H., Scyphers, S., Willis, J.M., & Hester, M.W. (2015b). Loss of oysters as a result of the Deepwater Horizon oil spill degrades nearshore ecosystems and disrupts facilitation between oysters and marshes. (NS_TR.30). DWH Oyster NRDA Technical Working Group Report.

Price, W.W., and R.A. Schlueter. 1985. Fishes of the littoral zone of McKay Bay, Tampa Bay system, Florida. Fla. Sci. 48(2): 83-96.

Reid, G.K., Jr. 1954. An ecological study of the Gulf of Mexico fishes, in the vicinity of Cedar Key, Florida. Bull. Mar. Sci. Gulf. Caribb. 4(1): 1-94.

Reid, G.K. 1955. A summer study of the biology and ecology of East Bay, Texas: Pt. II. Tex. J. Sci. 7: 430-453.

Relyea, K. 1983. A systematic study of two species complexes of the genus Fundulus (Pisces: Cyrinodontidae). Bull. Fla. St. Mus. Biol. Sci. 29(1): 1-64.

Renfro, W.C. 1960. Salinity relations of some fishes in the Aransas River, Texas. Tulane Stud. Zool. 8(3): 83-91.

Reynolds, C.S. 2006. The ecology of phytoplankton. Cambridge University Pres, Cambridge, 535 pp.

Rivas, L.R. 1948. Cyprinodont fishes of the genus Fundulus in the West Indies, with description of a new subspecies from Cuba. Proc. U.S.N.M. 98:215-222.

Rodriguez, A.B., M.L. Fassell, and J.B. Anderson. 2001. Variations in shoreface progradation and ravinement along the Texas coast, Gulf of Mexico. Sedimentology 48: 837-853.

Rogers, B.D. 1979. The spatial and temporal distribution of Atlantic croaker, Micropogon undulatus, and spot, Leiostomus xanthurus, in the upper drainage basin of Barataria Bay, Louisiana. M.S. Thesis. Louisiana State University, Baton Rouge. 96 pp.

Roman, H. 2015 Development of Oyster Nearshore Injury Quanitifcation. (NS_TR.04). DWH Oyster NRDA Technical Working Group Report.

Rozas, L.P., and C.T. Hackney. 1984. Use of oligohaline marshes by fishes and macrofaunal crustaceans in North Carolina. Estuaries 7: 213-224.

Rozas, L.P., and M.W. LaSalle. 1990. A comparison of the diets of gulf killifish, Fundulus grandis Baird and Girard, entering and leaving a Mississippi brackish marsh. Estuaries 13: 332-336.

Rozas, L.P., and T.J. Minello. 2011. Variation in penaeid shrimp growth rates along an estuarine gradient: implications for managing river diversions. Journal of Experimental Marine Biology and Ecology 397: 196– 207.

Rozas, L.P. and D.J. Reed. 1993. Nekton use of marsh-surface habitats in Louisiana (USA) deltaic salt marshes undergoing submergence. Marine Ecology-Progress Series, 96, pp.147-147.Rozas, L.P., T.J. Minello, R.J. Zimmerman, and P. Caldwell. 2007. Nekton populations, long-term wetland loss, and the recent effect of habitat restoration in Galveston Bay, Texas. Marine Ecology Progress Series 344, 19-130.

Rozas, L.P., T.J. Minello, and D.D. Dantin. 2012. Use of shallow lagoon habitats by nekton of the northeastern Gulf of Mexico. Estuaries and Coasts 35:572-586.

Rozas, L.P., Minello, T.J. and Miles, M.S., 2014. Effect of Deepwater Horizon oil on growth rates of juvenile penaeid shrimps. Estuaries and coasts, 37(6), pp.1403-1414.

Ruebsamen, R.N. 1972. Some ecological aspects of the fish fauna of a Louisiana intertidal pond system. M.S. thesis, Louisiana St. Univ., Shreveport, LA, 80 pp.

Sabins, D.S. and F.M. Truesdale. 1974. Diel and seasonal occurrence of immature fishes in a Louisiana tidal pass. Proc. Southeast. Assoc. Game Fish Wildlife Agency. 28: 161-171.

Sable, S.E., A.C. Hijuelos, A.M. O'Connell, and J.P. Geaghan. 2016. 2017 Coastal Master Plan: C3-17 – Bay Anchovy, Anchoa mitchilli, Habitat Suitability Index Model. Version II. (pp. 1-31). Baton Rouge, Louisiana: Coastal Protection and Restoration Authority.

Sable, S.E., A.C. Hijuelos, A.M. O'Connell, and J.P. Geaghan. 2017. 2017 Coastal Master Plan: Attachment C3-16: Spotted Seatrout, Cynoscion nebulosus, Habitat Suitability Index Model. Version Final. (pp. 1-29). Baton Rouge , Louisiana: Coastal Protection and Restoration Authority.

Saucier, M., and D. Baltz. 1993. Spawning site selection by spotted seatrout, Cynoscion nebulosus, and black drum, Pogonias cromis, in Louisiana. Environmental Biology of Fishes, Vol. 36, pp. 257-272.

Schmidt, T.W. 1993. Community Characteristics of Dominant Forage Fishes and Decapods in the Whitewater Bay-Shark River Estuary, Everglades National Park. Tech. Report NPS/SEREVER.NRTR-93-12. U.S. National Park Service. 67 p.

Seagle, J.H. 1969. Food habits of spotted seatrout (Cynoscion nebulosus, Cuvier) frequently turtle grass (Thalassis testudinum Konig) beds in Redfish Bay, Texas. TAIUS 2: 58-63.

SEDAR (Southeast Data, Assessment, and Review). 2006. SEDAR 9, Stock Assessment Report: Gulf of Mexico Greater Amberjack. North Charleston, SC, USA, 178 pp.

SEDAR. 2007. SEDAR 13: Small Coastal Shark Complex, Atlantic Sharpnose, Blacknose, Bonnethead and Finetooth Shark. Silver Spring, MD, USA, 395 pp.

SEDAR. 2012. SEDAR 29 Stock Assessment Report: HMS Gulf of Mexico Blacktip Shark. North Charleston, SC, USA, 197 pp.

SEDAR. 2013. SEDAR 32A: - Gulf of Mexico menhaden Stock Assessment Report. North Charleston, SC, USA, 422 pp.

SEDAR. 2016. SEDAR 45: Gulf of Mexico Vermillion Snapper. North Charleston, SC, USA, 188 pp.

Serrano, X., J. Serafy, and M. Grosell. 2011. Osmoregulatory capabilities of the gray snapper, Lutjanus griseus: salinity challenges and field observations. Marine and Freshwater Behaviour and Physiology. 44:3, 185-196. DOI: 10.1080/10236244.2011.585745Shaffer 1988

Shaffer, G.P., and M.J. Sullivan. 1988. Water Column Productivity Attributable to Displaced Benthic Diatoms in Well-mixed Shallow Estuaries. Journal of Phycology, Vol. 24, Issue 2.

Shaw, R., W.J. Wiseman, Jr., R.E.Turner, J.L. Rouse Jr., R.E. Condrey & F.J. Kelly Jr. 1985. Transport of Larval Gulf Menhaden Brevoortia patronus in Continental Shelf Waters of

Western Louisiana: A Hypothesis, Transactions of the American Fisheries Society, 114:4, 452-460, DOI: 10.1577/1548-8659(1985)114<452:TOLGMB>2.0.CO;2

Shepard, J.A. 1986. Salinity: a factor affecting fluctuation of spotted seatrout, Cynoscion nebu/osus, stocks. Louis. Dept. Wildl. Fish. Tech. Bull. 40:49-53.

Shipp, R.L. 1986. Guide to Fishes of the Gulf of Mexico. Dauphin Island Sea Lab., Dauphin Island, AL, 256 p.

Sikora, W.B, and F.H. Sklar. 1987. Benthos, in Conner, W.H., and Day, J.W., Jr., eds., The ecology of Barataria Basin, Louisiana—an estuarine profile: U.S. Fish and Wildlife Service, Biological Report 85.7.13, p. 58-79.

Silliman, B.R., and M.D. Bertness. 2002. A trophic cascade regulates salt marsh primary production. Proceedings of the National Academy of Sciences of the United States of America 99: 10500-10505.

Simmons, E.G. 1957. An ecological survey of the upper Laguna Madre of Texas. Publ. Inst. Mar. Sci., Univ. Texas 4(2): 156-200.

Simmons, E.G., and H.D. Hoese. 1959. Studies on the hydrography and fish migrations of Cedar Bayou, a natural tidal inlet on the central Texas coast. Publ. Inst. Mar. Sci. Univ. Texas 6: 56-80.

Simpson, D.G., and G. Gunter. 1956. Notes on habitats, systematic characters and life histories of Texas salt water Gyprinodontes. Tulane Stud. Zool. 4(4):115-134.

Sogard, S.M., G.V.N. Powell, and J.G. Holmquist. 1989. Utilization of fishes of shallow, seagrass-covered banks in Florida Bay: 2. Diel and tidal patterns. Environ. Biol. Fishes 24: 81-92.

Springer, V.G., and K.D. Woodburn. 1960. An ecological study of the fishes of the Tampa Bay area. Fla. Board. Cons., Prof. Pap. Ser. No. 1, p. 1-104.

Stanley, J.G. and M.A. Sellers. 1986. Species Profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Gulf of Mexico)- American oyster. USFWS Biological Report. 82(11.65). 25 pp.

Stewart, K.W. 1961. Contribution to the biology of the spotted seatrout (Cynoscion nebulosus) in the Everglades National Park, Florida. M.S. thesis, Univ. Miami, Coral Gables, FL, 103 p.

Stokes, G.M. 1977. Life history studies of southern flounder (Paralichthys lethostigmaI) and gulf flounder (P. albigutta) in the Aransas Bay area of Texas. Tex. Parks Wildl. Dept. Tech. Ser. No. 25, 37 p.

Stoner, A.W. 1979. Species-specific predation on amphipod crustacea by the pinfish Lagodon rhomboides: mediation by macrophyte standing crop. Mar. Biol. 55: 201-207.

Stoner, A.W. 1980. The feeding ecology of Lagodon rhomboides (Pisces: Sparidae): variation and functional responses. U.S. Nat 1. Mar. Fish. Serv. Fish. Bull. 78:337-352.

Stoner, A.M. 1982. The influence of benthic macrophytes on the foraging behavior of pinfish, Lagodon rhomboides (Linnaeuss). J. Exp. Biol. Ecol. 58:271-284.

Strawn, K., and J.E. Dunn. 1967. Residence of Texas salt and freshwater marsh fishes to heat death at various salinities. Tex. J. Sci. 19: 57-76.

Stunz, G., T. Minello, and L. Rozas. 2010. Relative value of oyster reef as habitat forestuarine nekton in Galveston Bay, Texas. Marine Ecol. Prog. Ser. 406, 147–159.

Subrahmanyam, C.B., and S.H. Drake. 1975. Studies on the animal communities in two north Florida salt marshes. Part I. Fish communities. Bull. Mar. Sci. 25(4):445-465.

Swarzenski, C.M., and S.M. Perrien. 2015. Discharge, suspended sediment, and salinity in the Gulf Intracoastal Waterway and adjacent surface waters in south-central Louisiana, 1997–2008: U.S. Geological Survey Scientific Investigations Report 2015–5132, 21 p., http://dx.doi.org/10.3133/sir20155132.

Swenson, E.M. and R.E. Turner. 1987. Spoil banks: effects on a coastal marsh water-level regime. Estuarine, Coastal and Shelf Science, 24(5), pp.599-609.

Swift, C., R.W. Yerger, and P.R. Parrish. 1977. Distribution and natural history of the fresh and brackish water fishes of the Ochlockonee River, Florida and Georgia. Bull. Tall Timbers Res. Sta., No. 20, 111 p.

Swingle, H.A. 1971. Biology of Alabama estuarine areas – Cooperative Gulf of Mexico estuarine inventory. Ala. Mar. Res. Bull. 5: 1-123.

Tabb, D.C. 1966. The estuary as a habitat for spotted seatrout (Cynosclon nebulosus). In Smith, R.F., A.H. Swartz, and W.H. Massman (eds.), A symposium on estuarine fisheries, p. 59-67. Am. Fish. Soc. Spec. Pub. No.3. American Fisheries Society, Washington, DC, 154 p.

Tabb, D.C., and R.B. Manning. 1961. A checklist of the flora and fauna or northern Florida Bay and adjacent brackish waters of the Florida mainland collected during the period July 1957 through September 1960. Bull. Mar. Sci. Gulf Caribb. 11(4): 552-649.

Tanaka, M., T. Goto, M. Tomiyama, and H. Sudo. 1989. Immigration, settlement and mortality of flounder (Paralichthys olivaceus) larvae and juveniles in a nursery ground, Shijiki Bay, Japan. Netherlands J. Sea Res. 24: 57-67.

Tango, P.J. and R.A. Batiuk. 2013. Deriving Chesapeake Bay Water Quality Standards. Journal of the American Water Resources Association (JAWRA) 1-18. DOI: 10.1111/jawr.12108.

Thayer, G.W., D.R. Colby, and W.F. Hettler. 1987. Utilization of the red mangrove prop root habitat by fishes in south Florida Bay. Mar. Ecol. Prog. Ser. 35: 25-38.

Thomann, R.V. and J.A. Mueller. 1987. Principles of surface water quality modelling and control. New York, Harper and Row.

Thomas, J.L., R.J. Zimmerman, and T.J. Minello. 1990. Abundance patterns of juvenile blue crabs (Callinectes sapidus) in nursery habitats of two Texas bays. Bull. Mar. Sci. 46: 115-125.

Thomson, J.M. 1966. The grey mullets. Oceanogr. Mar. Biol. Ann. Rev. 4: 301-335.

Thornten, K.W., and A.S. Lessem. 1978. A Temperature Algorithm for Modifying Biological Rates. Transactions of the American Fisheries Society, Vol. 107, Issue 2, pp. 284-287.

Turner, R.E. 1977. Intertidal vegetation and commercial yields of penaeid shrimp. Transactions of the American Fisheries Society, 106(5): pp.411-416.

Turner, R.E. and M.S. Brody. 1983. Habitat suitability index models: northern Gulf of Mexico brown shrimp and white shrimp. U.S. Department of the Interior Fish and Wildlife Service. FWS/OBS-82/10.54. 24 pp.

USACE (US Army Corps of Engineers). 2017. Hydrogeomorphic Approach. Available at: http://www.erdc.usace.army.mil/Media/Fact-Sheets/Fact-Sheet-Article-View/Article/476738/hydrogeomorphic-approach/. Accessed December, 2017.

USACE. 2018. Davis Pond Freshwater Diversion. Available at: http://www.mvn.usace.army.mil/About/Projects/Davis-Pond-Freshwater-Diversion/. Accessed December 2018.

USFWF (US Fish and Wildlife Service). 2020. Draft Fish and Wildlife Coordination Act Report on the Mid-Barataria Sediment Diversion Project. Submitted to USACE and CPRA. Prepared by USFWS Ecological Services, Lafayette, LA. August 2020.

U.S. Geological Survey (USGS). 2015. Louisiana coastal wetlands: A resource at risk. U.S. Geological Survey, Coastal & Marine Geology Program. Available at: http://pubs.usgs.gov/fs/la-wetlands/. Accessed May 2019.USGS 2016

USGS. 2018. National Water Information System: Web Interface. Available at: https://waterdata.usgs.gov/nwis.

Valiela, L.1995. Marine ecological processes, 2nd ed. Springer, New York. 712 pp.

Van Hoose, M.S. 1987. Biology of spotted seatrout (Cynoscion nebulas us) and red drum (Sciaenops ace/latus) in Alabama estuarine waters. In Lowery, T.A. (ed.), Symposium on the natural resources of the Mobile Bay Estuary, Miss. Ala. Sea Grant Consort. MASGP-87-007, p. 26-37.

Vanderkooy, S.J. and J.W. Smith (eds). 2002. The menhaden fishery of the Gulf of Mexico, United States: A regional management plan, 2002 revision. Gulf States Marine Fisheries Commission, Number 99.

Vaughan, D.S., K.W. Shertzer, and J.W. Smith. 2007. Gulf Menhaden (Brevoortia patronus) in the U.S. Gulf of Mexico: fishery characteristics and biological reference points for management. Fisheries Research 83:263–275.

Vetter, R.D. 1977. Respiratory metabolism of, and niche separation between, two co-occurring congeneric species, Cynoscion nebulosus and Cynoscion arenarius, in a south Texas estuary. M.S. thesis, Univ. Texas, Austin, TX, 114 p.

Visser, J.M., S.M. Duke-Sylvester, J. Carter, and W.P. Broussard III. 2013. LAVegMod a Computer Model to Forecast Wetland Vegetation Changes Resulting from Coastal Restoration and Protection in Coastal Louisiana. Journal of Coastal Research 67, 51-59.

Visser, J.M., S.M. Duke-Sylvester, G.P. Shaffer, M.W. Hester, B. Couvillion, W.P. Broussard III, J.M. Willis, and H. Beck. 2015. 2017 Coastal Master Plan: Model Improvement Plan Modeling: Attachment C3-5 – Vegetation. Version I. Baton Rouge, Louisiana: Coastal Protection and Restoration Authority.

Wagner, P.R. 1973. Seasonal biomass, abundance, and distribution of estuarine dependent fishes in the Caminada Bay System of Louisiana. Ph.D. dissertation, Louisiana State University., Baton Rouge, LA, 207 p.

Ward, G.H. and N.E. Armstrong. 1980. Matagorda Bay, Texas: its hydrography, ecology, and fishery resources. U.S. Fish and Wildlife Service. Biol. Rep. FWS/OBS 81/52, 230 p.

Ward, G.H., Jr., N.E. Armstrong, and the Matagorda Bay Team Project. 1980. Matagorda Bay, Texas: its hydrography, ecology and fishery resources. U.S. Fish Wildl. Serv. Biol. Rep. FWS/OBS-81/52.

Watkins, K.S., S.E. Sable, and K.A. Rose. 2014. Quality Assurance and Preparation of Key Species Data from the Coastal Louisiana Fisheries-Independent Monitoring Program Conducted by the Louisiana Department of Wildlife and Fisheries. Confidential Report submitted to the Louisiana Oil Spill Coordinator's Office, Baton Rouge, LA.

West, J., G. Decossas, A. Melancon, S. Potts, and J. E. Powers. 2014. Update Assessment of Spotted Seatrout Cynoscion nebulosus in Louisiana Waters: 2014 Report. Office of Fisheries, Louisiana Department of Wildlife and Fisheries.

West, J., H. Blanchet, J. Marx, J. Powers. 2016. Update Assessment of Blue Crab in Louisiana Waters: 2016 Report. Louisiana Department of Wildlife and Fisheries, Baton Rouge, LA.

Whaley, S.D., and Minello, T.J. 2002. The distribution of Benthic Infauna of a Texas Salt Marsh in Relation to the Marsh Edge. Wetlands, Vol. 22, No. 4, pg:753-766.

Williams, A.B. 1984. Shrimps, lobsters, and crabs of the Atlantic Coast of the Eastern United States, Maine to Florida. Washington, DC: Smithsonian Institution Press.

Wilson, C.A., and D.L. Nieland. 1994. Reproductive biology of red drum, Sciaenops ocellatus, from the neritic waters of the northern Gulf of Mexico. Fishery Bulletin. 92: 841-850.

Yakupzack, P.M., W.H. Herke, and W.G. Perry. 1977. Emigration of juvenile Atlantic croakers, Micropogon undulatus, from a semi-impounded marsh in southwestern Louisiana. Trans. Am. Fish. Soc. 106:538-544.

Zein-Eldin, Z. P. and M. L. Renaud. 1986. Inshore environmental effects on brown shrimp, Penaeus aztecus, and white shrimp, P. setiferus populations in coastal waters, particularly of Texas, Marine Fishery Reviews 48:9–19

Zengel S., B. Bernik, N. Rutherford, Z. Nixon, and J. Michel. 2015. Heavily Oiled Salt Marsh following the Deepwater Horizon Oil Spill, Ecological Comparisons of Shoreline Cleanup Treatments and Recovery. PLOS ONE 10(7): e0132324. https://doi.org/10.1371/journal.pone.0132324

Zimmerman, R.J., Minello, T.J., and L.P. Rozas. 2000. Salt marsh linkages to productivity of penaeid shrimps and blue crabs in the northern Gulf of Mexico. In: Weinstein MP, Krueger DA (eds) Concepts and controversies in tidal marsh ecology. Kluwer Academic Publishers, Dordrecht, p 293–314

zu Ermuggason, P.S.E., M.D. Spalding, R.E. Grizzle, and R.D. Brumbaugh. Quantifying the Loss of a Marine Ecosystem Service: Filtration by the Eastern Oyster in US Estuaries. Estuaries and Coasts, Journal of the Coastal and Estuarine Research Federation. ISSN 1559-2723.

N2 – Appendix A
Basis of Design Report

Rev 1

STATE OF LOUISIANA
COASTAL PROTECTION AND RESTORATION AUTHORITY

MID-BARATARIA SEDIMENT DIVERSION (MBSD) PROJECT
STATE PROJECT No. BA-153
LaGOV NO. 4400010386

Preparation of Engineering and Design
BASIS OF DESIGN REPORT

For

Prepared By:
AECOM Technical Services
7389 Florida Blvd.
Suite 300
Baton Rouge, LA 70806

October 12, 2018

Rev	Date	Description
0	09/07/2018	Draft Submittal
1	10/12/2018	Final Submittal Addressing QRF comments

Prepared in Association With

DISCLAIMER: The contents of this report are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products. All product names and trademarks cited are the property of their respective owners. The findings of this report are preliminary, not for construction, and not to be construed as official directives unless so designated by other authorized documents.

DESTROY THIS REPORT WHEN NO LONGER NEEDED. DO NOT RETURN IT TO THE ORIGINATOR.

Bruce R. Lelong, PE Lic #29393

TABLE OF CONTENTS

TABLES

FIGURES

APPENDICES

1. EXECUTIVE SUMMARY

The Coastal Protection and Restoration Authority (CPRA) has located the Mid-Barataria Sediment Diversion (MBSD) on the West Bank of the Mississippi River (MR) in Plaquemines Parish, Louisiana, at River Mile 60.7 Above Head of Passes (AHP), between the Phillips 66 Alliance Refinery upriver and the Town of Ironton downriver. The diversion will reconnect the MR to the Barataria Basin, delivering sediment to rebuild the delta marshes with the ultimate goal of improving coastal protection against the effects of sea level rise, subsidence, and storm events. The diversion intake is sited at a point bar to facilitate the capture of sand.

The Engineering and Design (E&D) of the MBSD Project is organized into two major phases. Phase 1 is the Basis of Design (BOD) Phase, which comprises alternatives analyses of major diversion components and major appurtenant features, conceptual (i.e., 15%-level) E&D and Class 5 and Class 3 cost estimates in support thereof. Major project features' Design Criteria were established during the BOD Phase. The numerical modeling and E&D performed during BOD Phase were based on available existing data and current conditions, not future conditions-see **Section 3.8** for these definitions. Phase 2 comprises detailed E&D and cost estimates of the selected component and appurtenance alternatives, development of the construction contract documents (plans and specifications); development of the Operations, Maintenance, Repairs, Replacement and Rehabilitation (OMRR&R) Plan, and the preparation and submittals of the Section 408 Permissions Application and Sections 404/10/CUP Joint Permit Application (JPA), along with supporting documents and reports; and the associated regulatory reviews. Phase 2 is divided into 30%-, 60%-, 90%-, and 100%-Level Phases.

Conceptual engineering performed during the BOD phase was initiated using existing data, studies, and reports. Additional data collection was begun during the BOD Phase, including additional geotechnical borings and lab data and additional topographic and geotechnical surveys, but this new data will not be used until Phase 2 design. Existing data has been deemed sufficient for executing the conceptual designs and performing alternatives analyses and selections.

The Basis of Design Report (BODR) and its appendices summarize and document the major project design criteria, the conceptual-level engineering and designs and evaluations of the engineering alternatives, which the Design Team (DT) is scoped to perform, and the conclusions and recommendations arising from the work completed during the BOD Phase. The fundamental goal of the BOD Phase is to develop what its title implies-a Basis of Design-, not the detailed engineering and designs. These will be performed during the subsequent task orders comprising the overall Engineering and Design Phase of the MBSD Project.

All alternatives studied in the BOD phase are documented herein, with the BOD drawings, studies, and reports included as Appendices. In performing the conceptual designs, the DT produced a Design Criteria Document (DCD) which serves to document the design criteria specific to the MBSD project. The DCD was developed with input from CPRA and the U.S. Army Corps of Engineers (USACE), and it is intended to be a living document which will be periodically updated as the design process progresses. The DCD is in **Appendix U**. Of particular note are the following other sections of the BODR:

- The numerical modeling efforts are summarized in **Section 8**; with modeling efforts presented in detail in **Appendix H**.

- Conceptual geotechnical engineering efforts are summarized in **Section 9**; with supporting geotechnical analyses presented in **Appendix G**.
- Conceptual structural designs of the project's hydraulic structural alternatives are summarized in **Section 10**; with supporting structural computations presented in **Appendix J**.
- Cost estimates are summarized in **Section 23**, with detailed back-up in **Appendix F**.

During the BOD Phase, the major project design criteria are established, and major diversion component alternatives are selected. For the three major components of the diversion system, i.e., the headworks, conveyance channel, and outfall, the diversion's invert elevation and basic geometry are selected, along with structure types and typical cross-sections. Major decisions and recommendations involving ancillary features are also made: the height of the riverine and hurricane flood protection, the modifications to the existing interior/site drainage necessitated by the diversion's construction, the alignment and basic geometrics of the new Hwy 23 and New Orleans Gulf Coast (NOGC) railroad bridges crossing the diversion, the features comprising the support facilities and associated site work, the disposition of the utilities/infrastructure crossing the diversion, and the use of excavated earthen materials unsuitable for levee construction and construction fill. These aspects of the Project will be refined and further developed during the detailed engineering and design phase of the Project, which comprises the remainder of the E&D.

CPRA established seven goals for BA-153 MBSD Project. The BOD Phase was organized, scoped and executed to establish a design basis in accordance with the project goals, in conjunction with the land-building modeling and other environmental modeling and engineering and science for the Project EIS:

Table 1-1: Conformance with Project Goals

Goal No.	Goal Description	BOD Phase E&D Role in Achieving Project Goals
1	Reconnection of the MR to the Barataria Basin	Diversion layouts and numerical hydraulic modeling were performed to establish the basis of design of a gravity-driven, controlled conveyance system that delivers sediment-laden, fresh water flows from the MR to Barataria Basin.
2	Establishment of conditions to allow the development of a delta area open to tidal exchanges	This goal will be partially achieved by E&D, starting with the BOD Phase, and partially through the modeling, engineering and science for the Project EIS. The BOD Phase E&D results demonstrate the system can deliver 75,000 cfs of diversion flow with a favorable sediment to water ratio (SWR), and by conceptually designing a conveyance channel that maintains velocities sufficient to keep sediment in suspension. The Basin's land-building management is addressed by the Basin-wide and Outfall Management modeling being performed by The Water Institute of the Gulf (TWIG), and by the development of the Environmental Impact Statement (EIS) by the EIS Team. (Documentation of the TWIG modeling and EIS development is not included in the BODR.)

Table 1-1: Conformance with Project Goals (Continued)

Goal No.	Goal Description	BOD Phase E&D Role in Achieving Project Goals
3	Development of the initial basis of design using 75,000 cubic feet per second (cfs) flow through the Conveyance Channel from the Mississippi River Levee (MRL) to the Barataria Basin by operating gates(s) of the diversion structure	BOD Phase numerical hydraulic modeling of alternatives demonstrates the alternatives being considered achieve 75,000 cfs of diversion flow for current conditions (see Section 3.2-Key Definitions for definition of current conditions). Engineering and design for future conditions will be performed during the 30% Phase.
4	Maintenance of the current level of riverine and hurricane flood risk reduction	Investigations and designs of the MR cofferdam alternative, tie-in flood protection, and Hurricane/Guide Levees follow Project Design Criteria, which were established to provide current level or better flood risk reduction.
5	Development of designs of the major diversion components and appurtenances to maximize sediment capture, maximize flow efficiency, and allow for operations adaptability based on monitoring data collected during project operation, while minimizing OMRR&R	This goal is generally the fundamental consideration used to develop the decision matrices to select alternatives under consideration. The strategies and processes to use monitoring data to be collected during operations in order to allow for operations adaptability will be addressed in Phase 2.
6	Conformance to state and federal design criteria and environmental compliance requirements as required to achieve project regulatory approval	Conformance to state and federal design criteria initially is documented during BOD Phase with the Project Design Criteria, which is reviewed by CPRA and USACE. In subsequent phases, the Section 408 review process will confirm and document that the design conforms to state and federal design criteria by project milestone reviews and Section 408 and JPA reviews by regulatory agencies and stakeholders. The NEPA process (not part of the E&D scope) will confirm that the project conforms to environmental requirements.
7	Development of an operational plan for the diversion structure	The Operational Plan is not part of the BOD Phase, other than to establish an initial range of diversion flows over which alternatives will be evaluated. The Operational Plan will be addressed in detail in Phase 2 of E&D.

In conformance with Goal No. 5, the BOD Phase was structured around an alternatives and evaluation screening process with two decision-points, alternatives-selection workshops during the BOD Phase. A third workshop will be held during the 30% Phase, during which the enlargement of the intake type selected during BOD Phase will be confirmed. The structure to the alternatives screening process is shown in **Figure 1-1**.

The two BOD Phase workshops are summarized in greater detail in **Section 7**. At Workshop No. 1, potential alternatives to be conceptually engineered and evaluated were identified, ranked and selected using decision matrices with qualitative scoring criteria. The diversion components for which potential alternatives were as follows: the River Intake-structure type and invert elevation, the Conveyance Channel-channel invert and invert profile, Back Gate vs. No Back Gate at Outfall but with parallel, dual-purpose Hurricane/Guide Levees, and Interior Drainage System modification alternatives to accommodate the diversion's disruption of existing drainage patterns.

The Intake Alternatives chosen at Workshop No. 1 to be conceptually designed and numerically modeled during BOD Phase were four structures types: open channel type, U-Frame, U-Frame with interior walls, and a submerged culvert. Three invert elevation alternatives also were selected: -20, -40, and -50, for a total of eight intake alternatives. **(Note: All elevations referred to in this report reference NAVD88 unless specifically noted otherwise.)** EL -40 was selected for evaluation because that is the elevation selected and engineered during previous designs. EL -50 was selected for evaluation because that is the deepest that workshop participants judged could be constructed within the construction budget and with acceptable risk, and EL -20 was selected for evaluation because that is the shallowest elevation participants judged could capture sufficient sand. All four structure types were chosen to be evaluated for EL -40, again because it was the invert elevation used in previous design, while two structure types were chosen to be modeled each at EL -50 and EL -20. The best performing open type as determined by modeling of EL -40 alternatives and the submerged culvert type were selected for EL -50. The best two performing open configuration types were chosen to be evaluated at EL -20.

The Conveyance Channel Alternatives chosen to be evaluated were two Channel predominant invert elevations (EL -20 and EL -25) and three invert profiles for each predominant invert elevation, for a total of six alternatives.

It also was decided at Workshop No. 1 that the Back Gate versus No Back Gate with Hurricane/Guide Levee alternatives comparison considered only these two alternatives. The Interior Drainage System Modification Alternatives analysis was decided to include a comparison of the 2014 Base Design's proposed drainage pump station versus an inverted siphon system.

It was decided for other appurtenant project features that 15%-level engineering would proceed but changes to these design concepts compared to the 2014 Designs would not be done through a decision matrix scoring process: Diversion Gate type selection, whether there is a requirement and need for an onsite, dedicated crane at the Diversion Gate Structure for emergency situations, river and channel armoring systems, Outfall Transition Feature geometric design, selection of the alignment of the proposed railroad bridge over the diversion, Hwy 23 Bridge layout and alignment; selection of secondary site features, and the identification of beneficial uses of excavated earthen materials unsuitable for levee construction or use as fill material. The 15% E&D for those items is documented in the BODR main body and appendices.

Referring to **Figure 1-1**, numerical modeling and conceptual engineering progressed after Workshop No. 1, and the results and conclusions were used as a basis of ranking at Workshop No. 2. First numerical modeling of the Intake alternatives was performed using FLOW-3D hydrodynamic modeling with particle tracking with 1,000,000 cfs of MR flow, current conditions, and steady state. Energy losses and SWRs were computed. Numerical modeling of the Conveyance Channel was performed using Delft3D and Coastal Modeling System (CMS) modeling. Back Gate modeling also used Delft3D and CMS. Civil layouts, geotechnical analyses and designs, and structural designs of the major diversion component alternatives and related features progressed; quantity take-offs were performed and Class 5 cost estimates were prepared for the alternatives under consideration. E&D of the other features not topics of the second alternatives workshop continued. Prior to Workshop No. 2, decision matrices with evaluation criteria were developed. The engineering and designs are documented in this BODR.

At Workshop No. 2, the results of the modeling, designs, and estimated life cycle costs for these alternatives were used to score and rank them in decision matrices with a combination of quantitative scoring criteria and semi-quantitative scoring criteria. The following selections were made:

1) Intake Alternative-Open Channel with Invert at EL -40 appears preferable but would be confirmed with additional H&H modeling for medium and low operating flows;
2) Conveyance Channel with invert at EL -25, with a constant, flat invert to the end of the Channel, and beyond sloping upwards to prevailing mud bottom in the Basin in the Outfall Transition Feature;
3) Hurricane Flood Protection-elimination of the Back Gate Alternative and selection of the Hurricane/Guide Levee Alternative chosen to provide hurricane storm damage risk reduction. This decision will be evaluated by the USACE as part of the Section 408 Permissions review. CPRA and the DT will perform a risk analysis according to USACE policies and procedures, comparing the risk of Hurricane/Guide Levees to the risk to the federal NOV-5a Levee without a diversion crossing its alignment. The CPRA will submit a risk assessment report documenting the analysis. The Hurricane/Guide Levee alternative will not be objectionable provided the analysis demonstrates incorporation of the Hurricane/Guide Levees into the NOV-5a line of protection does not increase the risk to the system;
4) Interior Drainage-an Inverted Siphon near the Timber Canal crossing beneath the Conveyance Channel.

Regarding the intake alternatives, it was decided at Workshop No. 2 that the selection of the Intake Alternative would be formally made after additional numerical modeling that considered medium and low MR flows as snapshot assessments of the selected intake alternative's performance to gage how the alternatives under consideration perform corresponding across the range of operational flows. FLOW-3D modeling, hydrodynamic only, no particle tracking, was done at low flows. Delft3D modeling was done for each alternative at high, medium, and low flows. When the post-Workshop No. 2 H&H modeling had been completed, the Intake Selection Matrix categories and their weightings were finalized and the alternatives were scored. The Open Channel with Invert EL -40 is the preferred selection. This is summarized in **Section 7**.

H&H conceptual design of modifications to the site (interior) drainage network performed during the BOD Phase consisted of designing a siphon bank to drain the upriver polder to Wilkinson Pump Station, located in the downriver polder at the Wilkinson Canal. The siphon's required capacity was assumed to need to match the established capacity for the 2014-proposed pumping station, which was part of the 2014 30% design scope. The pump station's purpose as well as the siphon's is to drain the upriver polder. Conceptual civil and structural layouts, designs, and associated geotechnical analyses were performed to develop drawings and prepare quantity take-offs and cost estimates. These were compared to the 2014 30% designs and cost estimate, with unit prices updated. Based on that comparison, the siphon alternative was selected at Workshop No. 2 based on anticipated cost savings, and the pump station was eliminated from further consideration. The use of the 2014 pump station design's required capacity as the basis for conceptually designing the inverted siphon alternative was done for the purposes of alternative selection. The detailed design of the siphon will be based on the computed required capacity determined from the area-wide HEC-RAS modeling.

After Workshop No. 2, the following decisions and recommendations were made apart from the Workshop-based alternatives evaluation process:

1) The Diversion Gate type should be a tainter gate. See **Appendix O**.
2) There is no USACE specific requirement that a dedicated on-site crane be installed at the Headworks (HW). CPRA should develop a specific operational strategy for emergency and planned maintenance situations, at which times a crane will be mobilized to the site. For example, putting in place an emergency contract so that a crane will be available and mobilized quickly to the site. See **Appendix P**.
3) The River Intake segment between the MRL and the Diversion Gate Structure should be a U-frame structure type without interior walls, except beneath the R/R Bridge and directly in front of the Diversion Gate Structure. This means that the U-Frame portion of the Intake will have a concrete floor, not riprap armoring.
4) The recommended river armoring system is riprap. See Section **10.4.6**.
5) The final selection of conveyance channel armoring system will be made during the 30% Phase after further design progression.
6) The railroad bridge alignment will be over the Intake U-Frame in line with the existing track. The low chord of the bridge will be at EL 16.4 or higher, and will not be a flood-proof bridge. See **Section 14**.
7) The Hwy 23 Bridge will be constructed along the current alignment of Hwy 23. See **Section 13**.
8) The Outfall Transition Feature will be approximately 1,500 feet long. The analysis and hydraulic design are discussed further in the Executive Summary and summarized in **Section 8**.
9) Proposed secondary site features and facilities are described in Sections 16 and 20. CPRA provided owner information about needs and preferences in mid-August, 2018. Based on this guidance, layout drawings are being developed and included in the update to this report. See **Sections 16 and 20**.
10) Beneficially used earthen materials unsuitable for levee construction and use as construction fill will be used to reconstruct a ridge on the north side of Wilkinson Canal in the Basin, and to fill a designated area near Bayou Dupont on the north side of the Outfall Transition Feature to construct wetlands. This is discussed further later in the Executive Summary and summarized in **Section 24**.

Subsequent to the selection of the Intake type and invert elevation, BOD Phase numerical modeling efforts concluded with starting the numerical modeling for future conditions to evaluate the sizes of the major diversion features (see **Section 8.9**) and concurrent investigations of geometric optimizations of the selected Intake Alternative (Open Channel with Invert EL -40) based on modeling of current conditions (see **Section 8.5.7)**. The three-component diversion system with the selected alternative was incorporated into the TWIG OMBA model along with the land-building topography and bathymetry from the Basin-wide model at Year 50 to create the FTN OMBA model. The FTN OMBA model has higher mesh resolution in the 3 diversion components. Tailwater conditions were derived from the Basin-wide model's offshore boundary. The model was run using a one-year MR hydrograph. The modeling results showed the system does not produce 75,000 cfs of flow at 1,000,000 cfs in MR. Therefore, the need to upsize the diversion system for future conditions to achieve 75,000 cfs of flow with 1,000,000 cfs of river flow has been established. The initial future conditions modeling is documented in this BODR. The initial future conditions modeling is the extent of modeling and E&D included in the BODR.

Four HW optimization simulations for the selected intake type and invert elevation were completed for the Open Channel, Invert EL -40 Intake, using FLOW-3D to model current conditions. Delft3D results are not included in the report; however they will be included in an update to this report. The objective of the optimization testing was to determine if the head loss through the system could be decreased by modifying the intake geometry without decreasing the SWR. The optimizations modeled were combinations of widening the River Intake geometry by increasing the flare angle of the training walls, removing the interior divider walls of the U-Frame segment of the Intake between the MRL and the Diversion Gate except beneath the railroad bridge and immediately in front of the Diversion Gates, an upwardly sloping Intake invert to the Diversion Gate with its sill set at the invert of the Conveyance Channel, and installing riprap armoring within the geometric U-Frame segment in lieu of a structural concrete U-Frame segment. The optimizations did not include improvements to the HW Discharge Transition geometry to improve hydraulic performance. Transition alternative geometries will be modeled after the BODR. Based on the computed energy losses and SWR performance of the four alternatives, Optimization 1a is recommended, but the results need to be confirmed by the Delft3d modeling results. Optimization 1a has a wider River Intake, an Invert at EL -40 through the entire Intake and Diversion Gate Structure, and U-Frame divider walls removed, except under the railroad bridge and immediately in front of the Diversion Gates. Optimization 1a reduces energy losses by 42% for river operational high flow and by 49% for river operational low flow. The Overall Sand SWR ratio, as computed by FLOW-3D, decreases by 7% compared to the base geometry; the overall decrease is driven by the decrease in SWR for the 250 **μ** grain size, which decreases by 18%. However, SWRs for grain sizes 125 **μ** and smaller are essentially the same. Base geometry is the geometry modeled for the screening of Intake Alternative Types and invert elevations. See **Section 8.5.7** for further discussion.

Hydraulic modeling will continue beyond the BOD Phase into the beginning of the 30% design phase, and this BODR will be updated to include optimizations of the three major diversions components and the additional findings and results. During the 30% Phase, a study will be performed to evaluate HW upsizing, coupled with assessing the benefits of maintenance dredging in the Basin to manage tailwater elevations in order to achieve target flows. The alternatives will be evaluated using life cycle cost estimates and the alternative chosen will be the upsized intake that will progress to final engineering. The upsized diversion system will be modeled using a 50-Year hydrograph to confirm target flows are achieved, to compute a cumulative SLR, and as the basis to modify dimensions to improve performance. Shoaling and scour near the Point Bar will be evaluated to assess Point Bar Stability and potential impacts to the MRL. The size and performance of the diversion's major components-HW, Conveyance Channel, and Outfall Transition Feature-based on this modeling, will be confirmed at Workshop No. 3 to be scheduled during the 30% Phase.

Two scaled physical models were designed in BOD Phase. A flume test was then performed and the results and findings summarized in a Flume Test Report included in **Appendix H**. The models' construction is ongoing. Testing will occur in the 30% Design Phase. Comparisons to the numerical modeling results are anticipated to occur during both 30% and 60% Design Phases.

Sections 11 and 10 of the BODR present two alternative levels respectively for hurricane and riverine storm/flood damage risk reduction. The hurricane flood protection components, i.e., Hurricane/Guide Levees and T-Walls, were conceptually designed for the 50-Year level, projected 50 years into the future, EL 15.6, storm surge coming from the Basin. Designs prorated for a lower level of protection, EL 12.1, which is approximately a 25-Year level of protection, 25 years into the future. The DT estimates that there will be a sufficient quantity of excavated earthen materials for levee construction to construct either alternative without having to important levee fill. The cost to construct the Hurricane/Guide Levees and T-walls to EL 15.6 is approximately $18 million more than constructing these levees to EL 12.1. The DT recommends that the Guide Levees and T-walls serving as hurricane protection be constructed to EL 15.6. See **Section 11** for further discussion.

The HW components in the line of MR protection were conceptually designed to the currently authorized MRL elevation at the project site, EL 16.4 and prorated for EL 20.1, which corresponds to the 50-Year level of hurricane protection, projected 50 years into the future, storm surge coming from the river. The MRL at this location is currently not authorized as hurricane flood protection. Incremental construction costs are presented in the Cost Estimates in **Appendix F**. The DT estimates that constructing to EL 20.1 will cost approximately $3.5million more than constructing to EL 16.4. The DT recommends that the riverine protection be constructed to EL 20.1. See **Section 10** for further discussion.

After Workshop No. 2, the designs of the interior drainage modifications did not advance because of lack of access to the Wilkinson Pump Station, which is needed to obtain intake basin water level data during a rain event to calibrate the HEC-GeoRAS model for existing (pre-project) conditions. This work will recommence after access to the station is obtained, likely to be in Phase 2. The BOD Phase H&H work is summarized in **Section 8**. The conceptual structural design of the siphon system is presented in **Section 10**.

It was decided during the BOD Phase, that utility relocation dispositions will be established during the 30% Phase. It is anticipated that buried utilities crossing the conveyance channel along Hwy 23 will be relocated to be mounted on the proposed Hwy 23 Bridge over the conveyance channel. It is also anticipated that the Shell 20” Nairn crude pipeline will need to be relocated beneath the Outfall Transition Feature by directional drilling prior to construction. Utilities and their respective points of contact are listed in **Section 19**.

The proposed auxiliary structures and site features comprising “Secondary Site Features” are described in **Section 20**.

The BODR includes design concepts for the beneficial placement of excavated and dredged materials unsuitable for use for levee construction and construction fill. The unsuitable material will be the top feet of the HW and Conveyance Channel excavations and the dredged material from the Outfall Transition Feature’s construction. The unsuitable material will be used to construct a ridge along the north side of Wilkinson Canal in the Basin, which will reduce the siltation within the canal from diversion operation. The other area where earthen material will be placed and wetlands constructed is in the Basin on the north side of the Outfall Transition Area. Designs will follow CPRA guidelines. See **Section 24,** which also lists the estimated quantity of unsuitable material.

Near the end of the BOD Phase, a Class 3 construction cost estimate was prepared for the overall project, reflecting the components selected at Workshop No. 2. Escalated to the mid-point of construction, the estimated cost inclusive of contingencies is $984.2 million. The escalation factor used is 15%. Contingency percentages selected vary by feature from 25% to 40%, but typically are 30%. The Class 3 estimate does not include enlarging the River Intake for future conditions. If it is determined to be needed based on the results of numerical modeling, the estimated cost to upsize the River Intake will be included in the BODR Update.

The current estimate includes the hurricane flood protection features constructed to design grade of EL 15.6, inclusive of construction overbuild of levees, and EL 16.4 for the headworks (HW) components forming part of the MRL line of riverine flood protection. If the hurricane flood protection features are constructed to EL 12.1, the construction cost decrease by $17.9 million. If the riverine flood protection features are constructed to EL 20.1, the construction cost increases by $3.0 million. These estimated incremental costs include contingency. See **Section 23** for further information.

Table 1-2: Selected Alternative Components-Estimated Construction Cost Summary

SELECTIVE ALTERNATIVE COMPONENT SUMMARY		
ID	Alternative Feature Description	Total Cost with Contingency
1	Open Cut U-Frame Intake, No Interior Walls, Top of Wall El 16.4	$245,010,743
2	Gated Diversion Structure, Top of Wall 16.4	$61,031,245
3	Transition and Wingwalls @ EL -40 to EL -25, Top of Wall EL 15.6	$53,244,418
4	Railroad Bridge (Low Chord at EL 16.4)	$44,388,923
5	Hwy 23 Roadway and Bridge (300' wide channel)	$53,249,158
6	Channel and Levee (TOL EL 15.6 to NOV, EL 11.5 to Back Levee, 300' Wide Channel at EL -25.0)	$258,752,377
7	Interior Drainage	$28,073,199
8	Secondary Site Features	$4,574,804
9	Utility Relocations	$32,955,000
10	Temporary Construction Features	$30,215,510
11	Beneficial Use Material	$997,500
12	Allowance for Flooding of the Cofferdam During a Hurricane	$2,000,000
13	***Construction Subtotal***	***$814,492,876***
14	Mobilization and Demobilization (3%)	$24,434,786
15	Misc. Insurance Hurricane & Builder's Risk Ins. (1%)	$8,389,277
16	Payment and Performance Bond (1%)	$8,473,169
17	Subtotal (Sept 2018 estimate including contingencies)	$855,790,108
18	15% escalation (Escalation Cost to mid-point construction Dec 2023):	$128,368,516
19	***Total Cost with Escalation and Contingencies:***	***$984,158,625***

Table 1-2: Selected Alternative Components-Estimated Construction Cost Summary (Continued)

OPTIONS TO THE SELECTED ALTERNATIVE		
ID	Add/Deducts	Total Cost with Contingency
1	Increase MRL Structures Height from EL 16.4 to EL 20.1	$3,040,089
1.1	Intake Structure to EL 20.1	+ $1,094,054
1.2	Gated Structure to EL 20.1	+ $1,428,034
1.3	MRL Wall to EL 20.1	+ $518,001
2	Decrease Channel Levees Height from 15.6 to 12.1	-$17,941,689
2.1	Transition Walls to EL 12.1	-$6,805,174
2.2	Top of Levee at EL 12.1	-$7,054,645
2.3	Hwy 23 T-walls at EL 12.1	-$2,040,935
2.4	Siphon T-walls at EL 12.1	-$2,040,935

In conclusion, the following noteworthy actions should be taken during 30% Design Phase to fully establish the Basis of Design.

1. Confirm the DT-recommended Intake optimizations as described previously in the Executive Summary considering the Delft3D modeling results. Note that geometry will be further refined during 30% Design Phase.
2. Select the magnitude of upsizing of the HW to meet Project Goals for future conditions, considering associated maintenance dredging needed in the Basin to manage future tailwater elevations.
3. Perform the assessment of point bar stability, and river scouring and shoaling, after the HW have been upsized for future conditions, based on upcoming modeling.
4. Assess water quality in the Conveyance Channel under maintenance flows.
5. Confirm the design grade of the HW MR flood protection components, which the DT recommends be set at EL 20.1. Note that final design grade may be based on wave overtopping, which will be assessed by near-field storm surge modeling of the Conveyance Channel.
6. Confirm the design grade of the hurricane flood protection features (protecting against storm surge from the Basin). Note that the decision may be influenced by the upcoming Risk Assessment being performed as a USACE requirement to approve the use of the Guide Levees to provide hurricane flood protection.
7. Finalize selection of the Channel armoring system type.
8. Confirm the low chord elevation of the railroad bridge, particularly if the decision is made to design the HW components tying into the MRL line of protection to EL 20.1.
9. Finalize the size of the inverted siphon(s) after the HEC-GeoRAS interior drainage model is calibrated.
10. Confirm the layout and sizes of the secondary project features to reflect CPRA guidance received in mid-August, 2018. This is expected confirmed after the DT submits layout drawings during the beginning of 30% Design Phase.

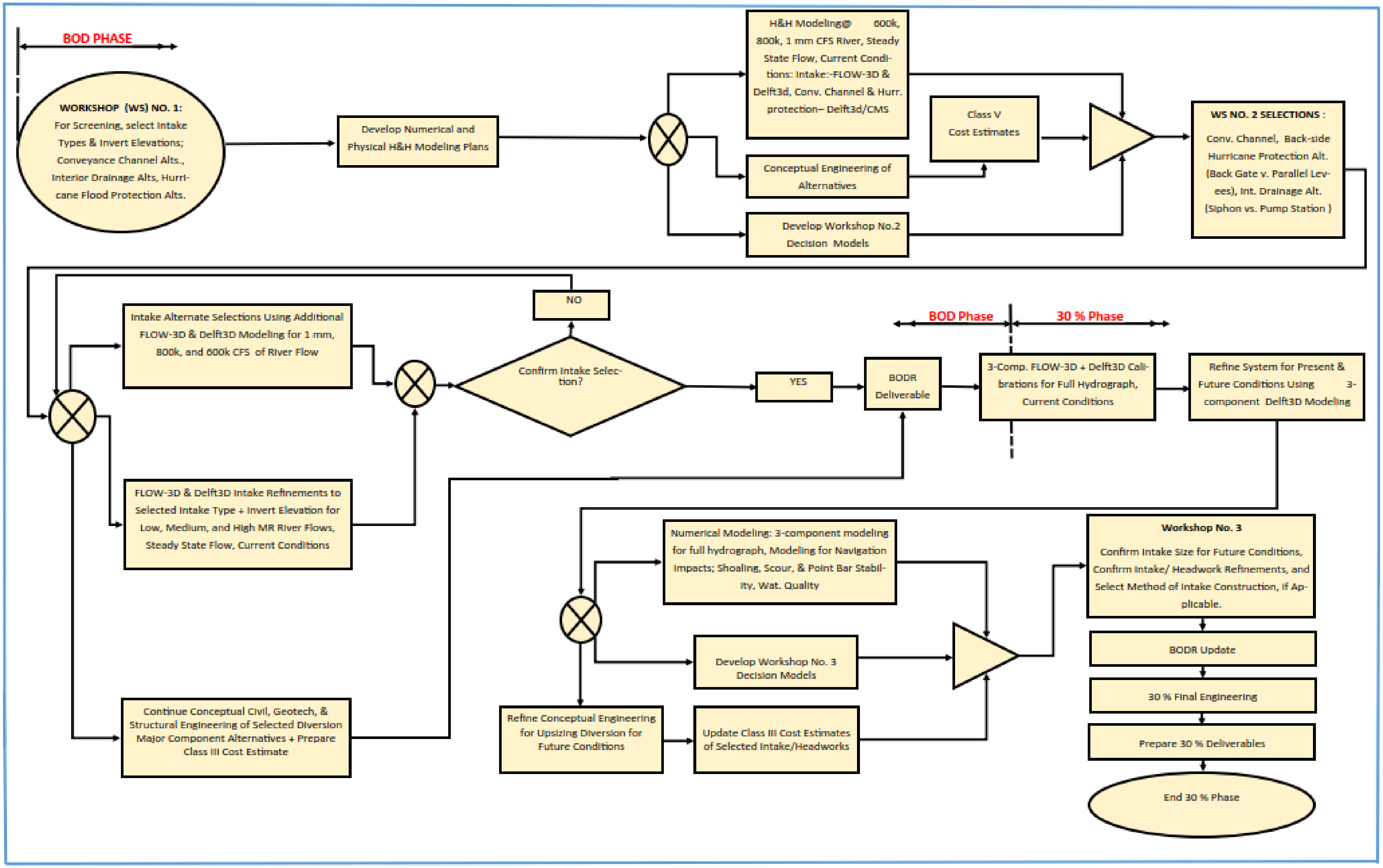


Figure 1-1: Flowchart of Alternatives Screening Process

2. PROJECT LOCATION

The project is located on the West Bank of the MR, in Plaquemines Parish, Louisiana, south of the Phillips 66 Refinery, near the town of Ironton, as shown in Figure 2-1. The proposed diversion intake is located at Mississippi River Mile (RM) 60.7 Above the Head of Passes (AHP) and intersects the MRL at Station 1109+58. The proposed diversion channel extends in a southwest direction where it will bisect the New Orleans to Venice (NOV) back levee, Reach NOV-NF-W-05c.

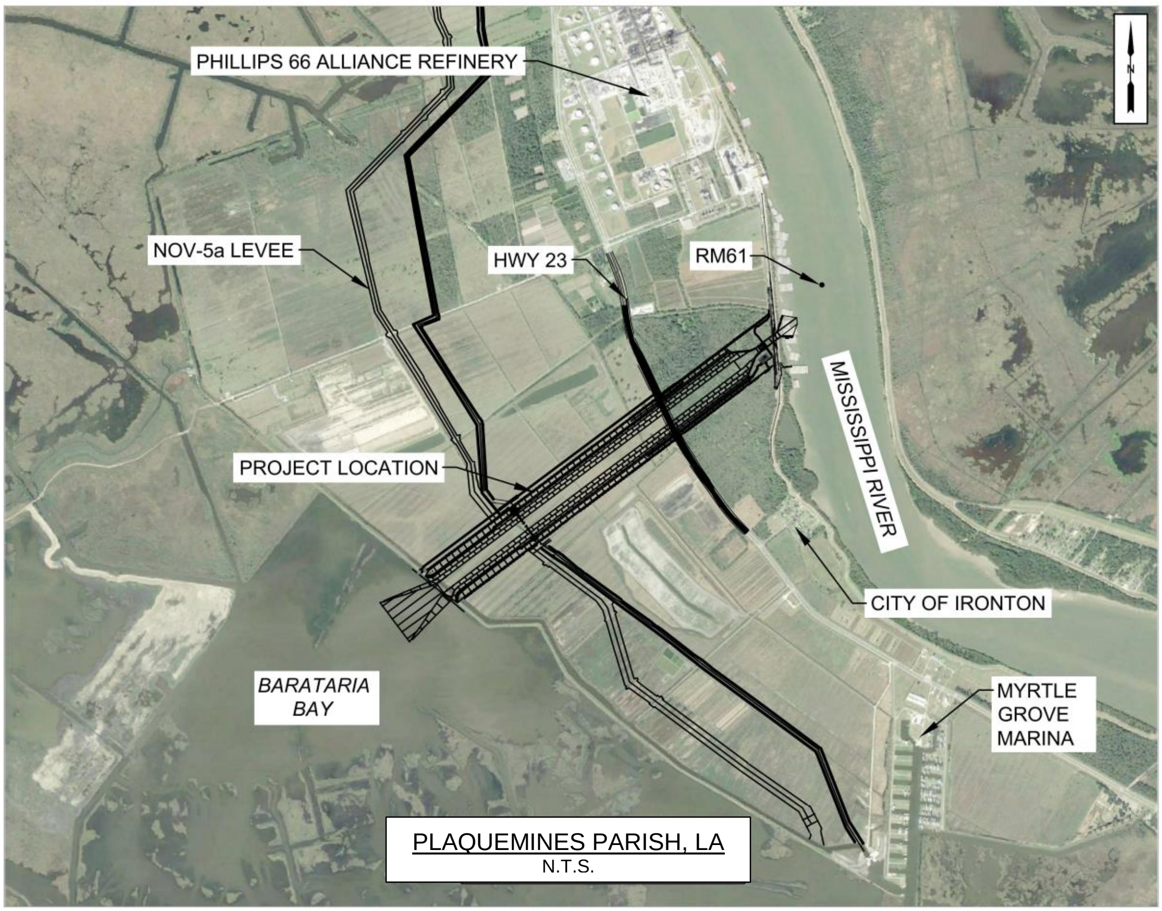


Figure 2-1: MBSD Project Location Map

Note: Other maps and drawings showing the project features to scale are included in **Appendix D**.

3. GENERAL

3.1 Project Goals and Description

The MBSD Project is one of two projects which comprise CPRA's Mississippi River Mid-Basin Sediment Diversion Program. The MBSD will divert river flow and sediment from the Mississippi River to the Barataria Basin, establishing conditions which will allow the development of a delta area via the transport and deposition of sediment carried downstream by the river during flood events. Goals of the project include:

- Reconnect the Mississippi River to the Barataria Basin
- Establish conditions to allow the development of a delta area open to tidal exchanges
- Use, as an initial basis of design, 75,000 cubic feet per second (cfs) flow through the Conveyance Channel from the MRL to the Barataria Basin by operating gates of the diversion structure. This flow rate was used as a basis to further develop design concepts at the proposed MBSD site. The final diversion flow rates are to be designed to meet the project goals
- Maintain the current level of flood risk reduction of the MRL and NOV levee
- Design the Intake Structure, control structure, channel, and appurtenances to maximize sediment capture, maximize flow efficiency, and allow for operations adaptability based on monitoring data collected during project operation, while minimizing Operations, Maintenance, Repairs, Replacement and Rehabilitation (OMRR&R)
- Meet state and federal design criteria and environmental compliance requirements as required to achieve project regulatory approval
- Develop an operational plan for the diversion structure

The sediment conveyance system is divided into three sections; intake, conveyance, and discharge. The intake consists of an Intake Structure, gated diversion and transition. The conveyance feature includes an approximate 2-mile Conveyance Channel and guide levees that parallel the channel. The discharge component includes an Outfall Transition Feature. Project components not directly related to sediment conveyance include: Hwy 23 Bridge and Roadway Realignment, Railroad Relocation (conceptual only for BOD Phase), Interim Flood Protection measures, Interior Drainage including a Siphon, Utility Relocations, and Secondary Project Features such as support buildings and a boat ramp. An overall site map is included in Appendix D, Selected Alternative Plans, Drawing #G-009.

3.2 Purpose and Goals of the Basis of Design Phase and Report

CPRA is executing the E&D services for the MBSD project in two phases: a BOD Phase, in which the DT performs 15%-level alternatives analyses, and Phase 2, which will include detailed E&D of the diversion, permitting support, and coordination with the Construction Manager at Risk (CMAR). The BODR documents the work performed in the BOD Phase.

The BOD Phase comprises 15% level-of-completion of alternatives analyses of major diversion system components to identify and select alternatives that improve sediment capture and transport capabilities, improve hydraulic performance and produce life cycle cost savings relative to previous 30%-level designs completed in 2014. Initial Project Design Criteria were established in accordance with project goals. Hydraulic modeling and E&D of the selected major diversion components to finalize their sizes and geometry will continue after the BOD Phase. The BODR serves to document the modeling and conceptual designs of the alternatives under consideration, and the screening process by which certain conceptual alternatives were selected. Alternatives evaluated included River Intake configurations and their invert elevations, Conveyance Channel inverts and profiles, HW structural components, levee and floodwalls, railroad and highway bridge alignments, and Interior Drainage modifications. Selection matrices were developed to evaluate River Intake alternatives, Conveyance Channel alternatives, and Interior Drainage modification alternatives. A matrix-based screening process for the Intake alternatives was developed to compare by scoring system established for their respective sediment capture and transport performance, hydraulic performance, cost, adaptability, and risk. The screening process for the Conveyance Channel compared hydraulic performance and cost. The other component alternatives were selected through individual studies, which are discussed in this BODR, but were not scored using evaluation matrices.

Hydraulic modeling of the major component alternatives has been completed for existing boundary conditions, and the results of those models are discussed in this BODR. During BOD Phase, evaluation of alternatives for hydraulic performance 50 years after the start of diversion operation, i.e., for future conditions, was limited to identifying the estimated future net potential energy head differential between the Mississippi River and Barataria Basin, as computed by TWIG's Basin-Wide Model, and comparing this future available net head to the computed head losses in the diversion system for each alternative. Systemic head loss exceeding the estimated, future available net head was considered a fatal flaw, and eliminated one of the Intake Types (submerged culvert alternative) from consideration.

At the end of the BOD Phase, an initial assessment was made of the capability of the diversion system, as sized for current conditions, to meet project goals in the future. The selected, major diversion components were modeled in a three-component model (i.e., HW, Conveyance Channel and Outfall Transition Feature) for Year 49 conditions, as imported from TWIG's Basin-Wide Model, and the results indicate that the selected components sized only for current conditions will not deliver 75,000 cfs of diversion flow with 1 million cfs of flow in the Mississippi River. The evaluation determined that the Conveyance Channel is properly sized, but the River Intake needs to be widened to some extent, currently undetermined. The next step is to perform more extensive hydraulic modeling for future boundary conditions, during which the Intake will be incrementally enlarged. This will be done also in conjunction with modifying the Basin's built land topography, as imported from TWIG's model, to include dredged distributary channels that lower tailwater elevations. The upsizing will be established through a life cycle cost comparison of various combinations of upsizing and future dredging to select an intake size that can be constructed within budget and whose associated Basin maintenance dredging is manageable for CPRA. The selection will be made through a final screening process.

The upcoming modeling and cost comparisons for future conditions will be documented in a forthcoming update to this BODR, which will occur during the 30% Phase of E&D. Starting in 30%, hydraulic modeling will include modeling for various operational scenarios in support of developing an operational plan. The detailed E&D of the Diversion components and associated features will be documented in a Design Documentation Report (DDR) during Phase 2 of the Project.

3.3 Report Structure

The BODR documents the engineering alternatives analysis performed during the BOD Phase of the MBSD project. The report narratives describe design processes and methods, summarize documents included in the appendices, and recommend selected alternatives. The appendices contains documents such as technical memos, reports, modeling plans and other documents previously submitted as deliverables during the BOD Phase, and conceptual drawings depicting both the selected alternatives and the eliminated alternatives. Specific appendices are referenced within the report sections as appropriate.

3.4 Design and Service Life

As directed by CPRA, the design life for the MBSD is forecasted to be 50 years, with a service life of 100 years. Ultimately, hydraulic modeling will be performed with future conveyance boundary conditions established at 50 years from project completion (2074).

3.5 Previous Reports and Studies

In 2014, CPRA contracted with a design consultant who completed a 30% BOD (herein referred to as the 2014 Base Design), which included reports and preliminary drawings. Although these deliverables were labeled as a 30% level of completion, CPRA recognized that not all of the designs were actually completed to a 30% level. CPRA tasked the DT with reviewing and verifying the feasibility of the BOD, and developing new concepts to save costs or add value to the project.

In addition to the 2014 Base Design Report, other previous reports and studies are referenced throughout the BODR, such as studies performed by TWIG, USACE, or CPRA. These publications are also documented as references in the reports and studies prepared for the MBSD project, which are included in the Appendices.

3.6 Existing Data

While efforts to obtain current data are ongoing throughout the BOD Phase, existing data was used to initiate conceptual designs and perform alternatives screening. Examples of existing data include the following:

- Results from previous geotechnical borings and testing
- Hydraulic models performed by TWIG and CPRA
- Aerial imagery
- LIDAR data
- 2013 River Bathymetry
- 2017 USACE Revetment Surveys
- TWIG's Mississippi River Sediment Data at the MBSD site

For further information regarding specific data used in the geotechnical analyses and hydraulic modeling, refer to **Appendix G** and **Appendix H**.

3.7 Site Conditions

The MBSD will span from the Mississippi River to Barataria Bay, intersecting the MRL, a railroad crossing, Hwy 23, an existing back levee, drainage ditches, and two drainage canals, the Timber Canal and Back Levee Canal. A river barge fleeting area, with mooring monopoles, is located along the river's right, descending bank, where the Intake Structure will be located. The barge fleeting area extends both upriver and downriver of the Intake location. The existing MRL crown elevation is approximately EL 15.5, but is authorized to EL 16.4. An existing railroad track, operated by NOGC Railway, is located at grade, on the protected side of the MRL, and terminates just south of the MBSD site. The wooded fastlands reach stretches from the MRL to Hwy 23, which is an at-grade 4-lane divided highway running in a north-south direction.

As part of the Plaquemines Port & Harbor Terminal District, a liquid petroleum products tank farm and marine export terminal are being considered for siting on the upriver side of the MBSD, immediately adjacent to the project. The project does not currently have necessary permits for construction and operations. The JPA has been filed. Numerical hydraulic modeling and conceptual designs have been performed independent and does not include any potential site development at the proposed terminal location.

Between Hwy 23 and the back levee, the existing site is mostly comprised of borrow pits and drainage ditches. The downstream end of the proposed Conveyance Channel will intersect the existing back levee, for which USACE is planning to construct improvements. This project, titled NOV-NF-W-05a.1 LaReussite to Myrtle Grove, originally called for the enlargement of the existing levee near its existing alignment. However, USACE is currently considering shifting this alignment close towards Hwy 23. After USACE announces their final alignment decision, the MBSD Conveyance Channel Levees will be designed to tie-in to the chosen levee alignment.

3.8 Key Definitions

Current Conditions-Current Conditions are present Mississippi River water surface elevations near the diversion intake (headwater) and water surface elevations in the Barataria Basin (tailwater). In the numerical models, these water surface elevations are specified as boundary conditions obtained from the results of the basin-wide Delft3D Model run PR15 1.5m SLR results completed by TWIG. Sediment boundary conditions are also obtained from the same TWIG model. The Mississippi River bed morphology is taken from the TWIG Outfall Model Barataria (OMBA) model and the bathymetry from USACE 2013 multibeam and USACE 2017 revetment surveys.

Future Conditions-Future Conditions include Mississippi River headwater elevations and Barataria Basin tail water elevations anticipated to occur during Diversion operational scenarios being used in the hydraulic design of the three components of the Diversion, i.e., the HW, Conveyance Channel, and the Outfall Transition Feature. The future water surface elevations are those anticipated to occur 50 years after commencement of Diversion operation. Future conditions account for the predicted amounts of SLR, land-building, and the regional soil subsidence in the Barataria Basin at Year-50. The rates of SLR and regional soil subsidence used for modeling of future conditions are specified by CPRA. Similar to the Current Conditions, these conditions are obtained from Year-50 of the TWIG basin-wide Delft3D model run PR15 1.5m.

Headworks-The Diversion HW comprise the River Intake/Inlet, the Diversion Gate Structure, the Diversion Gate Structure's discharge transition to the full trapezoidal Conveyance Channel, and MRL flood protection tie-in features. Ancillary features of the HW include access to the Diversion Gate Structure, localized scour protection armoring, toe sheeting, localized under-seepage reduction features, ground improvement/strengthening, and integral piers/bents for the railroad bridge crossing the Intake.

Outfall Transition Feature-The Outfall Transition Feature, aka, Outfall Transition Area, Outfall Apron or Outfall Ramp, is the pre-dredged flared geometric transition from the end of the fully trapezoidal Conveyance Channel where it crosses the existing non-federal NOV Levee alignment, and upwardly slopes from the invert of the Conveyance Channel, to prevailing mud bottom grade in Barataria Basin. As the feature becomes shallower it becomes wider. The dimensions of the Outfall Transition Feature are determined by discharge conveyance efficiency and sedimentation considerations.

4. SURVEY DATUM AND INFORMATION

4.1 Survey Datum

The survey datum used for horizontal coordinates is NAD 1983 (2011) 2010.00 Epoch and for vertical control NAVD 1988 (2009.55 Epoch) Geoid 12A.

4.2 Primary Survey Control

The primary survey control benchmarks used for this project are V 393 2006 and N 366 1984. Both benchmarks were established by the National Geodetic Survey (NGS) and were also used in the 2013 survey.

4.3 Project Surveys and Imagery

Survey data being obtained during the BOD Phase (will not be used for design until Phase 2) includes the following:

- Mississippi River Bathymetric and Magnetometer Surveys
- Topographic Survey of project site
- Outfall Bathymetric and Magnetometer Surveys
- High-resolution aerial photography from Mississippi River to Outfall

Detailed information is provided in the Survey Report in **Appendix K.**

5. PROJECT DESIGN CRITERIA

The DT developed an initial MBSD DCD which will serve as a record of the design criteria used during the design process. This initial document, which is included in **Appendix U**, will be updated by the DT as the design work progresses. During the BOD Phase, design criteria have been developed for the following disciplines and components:

- Geotechnical Engineering of Major Diversion Components
- Hydraulic Structural Engineering of Major Diversion Components
- Hydraulics and Hydrology, including Site Drainage
- Hwy 23 Bridge and Approaches
- Railroad Bridge
- MRL, Conveyance Channel, Outfall, and Channel Armoring

Design criteria for the Marine Structures, Mechanical, Electrical, Instrumentation & Controls, Architecture, and Secondary Site Features will be developed after the BOD Phase is completed, and the DCD will be updated accordingly.

6. PROJECT DESIGN GRADES

The DCD (**Appendix U**) identified the project design grades for various current and future design years for flood protection features. Table 6-1 summarizes the design grades under consideration for the MBSD project and used during the BOD Phase.

Table 6-1: Design Grades for Project Features

MBSD Reach	Design Grade (NAVD88 2009.55)
MRL – Riverine Design Grade	EL 16.4
MRL – Hurricane Design Grade	EL 20.1
HW Structures tying into MRL line of riverine flood protection	EL 16.4 (or EL 20.1)
HW Discharge Transition Walls and Conveyance Channel T-Walls	EL 15.6 (or EL 12.1)
Conveyance Hurricane/Guide Levee Design Grade	EL 15.6 (or EL 12.1)
Conveyance (only) Guide Levee Design Grade @ Outfall	EL 11.6 *

Notes:

1. EL 16.4 is the authorized grade for the MRL at the project site.
2. EL 20.1 is the hurricane design grade for a 50-Year return period event, projected 50 years into the future, storm surge from the Mississippi River side.
3. EL 15.6 is the hurricane design grade for a 50-Year return period event, projected 50 years into the future, storm surge from the Basin.
4. EL 12.1 is the hurricane design grade for a 25-Year return period event, projected approximately 25 years into the future, storm surge from the Basin.
5. "Headworks structures tying into the MRL line of riverine flood protection are: Intake U-Frame walls, tie-in T-Walls to MRL embankment, Diversion Gate Structure and Steel Gates.
6. There is no structural superiority for hardened flood protection structures.

*EL 11.6 provided in 2014 Base Design for retainment of operational diversion flows plus freeboard. Hydraulic modeling is ongoing to verify water surface elevations in Conveyance Channel, which will determine final conveyance levee design grade.

7. SUMMARY OF ALTERNATIVES SCREENING

7.1 General

The BOD Phase was structured around an alternatives and evaluation screening process with two decision-point, alternatives-selection workshops during the BOD Phase. A third workshop will be held during the 30% Phase, during which the enlargement of the intake type selected during BOD Phase will be confirmed.

The two BOD Phase workshops were held with the DT and CPRA Project Management Team (PMT), and observed by National Fish Wildlife Foundation (NFWF), first to identify and then to collaboratively evaluate and screen the alternatives for major project components. The workshops were structured in a similar manner. Prior to each workshop the DT, with input from the CPRA and PMT, developed a group of alternatives for evaluation and decision models in order to facilitate the scoring and ranking of the alternatives. The decision models included a group of scoring criteria with weighted factors assigned specifically to each component/feature. At each workshop, the DT and PMT collectively scored each feature alternative, ranked and selected the feature alternatives. Prior to each workshop held during BOD Phase, decision matrices were prepared collaboratively by the DT and CPRA. Each matrix included evaluation categories with corresponding rating scales and was assigned importance/weighting factors. At the workshops, the alternatives were evaluated and scored, and the matrices populated. Sensitivity analyses were performed by varying rankings and importance factors to evaluate bias. Selections were made at the workshops with one exception: selection of the River Intake structure type and invert elevation alternative. It was decided at the second workshop that the decision matrix and rankings should be considered preliminary pending results of further numerical H&H modeling. Based on the modeling completed after the second workshop, the matrix was finalized and scored. The final version of the matrix is presented in this summary. Meeting minutes of the two workshop document in greater detail than Section 7 the evaluation and scoring process, and are included in **Appendix R**. It was decided at the first workshop that for certain project features that 15%-level engineering would proceed but changes to these design concepts compared to the 2014 Designs would not be done through a decision matrix scoring process. This is described in **Section 7.5**.

The structure to the alternatives screening process is shown graphically in **Figure 1-1**. The alternatives screening followed this sequence:

- At the first workshop, potential alternatives to be conceptually engineered and evaluated were identified, ranked and selected using decision matrices with qualitative scoring criteria.
- Numerical H&H modeling and conceptual-level civil, geotechnical, and structural engineering and design were then performed for the alternatives selected at the first workshop for investigation. Numerical modeling was performed according to a CPRA-approved numerical modeling work plan (see **Appendix H.7**). Conceptual engineering performed during the BOD phase was initiated using existing data, studies, and reports. Existing data has been deemed sufficient for executing the conceptual designs and performing alternatives analyses and selections. Additional data collection was begun during the BOD Phase, including additional geotechnical borings and lab data and additional topographic and geotechnical surveys, but this new data will not be used until Phase 2 design. The numerical modeling is summarized in **Section 8** and presented in greater detail in **Appendix H**. The geotechnical engineering is summarized in **Section 9** and supporting analyses are presented in **Appendix G**. Civil engineering

used in the screening of the alternatives is summarized in **Sections 11 and 12**. Structural engineering of the major diversion components is presented in Section 10 with supporting computations in **Appendix J**. H&H and civil and structural engineering for the Interior Drainage alternatives comparisons are presented in **Section 8.11** and supporting computations presented in **Appendix I**.

- Class 5 life cycle cost comparisons were developed using the modeling and conceptual designs.
- A second workshop was held at which the alternatives were evaluated and scored. The engineering and designs of the discarded alternatives were stopped. E&D of the selected alternatives continued to further refine costs.
- BOD Phase numerical H&H modeling of the intake alternatives was completed.
- The intake alternatives selection matrix was revised and scored.

7.2 Workshop No. 1

Alternatives Workshop No. 1 occurred at the beginning of the BOD Phase, on December 7, 2017. The goal of this workshop was to identify major component/design feature alternatives to evaluate through numerical hydraulic modeling and conceptual E&D during the BOD Phase. The features selected for evaluation were: the Intake, Conveyance Channel, Back Gate, and two non-conveyance features: drainage of interior polder upriver of diversion, railroad bridge alignment. It was decided that establishing the railroad bridge alignment would be done outside of the screening process, by proposing alternatives and reaching agreement with the NOGC Railway through a series of coordination meetings.

7.2.1 Alternatives Evaluated

As shown in Table 7-1, the workshop alternatives were organized according to project components or design features. The DT clearly identified alternatives, including advantages and disadvantages for each where applicable, and presented schematics and figures to assist the workshop group in visualizing the differences among alternatives. A complete copy of the presentation is provided with the workshop meeting minutes included in **Appendix R**.

Table 7-1: Alternatives Presented at Workshop No. 1

COMPONENTS	WORKSHOP No. 1 ALTERNATIVES PRESENTED
Intake Structure Type	U-Frame with Interior Walls
	U-Frame without Interior Walls
	Open Channel
	Submerged Culvert
	Longer Intake with Gate Structure at Hwy 23
Open Channel Variations	Training Walls and Armoring
	Training Walls, Armoring and Turbulent River Side Structures
Sill Elevations	EL -40
	EL -20
	EL -50
	EL -50 with adjustable weir
	Varies EL -50 to EL -35 across intake length
Intake Angle with River	Straight Alignment with Conveyance Channel
	15 Degree Angle
	30 Degree Angle
Intake Construction	Conventional, Soil Founded
	Conventional, Pile Founded
	In-wet, in Conveyance Channel
	In-wet, Off-Site River Location
Diversion Gate Types	Tainter Gate
	Vertical Lift Gate
	Tainter Gate with Variable Weir
Diversion Gate Location	450 ft, P/S of MRL C/L
	250 ft, P/S of MRL C/L
	200 ft, F/S of MRL C/L
	800 ft, MRL C/L
	At Hwy 23
Channel Profile	Flat after transition to back structure
	Vary slope from transition to back structure
	Vary slope from transition through Outfall
Channel Linings	Riprap below water, ACB to top of levee
	ACB full width of channel section
	USACE ACM along channel bottom, up slope, and ACB to levee toe
	USACE ACM along channel bottom, up slope, and turf from channel bank to levee crown
	Geoweb, geocells or marine mattress

Table 7-1 Alternatives Presented at Workshop No. 1 (continued)

COMPONENTS	WORKSHOP No. 1 ALTERNATIVES PRESENTED
Transition Type	150 ft Concrete U-Frame
	Concrete Trapezoidal Flume
	Concrete Retaining Wall with Concrete Lined Channel
Back Structure Replacement with Hurricane Levees	Back Structure at Existing Back Levee, 50-Year Stage
	Back Structure at Realigned NOV Levee, 100-Year Stage
	Guide Levees as Hurricane Levees
	Back Structure at Existing Back Levee for Sediment Dispersal
NOV Levee	USACE to keep NOV Levee at current location
	USACE Realignment of NOV Levee, existing NOV Levee maintained
Interior Drainage	Pump Station to drain north polder
	Siphon in lieu of pump station; existing NOV levee alignment
	Siphon in lieu of pump station; NOV levee realigned
Railroad Bridge	RR alignment turns west, crossing MBSD at Hwy 23
	Maintain RR on MRL alignment with flood proof bridge crossing MBSD
Hwy 23 Bridge	Low chord clears levee crown plus 15 feet or maintenance road plus 16.5 feet
	Reduce low chord by including floodwall and underpass road crossing
	Reduce low chord by including floodwall and at-grade crossing
MRL Penetration and Interim Protection	DT provides concept design; CMAR performs detail design
	DT provides concept and final design with CMAR input
Pile Type Comparison	Large diameter pipe piles
	Prestressed concrete piles
	H-piles

7.2.2 Decision Models

Decision models were developed as a tool to evaluate some of the workshop alternatives, with the objective of advancing some alternatives to the BOD Phase while eliminating others. The DT proposed selection criteria to best capture the advantages and/or disadvantages of the alternatives in relation to achieving project goals. A scoring system was defined with numerical values between 1 and 4, with a score of 1 indicating the most favorable, and a score of 4 indicating the least favorable. Definitions for the selection criteria and a detailed explanation of the scoring system are included in the workshop meeting minutes in **Appendix R**. The workshop team also collaboratively assigned a weighted factor percentage to each selection criteria, as shown in Table 7-2. The same weighted factors were applied to all criteria/alternatives evaluated in this workshop.

Table 7-2: Selection Criteria for Workshop No. 1

Criteria	Weighted Factor
Design Complexity	10%
Adaptability	25%
Constructability	15%
Environmental Impact	10%
Operations & Maintenance	15%
Sediment Transport/Land Building Potential	25%

This decision model was applied to the screening process for the Intake Structure type, the Diversion Gate location, and the transition type alternatives. For those components, the workshop group collaboratively worked through the decision model, until a consensus was reached on assigning a score of 1-4 to the criteria for each alternative. Assigned scores measured how well each alternative achieved the project goals. The decision models for the Intake Structure type, Diversion Gate location, and transition type are shown in Figures 7-1, 7-2 and 7-3. By summing the products of the score and weighted factor percentages across an alternative, the result was a numerical score which served to rank the alternatives, with the lowest numerical score representing the highest ranked alternative. In some cases, a sensitivity analysis was performed with the decision model to determine whether adjusting the weighted factor percentage for a particular criterion affected the ranking outcome.

Results of the Intake Structure type decision model (Figure 7-1) showed the open channel with the highest composite ranking. Due to a low composite ranking and a decision model sensitivity analysis, the gated structure at Hwy 23 was eliminated for consideration as an Intake Structure alternative. The other alternatives were selected for further consideration in the BOD Phase.

		Criteria							
	Importance	1	2	3	4	5	6	7	Composite Ranking*
		Design Complexity	Adaptability	Constructability	Environment Impacts	Operability / Maintenace	Land Building Potential		
	Factor %	10.0%	25.0%	15.0%	10.0%	15.0%	25.0%		100.0%
Alternative 1a	U-Frame - Bays - Soil Founded (2014 Design Report)	3	3	3	2	3	2		2.65
Alternative 1b	U-Frame w/o Interior Walls	3	3	3	2	3	2		2.65
Alternative 1c	Open Channel	2	2	2	1	2	3		2.15
Alternative 1d	Tunnel	3	4	4	2	4	1		2.95
Alternative 1e	Gated Structure at Hwy 23 w/longer intake (4400 vs 1100)	3	3	4	2	4	2		2.95

Figure 7-1: Decision Model for Intake Structure Type

Results of the Diversion Gate location decision model (Figure 7-2) showed the Hwy 23 gated structure and 200 feet flood side of the MRL gate alternatives with the lowest composite rankings. These two alternatives were eliminated from further study. The other alternatives were advanced for evaluation in the BOD Phase.

	Importance	Criteria 1	2	3	4	5	6	7	Composite Ranking*
		Design Complexity	Adaptability	Constructability	Environment Impacts	Operability / Maintenace	Sediment Transport/Land Building Potential		
	Factor %	10.0%	25.0%	15.0%	10.0%	15.0%	25.0%		100.0%
Alternative 7a	450ft to the P/S of MRL C/L – 2014 Report	2.5	2	3	2	2	2		2.2
Alternative 7b	250ft to the P/S of MRL C/L	3	2	2.5	2	2	2		2.2
Alternative 7c	200ft to the F/S of MRL C/L	3	2	3	2.5	3	2		2.5
Alternative 7d	750 from CL inland	2	2	2	2	2	2		2.0
Alternative 7e	gated structure at Hwy 23 (4300 from CL)	3	3	2.5	2.5	2.5	2		2.6

Figure 7-2: Decision Model for Diversion Gate Location

Results of the transition type decision model (Figure 7-3) showed the stepped sheet pile wall alternative having the lowest composite ranking. This alternative was eliminated from further study, and the other two alternatives were advanced for evaluation in the BOD Phase.

	Importance	Criteria 1	2	3	4	5	6	7	Composite Ranking*
		Design Complexity	Adaptability	Constructability	Environment Impacts	Operability / Maintenace	Land Building Potential		
	Factor %	10.0%	25.0%	15.0%	10.0%	15.0%	25.0%		100.0%
Alternative 11a	150ft – Stepped Sheet PileWall	3	3	2.5	1	3	2		2.5
Alternative 11b	Concrete Retaining Wall w/ all concrete floor	2	2	2	1	2	2		1.9
Alternative 11c	Concrete Retaining Wall w/ Riprap lined Channel	2	2	1.5	1	2	2		1.8

Figure 7-3: Decision Model for Transition Type

Some of the component alternatives and design features discussed during Workshop No. 1 were not conducive to being evaluated through the decision model process. The alternatives for the open channel variations, sill elevations, intake angles, intake construction methods, and the Diversion Gate types were discussed among the workshop group members, and through an open dialogue the advantages and disadvantages were openly discussed, although not numerically ranked. A summary of the all selected alternatives is shown in Table 7-3.

For a complete discussion of the decision models and selection process, refer to the workshop meeting minutes in **Appendix R**.

7.2.3 Alternatives Workshop No. 1 Selections

As evidenced through the alternative evaluation process detailed in the meeting minutes, any alternatives that were determined to contain fatal flaws were removed from consideration. If an alternative was determined through the group discussion to be neither economically nor physically feasible, or could not achieve a project goal, it was classified as having a fatal flaw.

Based on the results of the decision models or discussions during the workshop, remaining alternatives were selected to advance for further consideration in the BOD Phase. A list of these selected alternatives is provided in Table 7-3.

Table 7-3: Selected Alternatives - Workshop No. 1

COMPONENTS	WORKSHOP No. 1 SELECTED ALTERNATIVES
Intake Structure Type	U-Frame with Interior Walls
	U-Frame without Interior Walls
	Open Channel
	Submerged Culvert
Open Channel Variations	Training Walls and Armoring
	Training Walls, Armoring and Turbulent River Side Structures
Sill Elevations	EL -40
	EL -20
	EL -50
*Intake Angle with River	Straight Alignment with Conveyance Channel
Intake Construction	Conventional, Pile Founded
	In-wet, in Conveyance Channel
Diversion Gate Types	Tainter Gate
	Vertical Lift Gate
Diversion Gate Location	450 ft, P/S of MRL C/L
	250 ft, P/S of MRL C/L
	200 ft, F/S of MRL C/L
	800 ft, MRL C/L
Channel Profile	Flat after transition to back structure
	Vary slope from transition to back structure
	Vary slope from transition through Outfall
Channel Linings	Riprap below water, ACB to top of levee
	ACB full width of channel section
	USACE ACM along channel bottom, up slope, and ACB to levee toe
	Geoweb, geocells or marine mattress
Transition Type	Concrete Trapezoidal Flume
	Concrete Retaining Wall with Concrete Lined Channel
Back Structure Replacement with Hurricane Levees	Back Structure at Existing Back Levee, 50-Year Stage
	Back Structure at Realigned NOV Levee, 100-Year Stage
	Guide Levees as Hurricane Levees
	Back Structure at Existing Back Levee for Sediment Dispersal
NOV Levee	USACE to keep NOV Levee at current location
	USACE Realignment of NOV Levee, existing NOV Levee maintained

Table 7-3: Selected Alternatives - Workshop No. 1 (Continued)

COMPONENTS	WORKSHOP No. 1 SELECTED ALTERNATIVES
Interior Drainage	Pump Station to drain north polder
	Siphon in lieu of pump station; existing NOV Levee alignment
	Siphon in lieu of pump station; NOV Levee realigned
Railroad Bridge	RR alignment turns west, crossing MBSD at Hwy 23
	Maintain RR on MRL alignment with flood proof bridge crossing MBSD
Hwy 23 Bridge	Low chord clears levee crown plus 15 feet or maintenance road plus 16.5 feet
	Reduce low chord by including floodwall and underpass road crossing
	Reduce low chord by including floodwall and at-grade crossing
MRL Penetration and Interim Protection	DT provides concept design; CMAR performs detail design
	DT provides concept and final design with CMAR input
Pile Type Comparison	Large diameter pipe piles
	Prestressed concrete piles
	H-piles

*Note: The angled intake alternatives were considered as part of the optimization process for the selected intake alternative. Because the selected alternative is the open channel, for which numerical modeling revealed that the size and geometry of the sediment capture zone is the relevant characteristic, the variation in intake geometry entailed modifying the angles of the training walls rather than rotating the overall orientation of the intake. This is further described in Section 8.5.7.

7.3 Workshop No. 2

Alternatives Workshop No. 2 was held June 7, 2018, with DT and PMT members in attendance. The goal of this workshop was to select design alternatives for major project components using numerical modeling results, civil layouts and conceptual geotechnical and structural designs. Design features included Interior Drainage Alternatives, Conveyance Channel Profiles, Back Gate Structure/Hurricane Grade Levees, and Intake Structure Type/Invert Elevations.

7.3.1 Alternatives Evaluated

As shown in Table 7-4, Workshop No. 2 alternatives were organized according to project components. Based on results from Workshop No. 1 and subsequent engineering analysis, the DT clearly identified alternatives including advantages and disadvantages for each where applicable, and presented schematics and figures to assist the workshop group in visualizing the differences among alternatives. The presentation is provided with the workshop meeting minutes included in **Appendix R**.

Table 7-4: Alternatives Presented at Workshop No. 2

COMPONENTS	WORKSHOP No. 2 ALTERNATIVES PRESENTED
Interior Drainage	Pump Station
	Siphon
Conveyance Channel Profile	Channel invert at constant EL -25
	Constant sloping invert from EL -25 at transition to EL -15 at NOV Levee and EL-9.5 at Outfall
	Constant invert at EL -25 to NOV Levee, then slope to EL -12 at Outfall
	Channel invert at constant EL -20
	Constant sloping invert from EL -20 at transition to EL -12 at NOV Levee and EL -7 at Outfall
	Constant invert at EL -20 to NOV Levee, then slope to EL -10 at Outfall
Back Gate Structure vs. Hurricane Grade Levees	Back Gate Structure with Guide Levees
	Hurricane Grade Guide Levees with No Back Structure
Intake Structures	U-Frame with Interior Walls @ EL -40
	U-Frame without Interior Walls @ EL -40
	Open Channel @ EL -40
	Submerged Culvert @ EL -40
	Open Channel @ EL -50
	Submerged Culvert @ EL -50
	Open Channel @ EL -20
	U-Frame without Interior Walls @ EL -20

7.3.2 Decision Models

Decision models were developed as a tool to evaluate, rank, and select the workshop alternatives, with the objective of advancing the selected alternatives to the 15% BOD level. The DT proposed selection criteria and a scoring system somewhat similar to those used in Workshop No. 1. However, the evaluation criteria and weighted factor percentages for Workshop No. 2 were specifically tailored to each project component. Quantitative results of numerical H&H modeling; conceptual-level civil, geotechnical engineering; and Class 5 cost comparisons were used to rank the alternatives.

The decision models were presented as interactive spreadsheets, which enabled the group to perform an interactive screening process and perform sensitivity analyses, if appropriate, by adjusting the weighted factors. Definitions for the Workshop No. 2 selection criteria, detailed explanations of the scoring systems, and explanations of sensitivity analyses performed are included in the workshop meeting minutes in **Appendix R**.

Figures 7-4 through 7-6 present the final versions of the decision models, including weighted criteria and ultimate ranking of alternatives. For the purposes of the Workshop No. 2 selection process, the hydraulic models used to develop decision model criteria for the Intake Structure were based on existing conditions for a river flow of 1,000,000 cfs and channel flow of 75,000 cfs.

Interior Drainage	Importance	Criteria				Composite Ranking
		1	2	3	4	
		Construction Cost	Operability/ Maintenance Cost	Resilience	Additional Real Estate	
	Factor %	40%	35%	20%	5%	100%
Alternative 1	Pump Station	5	5	2	3	4.3
Alternative 2	Siphon	1	1	3	1	1.4

Figure 7-4: Workshop No. 2 Decision Model for Interior Drainage

Conveyance Channel Profile	Importance	Criteria		Composite Ranking
		1	2	
		Energy Loss	Construction Cost	
	Factor %	60%	40%	100%
Alternative 1	Channel Invert at Constant EL -25	1	1	1.0
Alternative 2	Constant sloping invert from EL -25.0 at transition to EL -15.0 at NOV levee and EL -9.5 at outfall	5	2	3.8
Alternative 3	Constant invert at EL -25 to NOV levee, then slope to EL -12 at the outfall	2	2	2.0
Alternative 4	Channel Invert at Constant EL -20	1	1	1.0
Alternative 5	Constant sloping invert from EL -20 at transition to EL -12 at NOV levee and EL -7 at outfall	4	5	4.4
Alternative 6	Constant invert at EL -20 to NOV levee, then slope to EL -10 at the outfall	3	2	2.6

Figure 7-5: Workshop No. 2 Decision Model for Conveyance Channel Profile

Back Gate vs. Hurricane Levees	Importance		Criteria				Composite Ranking
		1	2	3	4	5	
		Energy Loss	Hydraulic - Benefits of Sediment Distribution	Impacts to Siltation Levels	Construction Cost	Routine Operability/ Maintenance Cost	
	Factor %	25%	25%	10%	30%	10%	100%
Alternative 1	Back Gate w/ Guide Levees	5	1	1	5	5	3.6
Alternative 2	No Back Gate, Hurricane Levees	4	1	5	1	1	2.2

Figure 7-6: Workshop No. 2 Decision Model for Back Gate Structure vs. Hurricane Grade Levees

7.3.3 Alternatives Workshop No. 2 Selections

Based on the results of the decision models and/or discussions during the workshop and after the initial hydraulic modeling was completed, the siphon, channel profile EL -25, and Hurricane Grade Levees with no back structure were selected as the preferred alternatives for each feature respectively. A preliminary decision model was performed on the intake structure types at the workshop. This exercise resulted in the elimination of the submerged culvert alternatives, due to the calculated head loss values. Discussion of this screening process is included in **Appendix R**.

The selected alternatives for Workshop No. 2 are summarized in Table 7-5.

Table 7-5: Selected Alternatives - Workshop No. 2

COMPONENTS	WORKSHOP No. 2 ALTERNATIVES SELECTED
Interior Drainage	Siphon
Conveyance Channel Profile	Channel invert at constant EL -25
Back Gate Structure vs. Hurricane Grade Levees	Hurricane Grade Levees with No Back Structure
Intake Structure	Submerged Culvert Alternatives Eliminated

7.4 Additional Screening for Intake Alternatives

After Workshop No. 2, at the July Monthly Technical Meeting, the DT performed additional screening on the intake alternatives using Delft3D with three operational river stages: 1,000,000; 800,000; and 600,000 cfs; and additional FLOW-3D modeling for river stage at 600,000 cfs, but capturing hydrodynamic effects only to calibrate energy losses in the Delft3d models. The new model results were then used in a revised intake decision matrix (see **Figure 7-7**). One weighted SWR was calculated for each alternative, and this SWR considered the duration of each operational stage. The weighted average SWRs were computed by estimating time durations when the respective river stages were historically recorded at the Belle Chasse Gage. Because the submerged culvert alternatives were eliminated from consideration at Workshop No. 2, they were not evaluated in this additional screening process.

The decision matrix was modified to include a column for the Workshop No. 2 FLOW-3D SWR and a column for the weighted SWR from the additional Delft3D modeling. The DT-guided decision model demonstrated the Open Channel at EL -20 as the best-performing alternative, with the Open Channel at EL -40 as the second best. At the end of July, CPRA informed the DT that the PMT performed a separate additional screening exercise internally, in which the scoring was modified to lend more weight to the adaptability scoring factor. As shown in Figure 7-8, this modified decision model demonstrated the Open Channel at EL -40 as having the highest composite ranking.

The scoring scales and weighted importance of the evaluation criteria in the matrix were also revised after Workshop No. 2. Extremes for the SWR scoring range were established by using the lowest and highest SWRs computed for historic TWIG modeling of intake alternatives and then divided into five equal banded ranges. The energy loss scoring range was selected as a range of 0.7 feet to 4.7 feet, in five equally banded ranges of 0.8 feet each. The construction cost scoring range for the headworks alternatives was established as $202 million to $867 million, comprising five equally banded ranges of

$133 million each. The "Risk (Design/Construction)" Category was used in lieu of the Operational Risk Category in the interim matrix because it was concluded that the "Operability/Maintenance" Category includes operational risk. The Adaptability Category remained the same as was established in the interim scoring matrix. Risk, Operability/Maintenance, and Adaptability are qualitative categories.

The weighting factors of the evaluation criteria were modified from the original matrix. The performance categories collectively were kept at a weighting of 50% of the overall ranking, but also included the SWR category for Delft-3d results. Adaptability was increased from 10% to 25% because scoring participants concluded that the uncertainty of future conditions and events demand a system whose design can be modified if required. For example, the construction or modification of marine facilities directly upriver of the diversion could adversely affect diversion performance. Other variables include regional subsidence and sea level rise. Potential countermeasures could include modifying intake geometry. A hardened intake, such as a U-frame, would require demolition and reconstruction, whereas the Open Channel could be more readily modified more readily by demolishing and reconstructing the training walls and additional dredging and stone armoring. The Risk Category rating was kept at 10%, as was the Operability/Maintenance Category. The Construction Cost category's weighting was reduced from 20% to 5%, reflecting that the most important quality is that the system meet performance specifications, both during the initial operational period and in the future as river and conveyance conditions evolve.

After revising the scoring matrix and ranking the alternatives, the Open Channel at EL -40 was selected as the preferred intake configuration.

Intake Structure Selection (Modified)		Criteria - Maintaining 75,000cfs at Current Boundary Conditions							Composite Ranking
	Importance	1	2	2	3	4	5	6	
		Hydraulics (Head Loss)	SWR River (Flow3d)	SWR River (Delft)	Adaptability to Change	Risk (Design/ Construction)	Construction Cost	Operability/ Maintenance	
	Factor %	25%	5%	20%	25%	10%	5%	10%	100%
Alternative 1	U-Frame with Walls @ EL -40	5	3	3	3	4	3	1	3.25
Alternative 2	U-Frame without Walls @ EL -40	4	2	3	3	4	3	1	3
Alternative 3	Open Channel @ EL -40	3	1	3	1	3	2	1	2.15
Alternative 4	Submerged Culvert @ EL -40								n/a
Alternative 5	Open Channel @ EL -50	3	2	4	1	3	3	2	2.45
Alternative 6	Submerged Culvert @ EL -50								n/a
Alternative 7	Open Channel @ EL -20	2	2	2	4	2	2	1	2.4
Alternative 8	U-Frame without Walls @ EL -20	3	2	2	5	3	2	1	2.9

Figure 7-7: Final Decision Model for Intake Selection

7.5 Alternative Selections Performed Apart from the Workshop Evaluation Process

Certain project features that 15%-level engineering investigated compared to the 2014 Designs were not done through a decision matrix scoring process. The DT has performed the evaluations and the recommendations are listed below:

Table 7-6: Alternatives Recommendations Developed Outside of Alternatives Workshop Screening Process

Project Component/Feature	Selection Recommendation
Headworks-River Armoring	Riprap armoring was selected as the armoring type. See **Section 10.4.6**.
Headworks-Diversion Gate Type	The tainter gate type is recommended. See **Appendix O**.
Headworks-riverine flood protection structures	Riverine protection constructed to EL 20.1 is recommended. See **Section 10.6**.
Headworks-on-site emergency crane	A dedicated, on-site crane is not required. See **Appendix P**.
Conveyance Channel-Revetment System	System will be either riprap or a modular revetment system. This will be selected during 30% Phase. See **Section 11.5** and **Appendix N**.
Conveyance Channel-Guide Levees, top of flood protection	Select EL 15.6 as top of levee. See **Section 11**.
Conveyance Channel-Guide Levees, ground improvements	Construct guide levees using wick drain system and staged construction. **See Section 9.16.4**.
Outfall Transition Feature-Ramp Geometry	A 1,500-foot ramp length is recommended. See **Section 8.8**.
NOGCC Railroad Bridge	Construct the bridge along the existing alignment of the rail line. The low chord of the bridge across the diversion intake will be at or higher than EL 16.4. See **Section 14**.
LA-23 Bridge	Construct the bridge along the existing highway's alignment. See **Section 13**.
Beneficial Use of Unsuitable Materials for Levee Construction	Construct wetlands in areas designated for disposal of materials. See **Section 24**.
Secondary Project Features	Incorporate into project those features identified in **Section 20**.

8. HYDROLOGY, COASTAL ENGINEERING, AND HYDRAULICS

8.1 General

The hydrologic and hydraulic analyses along with the numerical and physical modeling to support the E&D are described in this section. The major hydraulic features of the project and the key hydraulic processes are described in the beginning followed by summary of the various analyses. The details of the analyses are provided in **Appendix H**.

The methods were influenced by the fact that CPRA has a parallel, ongoing modeling effort with TWIG on MBSD. The DT's modeling is expected to be consistent with those efforts. The analysis performed leverages work already completed by CPRA/TWIG including the model setup (e.g. model geometry, boundary conditions, Relative Sea Level Rise and Subsidence) and findings.

The overall goal of the numerical modeling is to develop the design of an Intake Structure that can divert a maximum flow of 75,000 cfs flow when the Mississippi River reaches 1,000,0000 cfs at the Belle Chasse gage with as high Sediment-to-Water (SWR) ratio as achievable; approaching 1.0. The BODR presents modeling analysis under present Relative Sea Level Rise and Subsidence (RSLR) conditions. It also demonstrates diversion system performance under future (Year-50) RSLR conditions.

8.2 References and Publications

- Allison, M. and Meselhe, E. (2010). "The Use of Large Water and Sediment Diversions in the Lower Mississippi River (Louisiana) For Coastal Restoration." *Journal of Hydrology*, 387 (3-4),346-360.
- Allison, M. (2011). "Water and Sediment Surveys of the Mississippi River Channel Conducted at Myrtle Grove and Magnolia in Support of Numerical Modeling (October 2008 to May 2011)." *A report to the State of Louisiana Office of Coastal Protection and Restoration as subcontracted to C.H. Fenstermaker and Associates.*
- Allison, M., Vosburg, B., Ramires, M. and Meselhe, E. (2012). "Mississippi River Channel Response to the Bonnet Carre Spillway Opening in the 2011 Flood and Its Implications for the Design and Operation of River Diversions." *Journal of Hydrology*, 477, 104-118.
- Allison, M., Demas, C., Ebersole, B., Kleiss, B., Little, C., Meselhe, E., Powell, N., Pratt, T. and Vosburg, B. (2012). "A Water and Sediment Budget for the Lower Mississippi-Atchafalaya River in Flood Years 2008-2010: Implications for Sediment Discharge to the Oceans and Coastal Restoration in Louisiana." *Journal of Hydrology*, 432-433, 84-97.
- Allison, M., Vosburg, B., Ramires, M. and Meselhe, E. (2014). "Diversion of Mississippi River Water Downstream of New Orleans, Louisiana, USA to Maximize Sediment Capture and Ameliorate Coastal Land Loss." *Water Resources Management*, 28, 4113-4126.
- Bettelle. (2017). "Final Panel Comments on the Independent External Peer Review of the Louisiana Coastal Area Mississippi River Hydrodynamic Study Technical Report and Tool development: PHASE 3."
- Esposito, C., Liang, M., and Meselhe, E. (2017). "TO5 Outfall Management Mid-Barataria and Mid-Breton Diversions."

- Esposito, C., Liang, M., Sadid, K. and Meselhe, E. (2017). “Mid-Barataria Sediment Diversion Modeling Package.”
- FTN Associates. (2013). “Numerical Modeling for LCA Medium Diversion at Myrtle Grove with Dedicated Dredging: Model Calibration and Validation.” *Report prepared for CPRA.*
- Gaweesh, A. and Meselhe, E. (2016). “Evaluation of Sediment Diversion Design Attributes and Their Impact on the Capture Efficiency.” *Journal of Hydraulic Engineering*, 142(5).
- HDR. (2014). “Mid-Barataria Sediment Diversion Alternative 1, Base Design Report 30% Basis of Design.”
- HDR. (2014). “Mid-Barataria Sediment Diversion Hydraulic Report 30% Basis of Design and Value Engineering.”
- Hydraulic Design Handbook, Larry W. Mays, McGraw-Hill Education, 1999
- Jung, H., Baustian, M. and Meselhe, E. (2016). “TO15/16: Outfall Areas in Barataria and Breton Sound Vegetation Model Improvement.”
- Jung, H., Baustian, M. and Meselhe, E. (2016). “TO15/16: Outfall Areas in Barataria and Breton Sound Water Quality Model Improvement.”
- Khadka, A., Sadid, K. and Meselhe, E. (2016). “TO 15/16 Analysis of Outfall Areas in the Barataria and Breton Sound Basins: Improvement of Sand Load Transport and Dredging Calibration in the Mississippi River.”
- Liang, M., Meselhe, E., Messina, F. and Ortals, C. (2016). “TO5/TO41/TO44 Sediment Diversions: Optimization of the Operation Plans.”
- Liang, M., Esposito, C. and Meselhe E. (2017). “Technical Memorandum Mid-Barataria Invert Elevation and Outfall Channel Configuration.”
- Meselhe, E., Georgiou, I., Allison, M. and McCorquodale, J. (2012). “Numerical Modeling of Hydrodynamics and Sediment Transport in Lower Mississippi at a Proposed Delta Building Diversion.” *Journal of Hydrology*, 472-473, 340-354.
- Meselhe, E.A., Baustian, M.M. and Allison, M.A. (2015). “Basin Wide Model Development for the Louisiana Coastal Area Mississippi River Hydrodynamic and Delta Management Study.” The Water Institute of the Gulf, Baton Rouge, LA.
- Meselhe, E., Baustian, M. and Allison, M. (2015). “Basin Wide Model Development for the Louisiana Coastal Area Mississippi River Hydrodynamic and Delta management Study.”
- Meselhe, E., Messina, F., Sadid, K. and Jung, H. (2016). “TO5/TO41/TO44 Internal Model Dynamic.”
- Meselhe, E., Baustian, M. and Jung, H. (2016). “Technical Memorandum TO5/TO41/TO44: Vegetation Sensitivity Test Runs.”
- Meselhe, E.A., Sadid, K.M., Xing, F., Jung, H., Baustian, M., Smiths, J.G.C., Van Maren, B.D.S., Sylvester, S.M.D. and Visser, J.M. (2016). “Louisiana Coastal Area (LCA), Louisiana Ecosystem Restoration Study Mississippi River Hydrodynamics and Delta Management Study (MRHDMS): Assessment and Analysis of Alternatives.” *Final Report to the LA CPRA in support of TO # 36.1 and TO # 5.*
- Messina, F. and Meselhe, E. (2016). “TO 15/16 Improvements to the Hydrodynamics and Salinity in Barataria: Basin-wide Model Version 2.”
- Meselhe, E., Sadid, K. and Allison, M. (2016). “Riverside Morphological Response to Pulsed Sediment Diversions.” *Geomorphology*, 270, 184-202.
- Messina, F. and Meselhe, E. (2017). “Technical Memorandum TO46: Mid-Barataria Optimization Plane-Base Flow Option.”
- Meselhe, E., Jung, H. and Esposito, C. (2017). “Technical Memorandum TO46: Existing Diversion Analysis and Head Differential Analysis.”

- Meselhe, E., Sadid, K., Messina, F. and Jung, H. (2017). "Technical Memorandum TO48: Basin-Wide Delft Evaluation of Diversion Operations (Production Run 11-15) Appendix A."
- Meselhe, E., Sadid, K., Messina, F. and Jung, H. (2017) "Technical Memorandum TO48: Basin-Wide Delft Evaluation of Diversion Operations (Production Run 11-15)."
- Meselhe, E., Costanza, K., Jung, H., Ainsworth, C., Simpson, E., Chagaris, D., Addis, D., Rodrigue and M., Smits J. (2017). "Models Performance Assessment Metrics for the LCA Mississippi River Hydrodynamic and Delta Management Study (TO5)."
- Meselhe, E., Jung, H., Sadid, K., Messina, F. and Baustian, M. (2017). "Calibration and Validation of Delft3D Model Version 2 Comparison of V1 and V2 Model Performance."
- Meselhe, E., Sadid, F., Messina, F. and Jung, H. (2017). "Technical Memorandum TO46: Basin-Wide Delft Evaluation of Diversion Operations (Production Runs 11-15)."
- Nittrouer et al (2011) Punctuated sand transport in the lowermost Mississippi River. *J. Geophysical Research*, Vol. 116.
- Rego, J., Meselhe, E., Stronach, J. and Habib, E. (2010). "Numerical Modeling of Mississippi-Atchafalaya Rivers' Sediment Transport and Fate: Consideration for Diversion Scenarios." *Journal of Coastal Research*, 26, 212-229.
- Sadid, K., Xing, F., Messina, F. and Meselhe, E. (2016). "TO 15/16 Improvement of Model Grid and Bathymetry."
- Sadid, K., Meselhe, E., Allison, M. and Van Maren, B. (2016). "TO 15/16 Sediment Properties used in the Basin-wide Model."
- Wang, H., Steyer, G., Couvillion, B., Rybczyk, J., Beck, H., Sleavin, W., Meselhe, E., Allison, M., Boustany, R., Fishchenich, C. and Rivera-Monroy, V. (2014). "Forecasting Landscape Effects of Mississippi River Diversions on Elevation and Accretion in Louisiana Deltaic Wetlands under Future Environmental Uncertainty Scenarios." *Estuarine, Coastal and Shelf Science*, 138, 57-68.

8.3 Diversion System Components and Key Hydraulic Processes

The proposed MBSD is a sediment delivery system made up of several components or hydraulic structures/features. Each component supports one or more functions and together they help accomplish the project goals. The design of each component is driven by specific hydraulic processes that will be modeled. The system components, functions and hydraulic processes are shown in **Figure 8-1**. The general hydraulic characteristics of each component are described briefly in the following sub-sections.

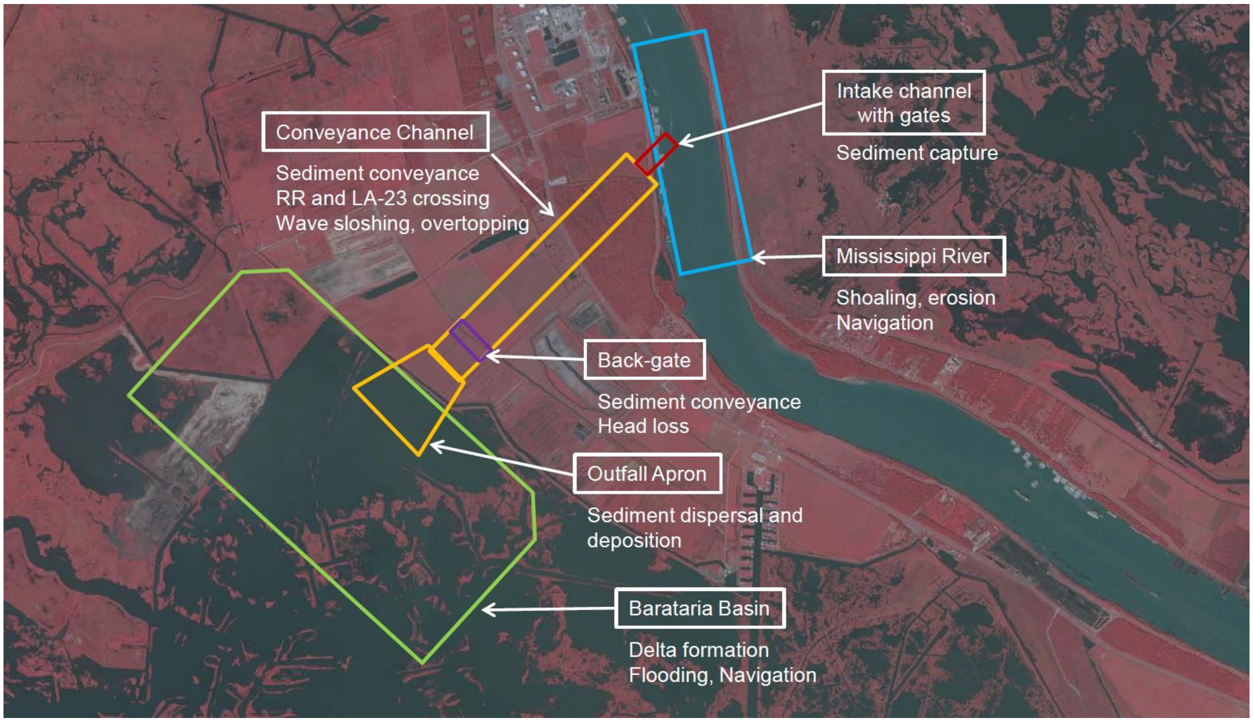


Figure 8-1: MBSD System Components, Functions and Key Hydraulic Processes

8.3.1 Mississippi River

The Mississippi River carries sediment-laden flows south to the Gulf of Mexico. At the project location, the depth of the River is approximately 120 feet and a sand bar exists at a depth of about 50 feet. The top width of the River is approximately 2,000 feet. At this location, the River carries a flow ranging from 425,000 cfs to 1,250,000 cfs during typical annual flood events. The transported sediment consists of clay, silt and sand particles. The dominant hydraulic processes in the vicinity of the diversion are longitudinal, transverse and vertical velocities due to the upstream river bend, suspended sediment transport through the water column and bed load transport along the sandbar present at the proposed diversion. The presence of the diversion may also induce erosion and deposition in the river. The changes induced in the velocity patterns in the river are also important to assess potential impacts on navigation.

8.3.2 Intake Channel with Diversion Gates, aka, Headworks (HW)

The intake channel and gated diversion structure is proposed on the west MRL bank to laterally divert a portion of the river flow and sediment. A riprapped or concrete river bank cut will lead to a rectangular bay(s) where gates will be situated. The bays will open in to the conveyance channel via a transition channel segment. The existing railroad will cross the rectangular bays.

The key hydraulic processes modeled in the river are the 3D velocity distribution, transport of sediment, potential erosion and deposition, shear stress variation and significance to the navigation. In the intake the important processes are the turbulence losses, sediment suspension, vorticity and any deposition.

The evaluated intake channels were either open cut channels or a concrete U-Frame type structure with inverts ranging from -50 to -20 feet NAVD88 (Note- all intake invert elevations referenced are in NAVD88 datum). A submerged culvert was also investigated. The gated diversion opening is approximately 150 feet wide. The gated structure is located on the protected side of the MRL. The structure is designed to capture as much sediment as possible at the design flow of 75,000 cfs and to obtain as high a SWR as achievable. Numerical models show that during operation, a complex three-dimensional velocity and turbulence field associated with sediment transport is generated at the structure entrance. The depth-averaged longitudinal velocities through the gate were around 15 ft/s. A transition section, most likely trapezoidal in section, is required between the back side of the Gated Structure and the Conveyance Channel which has a bottom width of about 300 feet.

8.3.3 Conveyance Channel

The discharge and sediment from the gated structure enters the Conveyance Channel which transports it into the Barataria Basin. This channel has a trapezoidal cross-section with berms, a bottom width of about 300 feet and side slopes of about 4:1. The length of the channel from the Diversion Gates to the Outfall at the basin-side is approximately 2 miles. The channel invert is EL -25. The maximum design flow capacity is 75,000 cfs. The Hwy 23 Bridge crosses the proposed channel. A gated back structure was evaluated toward the basin-side where the channel cuts through the non-federal NOV Levee System.

The key hydraulic processes being modeled are the transport of sediment, potential deposition of sediment along the channel and through the railroad and highway crossing, transport through the Back Gate Structure, and uphill through the Outfall Transition Feature to the basin-side, which has a prevailing mud bottom grade elevation at about EL -4. The energy losses at the entrance, railroad, highway crossings and at the Back Gate are an important factor in maintaining 75,000 cfs design capacity.

It is anticipated that a base flow or pulsed low flow will be required during river low flow periods (when the diversion is not operating for sediment delivery). This base or pulsed low flow is likely necessary to maintain water quality standards in the Conveyance Channel and the receiving basin. There is a possibility that sediment deposition will occur in the Conveyance Channel during these low flow operations and the potential for and extent of the deposition will need to be evaluated after the BOD Phase.

8.3.4 Back Gate Structure

A gated structure with multiple bays was evaluated along the NOV Levee where the Conveyance Channel cuts through to enter the basin. The key hydraulic processes at this structure are the complex velocity field upstream and downstream of the structure affecting discharge and sediment-carrying capacity of the Conveyance Channel. See **Appendix H.4** for the Back Gate Memo which describes analyses performed on the proposed Back Gate Structure.

The back structure was eliminated from the conveyance system at Workshop No. 2 conducted on 7 June 2018 and will no longer be included in conveyance modeling.

8.3.5 Outfall Transition Feature

The Outfall Transition Feature (or Outfall Area or Outfall Ramp) is a gradually flaring portion of the Conveyance Channel as it transitions from a deeper, regular trapezoidal cross-section to a shallower, wider basin Outfall. The key hydraulic processes in this region are the decelerating velocity field and uphill sediment transport. The purpose of this feature is to eliminate the sudden diversion system invert change from the conveyance channel to the basin so that the design flow can be achieved. The design is primarily useful in the initial years of full operation during which the transition will evolve.

8.3.6 Barataria Basin

The discharge and sediment are released directly into the middle portion of the Barataria Basin. The basin is about 1,600 square miles with depths ranging from 4 to 10 feet. The important hydraulic considerations in the basin are sediment dispersal and, deposition and erosion in the vicinity of the Outfall and the surrounding areas. Water levels near the communities in the basins and velocities and sediment deposition in the navigation waterways are also important considerations.

The Outfall and conveyance flow and sediment conditions shall be determined by the DT and provided to CPRA/TWIG who in turn shall model the changing basin conditions. A potential iterative process is currently being discussed between the DT and CPRA/TWIG to address conveyance aspects with respect to the future basin tailwater conditions. Tailwater conditions in the basin include the revised SLR provided to the DT in June 2018.

8.4 Overall Modeling Approach

As described in the previous section, the nature of the hydraulics varies from the MR to the basin. The three-dimensional nature of the flow is important at the intake side while two-dimensional treatment of flow is sufficient at the basin side. Analyzing this large system entirely with a three-dimensional model would have made meeting the project schedule impossible, would have been cost-prohibitive and was determined to be unnecessary. Instead, each of the system components was modeled separately using appropriate modeling programs, while maintaining consistency in the boundary conditions. In Phase 2, a larger model will be assembled combining the individually finalized diversion components so that the performance of the entire diversion system can be evaluated. The analysis of each of the diversion components is summarized below. The details of the modeling are found in **Appendix H**.

There are several related modeling activities that were not completed in Phase 1, as they do not directly affect the sizing of diversion system. The activities will be completed in in Phase 2. The activities are:

- River deposition and/or erosion
- Support for river navigation analysis
- Analysis of water quality in the Conveyance Channel during non-operation
- Diversion intake induced scour and point bar stability
- Evaluation of basin-side impacts on flooding
- Evaluation of secondary project features such as diversion intake marine protection features

8.5 Diversion Intake Numerical Modeling

The DT evaluated eight Intake Structure configurations in terms of the total energy head loss through the intakes and SWR. The energy loss was estimated using FLOW-3D model while the SWR was calculated using both the FLOW-3D and Delft3D models. All eight structures were simulated under Low, Medium and High Flow conditions in the Mississippi River. The energy loss and the SWR values were used as one of the parameters in the decision matrix that was used to make Intake Structure selection. The summary of model setup, inputs, and results is provided in the following sub-sections. The detailed modeling is described in **Appendix H**.

8.5.1 Intake Structure Configurations

The primary considerations for selection of the Intake Structure were the type of structure, such as an “open” configuration or a “submerged” configuration and an invert elevation. For “open” configurations, the possibilities were an Open Cut channel or a concrete U-Frame with or without interior walls. The “submerged” configuration consisted of a Submerged Culvert type Intake Structure. For intake inverts, a range from of EL -50 to EL -20 was considered. To limit the number of alternatives analyzed, eight representative Intake Structure alternatives were selected from which a final structure configuration and elevation would be selected. The eight alternatives are shown in Figure 8-2. The EL -40 invert was selected as a base case design as it was considered and analyzed in the 2014 Basis of Design Report (HDR, 2014). All four structure types were considered at this invert. The deeper invert, EL -50, was considered for the Open Channel and the Submerged Culvert structure types as these were anticipated to have access to deeper sediment. The shallower invert at EL -20 was considered for the U-Frame and the Open Channel structure types.

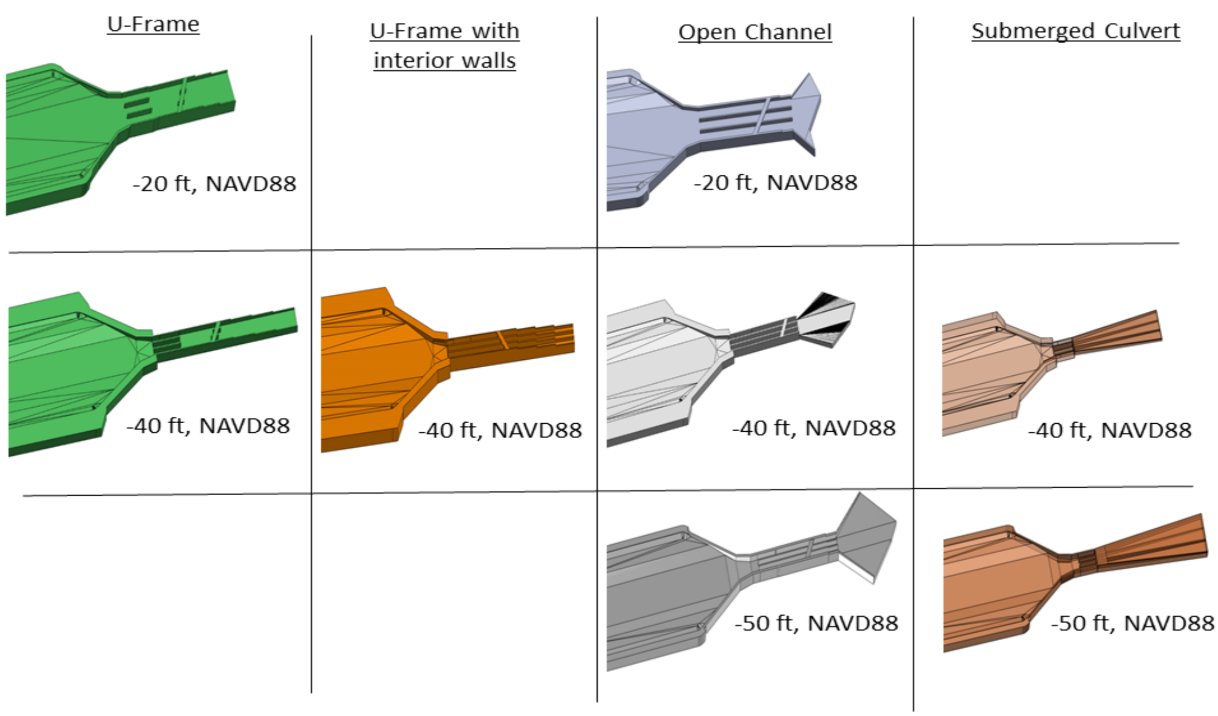


Figure 8-2: Schematic Representation of Eight Intake Structures Evaluated

8.5.2 Modeling Tools

Two modeling software programs were used in the analysis, FLOW-3D and Delft3D, due to their unique capabilities in modeling the relevant hydraulic processes. Being a non-hydrostatic model, the FLOW-3D provides a detailed simulation of three-dimensional velocity in the nearfield region of the structure and is most accurate to calculate energy losses and sediment particle capture efficiency through particle tracking. However, it does not have tested features for natural sediment transport process. FLOW-3D is also computationally intensive and suited to simulate relative smaller study area. On the other hand, Delft3D simulates velocities in the vertical dimension with less accuracy but does offer ability to simulate natural sediment process of suspended and bedload transport. In simulating detailed nearfield flow through Intake Structure, the energy loss for Delft3D was determined by calibrating it with energy loss obtained from a FLOW-3D model. Comparatively, Delft3D is less computationally intensive and therefore allows for simulation of larger study areas.

8.5.3 Model Geometry and Specification of Boundary Inputs

The eight structures were first modeled using FLOW-3D model. An example of FLOW-3D model domain is shown in Figure 8-3. The model focusses on simulating three-dimensional nearfield hydraulics of flow diversion. It extends from RM 58.1 to RM 62.7 on the MR Above Head of Passes (AHP) and includes a portion of the Conveyance Channel approximately 1,600 feet long.

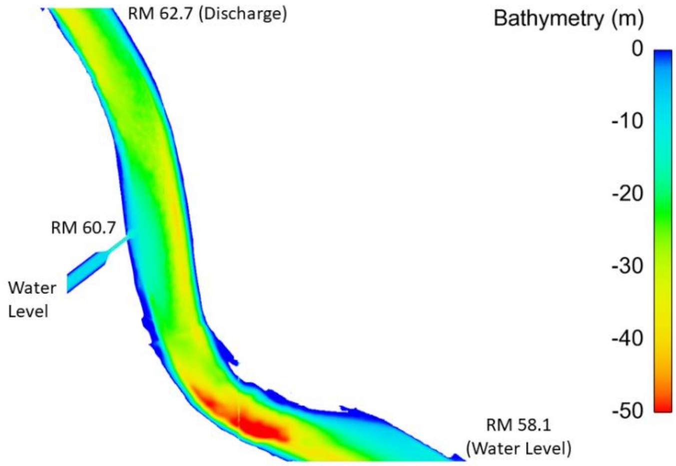


Figure 8-3: FLOW-3D Model Extent, Bathymetry (m, NAVD88) and Boundary Conditions. Horizontal Datum is UTM 15N.

An example of the Delft3D model domain is shown in Figure 8-4. The model is used for simulating sediment transport along the relevant segment of the MR and through the diversion. It extends from RM 56 to RM 66 on the MR and includes the same portion of the Conveyance Channel as the FLOW-3D. The model bathymetry was based on the USACE 2013 multibeam data and the USACE 2017 revetment survey data.

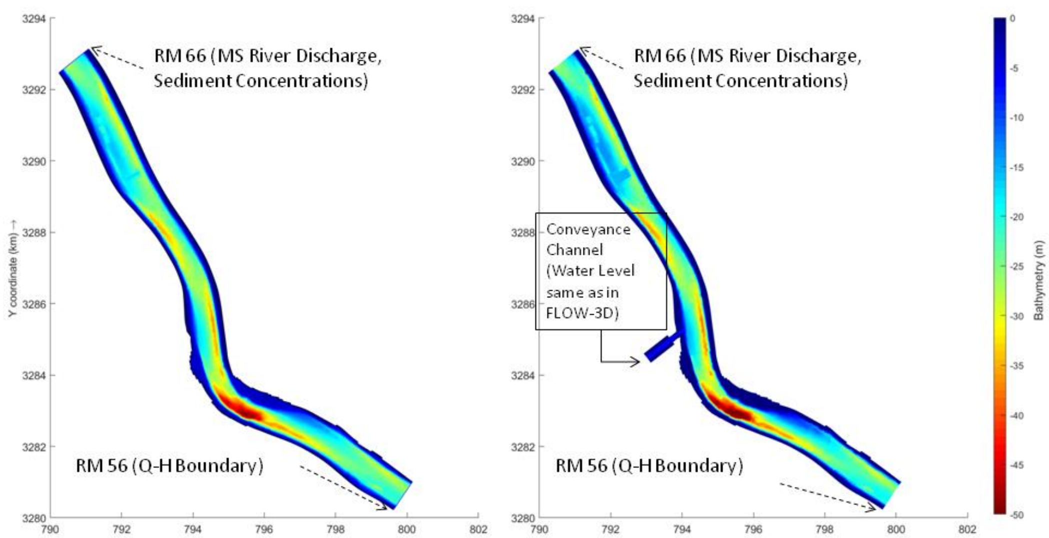


Figure 8-4: Delft3D Model Extent, Bathymetry (m, NAVD88) and Boundary Conditions. Horizontal datum is UTM 15N. Left panel shows the without-diversion case and the right panel shows with-diversion case.

8.5.4 Model Calibration and Validation

The models were calibrated using the discharge, water level and sediment data from April-2009 field collection performed by Allison (Allison, 2011). The MR flow was approximately 740,000 cfs. The models were then validated using March-2011 field data collected by Allison (Allison, 2011). The MR flow was approximately 966,000 cfs.

8.5.5 Discharge, Water Level and Sediment Boundary Conditions for Alternatives Evaluation

To satisfy the design criterion of delivering 75,000 cfs diversion flow at MR flow of 1,000,000 cfs, these conditions were modeled and termed as the High Flow (HF) condition. To account for the variable flows during a typical annual flood, Low Flow (LF) conditions were simulated when the MR was at 600,000 cfs. A Medium Flow (MF) condition was simulated at the midpoint of this range at 800,000 cfs. The flow was specified as an input to the models at the upstream end of the model geometry. The choice of the MR flows is discussed further in **Appendix H.1**.

At the downstream end of the MR and the basin-side of the Intake Structure, water surface elevations were specified. The MR water surface elevation were obtained and specified from a larger, system-wide model, which was previously completed by TWIG. At the basin-side of the Intake Structure, the water surface elevations were set such that the model drew 75,000 cfs through the Intake Structure.

In FLOW-3D, the sediment transport was simulated through particle tracking method. The particles were released upstream of the diversion and were converted to sediment concentrations as explained in **Appendix H.1**.

For sediment modeling, similar to TWIG's basin-wide model (Meselhe et al., 2017), both sand (defined as non-cohesive sediment with median grain size (d_{50}) $\geq$ 63 µ) and fines (defined as cohesive sediment with d_{50} < 63 µ) were modeled. The fines have been divided into silt and clay similar to all the previous modeling efforts by TWIG. The sand sizes are further divided into 83 µ, 125 µ and 250 µ sizes. Both suspended load (sediment moving in from upstream) and the bed material load (sources from the local sand bar) is modeled in Delft3D which helps to identify the distinct capture behavior of sand by various types of intake invert elevation combinations. The sediment concentrations were specified similar to the basin-wide model that is developed in parallel with and applied by TWIG for CPRA for this project.

8.5.6 Model Results of Energy Loss and SWR

To quantify the conveyance performance the total energy head loss was used. The total energy head is defined as:

$$Total\ Energy\ Head \quad = \frac{v^2}{2g} + WSE$$

Where, *v* indicates the depth-averaged velocity along the centerline of the structure, *g* is the gravitational acceleration and *WSE* is the water surface elevation in reference to the NAVD88 datum. The total energy loss from the MR to the outlet of the Conveyance Channel is used to evaluate hydrodynamic friction, expansion and contraction losses caused by the Intake Structures.

The main energy losses occur at two locations. First, where the river flow enters the structure between the intake and the interior U-Frame walls (for the U-Frame alternative) and second, just after the gated structure and through the vertical and horizontal transitions into the Conveyance Channel. The U-Frame structures have larger energy losses due to the presence of helical vortices compared to the Open

Channel. In general, the energy loss decreases as inverts become shallow. This is primarily due to the fact that as the shallower invert configurations have larger width (to maintain the cross-sectional area). The entrance and exit transitions in case of wider configurations are more gradual resulting in reduced contraction/expansion losses. Also, as the invert is deepened, the vertical transition becomes more abrupt causing more losses. Note that the EL -20 invert has no invert change transitioning into the Conveyance Channel. The submerged culvert at EL -50 , has better conveyance than that at EL -40 because the design for the EL -50 submerged culvert was altered to have a larger opening size (25 feet) than that at EL -40 (20 feet). Table 8-1 shows the structures ranked by conveyance (defined as the difference in energy head between the upstream MR and at the end of the downstream Conveyance Channel).

Table 8-1: Total Energy Head Loss for the Intake Structures

Structure Type	Invert (EL)	Total Energy Head Loss (ft)	
		High Flow	Low Flow
Open Channel	-20	1.81	1.22
Open Channel	-40	2.32	1.27
Open Channel	-50	2.38	1.17
U-Frame	-20	2.43	1.27
Submerged Culvert	-50	2.89	1.47
U-Frame	-40	3.71	1.83
U-Frame with Walls	-40	4.02	1.99
Submerged Culvert	-40	4.16	1.82

The total energy loss calculated for the High Flow scenario case was used in the decision matrix to select diversion intake alternative.

The DT had initially proposed to evaluate turbulence generating structures in terms of monopiles, but the concept was not carried forward. This is because the modeling showed that sufficient sediment suspension exists in the system to meet the target SWR close to 1.0 without the need of additional turbulence structures. Also, the presence of such structures, would lead to additional energy loss through the structures, which is a very important quantity that needs to be managed for better diversion capacity.

To quantify the sand capture performance, the sediment to water ratio at steady state was used and it is defined as

$$\text{Steady State Sediment To Water Ratio (SSSWR)} = \frac{\text{SSSL}_d/\text{SSSL}_r}{SSQ_d/SSQ_r} = \frac{\text{ParticleRate}_d/\text{ParticleRate}_r}{SSQ_d/SSQ_r}$$

where, SSSWR denotes the steady state sediment to water ratio, SSSL is the steady state sediment load, SSQ is the steady state discharge and Particle Rate indicates the particle passing rate at any given location. The subscripts *d* and *r* indicate diversion and river, respectively. The information on particle passing rates and flow discharge rates at both the diversion and immediately downstream of the MR was obtained from FLOW-3D results to calculate the final steady state sediment to water ratio.

Table 8-2 shows the ranking of the structures based on the total SWR for sand. The total SWR was used in the decision matrix to select diversion intake alternative.

Table 8-2: SWR for the Intake Structures from FLOW-3D at High Flows (1M cfs MR)

Structure Type	Invert (EL)	SWR: Total Sand	SWR: 250 µ Sand	SWR: 125 µ Sand	SWR: 83 µ Sand
Open Channel	-40	1.22	1.34	1.30	0.97
U-Frame	-20	1.20	1.29	1.31	0.96
U-Frame	-40	1.18	1.30	1.28	0.90
Open Channel	-50	1.17	1.28	1.28	0.92
Open Channel	-20	1.16	1.22	1.27	0.93
Submerged Culvert	-50	1.15	1.36	1.16	0.91
U-Frame with Walls	-40	1.11	1.22	1.19	0.87
Submerged Culvert	-40	1.01	1.31	1.01	0.69

The Open Channel with an invert of EL -40 (herein referred to as “Open Channel -40”) shows the highest SWR followed by the U-Frame with an invert of EL -20, (herein referred to as “U Frame -20”). Note that the SWR for difference size fractions increase with particle size. This is because of the variation in the distribution of these particles across the river. In the west bank region (where the diversion is located), the depths are shallow (10-50 feet) and the source of the suspended sand is primarily the sand bar that will have coarser sand. Towards the middle of the river (the east bank) with depths of 80 to 120 feet, the source of suspended sand is the river load which is coming from upstream with finer sand which is easier to suspend.

Calibrating the model to the physical observations by seeding particles near the surface allows the model to reproduce this cross-sectional variation. This causes the shallower west bank to have coarser particles (250 microns, 125 microns) near the bed which can enter the diversion. The finer particles that are uniformly distributed show a SWR approximately equal to 1.0. It is to be noted that though FLOW-3D was used here because of its superior hydrodynamics, a more robust sediment transport model like Delft3D which integrates bed morphology changes with suspended and bed load transport should also be used to compute values of the SWR. The difference in SWR capture efficiency by the different structures is correlated well to the difference in the zone in the MR from which the diversion draws the water under steeper velocity gradients. The higher SWR is a result of larger withdrawal zones with steeper velocity gradients. This is explained in greater details in **Appendix H.1**.

Table 8-3 shows the sand SWR values obtained from the Delft3D simulations. The SWR for fines was found to be 1.01 for all structures and hence does not impact the relative ranking of the structures. For the LF and MF scenarios, the U-Frame with an invert of EL -20 shows the highest SWR followed by the Open Channel with an invert of EL -20. The HF scenario shows the Open Channel with an invert of EL -40 to be the highest SWR followed by the U-Frame with an invert of EL -20. Note that the relative difference in sediment capture performance decreases at HF and is more prominent at LF and MFs.

In general, SWR for individual sand size fractions increases with particle size except at HF. This is because the smaller the particle size, the greater is the chance of it being in the suspended load and being well distributed across the river; this means a greater amount of it can be bypassed around the diversion when compared to the amount entering the diversion. Thus, the coarser particles are more likely to be locally sourced, hence greater is its relative concentration on the sand bar (near the diversion intake) compared to the Thalweg and the LDB, and hence the greater the SWR of coarser particles. At HF the medium to coarse sand on the sand bar enters into the suspension and the effect of the locally sourced sediment diminishes, yielding an almost uniform SWR for all sand classes.

Table 8-3: SWR for the Intake Structures (Delft3D)

Structure Type	Invert (ft NAVD88)	Sand 250 µ	Sand 125 µ	Sand 83 µ	Silt	Clay	Total Sand	Total Fines
		SWR: High Flow (1,000,000 cfs)						
Open Channel	-40	0.83	0.88	0.88	1.01	1.00	**0.87**	1.01
UFrame	-20	0.83	0.86	0.87	1.01	1.00	**0.86**	1.01
U Frame with Walls	-40	0.80	0.86	0.88	1.01	1.00	**0.86**	1.01
U Frame	-40	0.78	0.85	0.87	1.01	1.00	**0.85**	1.01
Open Channel	-20	0.78	0.84	0.86	1.01	1.00	**0.83**	1.01
Open Channel	-50	0.72	0.83	0.86	1.01	1.00	**0.82**	1.01
		SWR: Medium Flow (800,000 cfs)						
		Sand 250 µ	Sand 125 µ	Sand 83 µ	Silt	Clay	Total Sand	Total Fines
UFrame	-20	1.42	1.20	1.15	1.01	1.00	**1.21**	1.01
Open Channel	-20	1.33	1.17	1.13	1.01	1.00	**1.18**	1.01
Open Channel	-40	1.23	1.14	1.12	1.01	1.00	**1.14**	1.01
U Frame	-40	1.08	1.07	1.08	1.01	1.00	**1.08**	1.01
U Frame with Walls	-40	1.10	1.08	1.08	1.01	1.00	**1.08**	1.01
Open Channel	-50	0.82	0.98	1.04	1.01	1.00	**0.98**	1.01
		SWR: Low Flow (600,000 cfs)						
		Sand 250 µ	Sand 125 µ	Sand 83 µ	Silt	Clay	Total Sand	Total Fines
UFrame	-20	1.63	1.34	1.22	1.01	1.00	**1.33**	1.01
Open Channel	-20	1.54	1.32	1.21	1.01	1.00	**1.30**	1.01
Open Channel	-40	1.18	1.17	1.13	1.01	1.00	**1.15**	1.01
U Frame	-40	1.13	1.15	1.12	1.01	1.00	**1.13**	1.01
U Frame with Walls	-40	1.11	1.14	1.11	1.01	1.00	**1.12**	1.01
Open Channel	-50	0.97	1.10	1.10	1.01	1.00	**1.08**	1.01

It is observed that the SWR for sand decreases for increasing flow. This is because as the flow increases, the sand flux passing the deeper (near the thalweg) part of the river channel increases faster than that passing near the shallower inverts (EL -40 to -50), which causes a slower increase in sand load entering the diversion than the amount of sand bypassing the diversion.

Also, the shallower inverts have a better SWR, particularly at low and medium flows. This was also observed by TWIG in their invert screening modeling (Liang et al., 2017). As the invert becomes shallower the intake width increases, maintaining the same cross-sectional area (approximately 125 feet for EL -40 invert to approximately 240 feet for EL -20 invert). The increase in width entrains more suspended sediment which offsets for the decrease in local concentration at the diversion toe and accordingly increases the total load diverted.

Similar to the FLOW-3D SWR, the Delft3D SWR values were used for the decision matrix used to select diversion intake alternative. The total SWRs for the low, medium and high flows were aggregated to determine weighted averaged SWR using annual exceedance probabilities of the flows as weights. Table 8-4 shows the total weighted SWR values for each structure. These were used in the decision matrix. The MR flow exceedance probability curve is shown in Figure 8-5.

Table 8-4: Weighted Total SWR for the Intake Structures (Delft3D)

Structure Type	Invert (ft)	Total sand SWR			Weighted SWR
		Low Flow 600,000 cfs 73 days	Medium Flow 800,000 cfs 46 days	High Flow 1,000,000 cfs 29 days	
U-Frame	-20	1.33	1.21	0.86	1.20
Open Channel	-20	1.30	1.18	0.83	1.17
Open Channel	-40	1.15	1.14	0.87	1.09
U-Frame with interior walls	-40	1.12	1.08	0.86	1.06
U-Frame	-40	1.13	1.08	0.85	1.06
Open Channel	-50	1.08	0.98	0.82	1.00

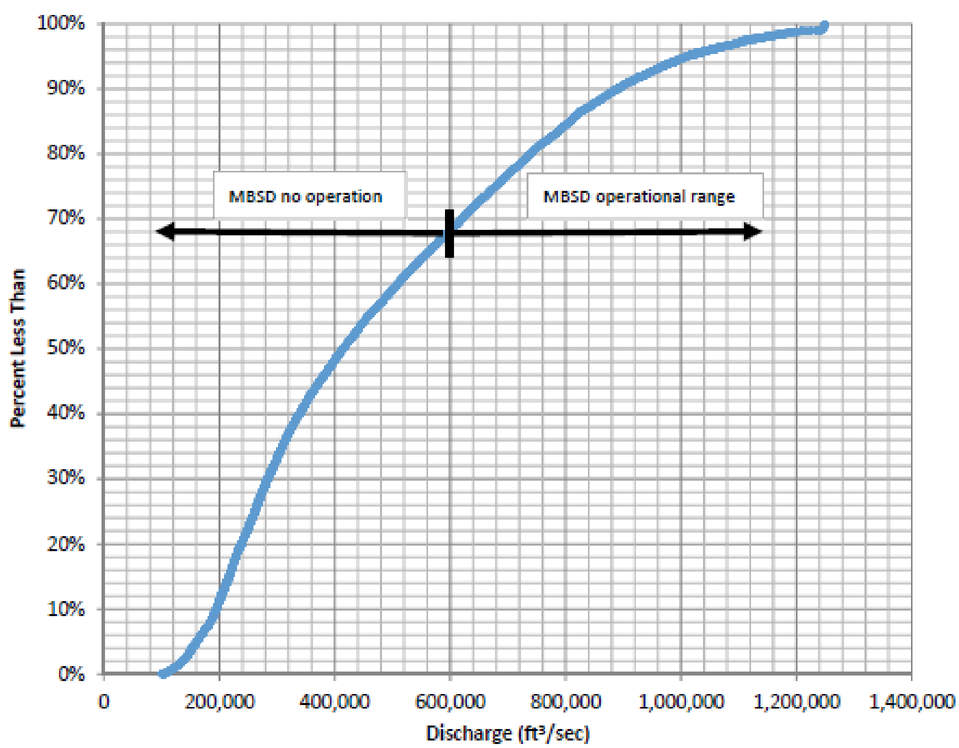


Figure 8-5: Occurrences of Mississippi River at Tarbert Landing Based on Data from 1961 to 2012 (Reproduced from HDR, 2014)

8.5.7 Optimization Testing for Intake Channel

Four modifications to the base geometry were evaluated in this study. The geometries were based on the Open Channel -40 feet alternative from FTN's study (FTN, 2018). The base geometry was modeled in a FLOW-3D model that includes 3.75 miles ft of the Mississippi River and about 1,000 feet of the Conveyance Channel from the narrowest part of the intake to the downstream end of the intake (see **Appendix H.5**). The width of the Open Channel with vertical side walls is about 150 feet with a length of 815 feet. The river bathymetry was the same as that used by FTN (FTN, 2018) The Open Channel is split into three equal widths with two divider walls that extend the full length of the Open Channel (Figure 8-6). The invert elevation of the 150 feet wide channel is -40 feet and the profile is shown in Figure 8-8.

The base geometry and the geometries of the four optimizations are shown in Figure 8-6 and Figure 8-7. Figure 8-8 shows a comparison of the footprint of the base case to Optimization 1 and of Optimization 1 to Optimizations 2 and 3. Figure 8-8 shows the elevation profiles along the centerline of the optimizations. The bottom elevation of Optimizations 1 and 2 is -40 feet from the intake entrance to just past the gate piers, where the bottom elevation slopes upward until it reaches EL -25 in the transition to the conveyance channel. The bottom elevation of Optimization 3 slopes upward from EL -40 starting at the intake entrance and reaches EL -20 at the upstream end of the gate piers. The base condition was not rerun as part of the optimization. Results for the base condition that are shown in Section 3.0 are taken from FTN (FTN, 2018).

Optimization 1 has a wider zone of influence as the training walls were angled further away from the channel center, the training wall top elevations were also lowered to allow more overtopping flow. The open channel in Optimization 1 is the same as in the base condition. All three optimizations extend to Station 22+00 (the same as the base intake geometry). The three optimizations flare out and end at approximately the same horizontal location (X-Y). The ends of the training walls also stop at the same river contours; the upstream wall at the EL -10 contour and the downstream wall at EL -25. The wall top stepped elevations were kept the same for all optimizations and the lengths were changed slightly to agree with the horizontal geometry.

Optimization 1A is the same as Optimization 1 except that the interior walls were removed and the bridge low chord was raised from 4.9 feet to 8.0 feet (1.5 m to 2.4 m).

Optimization 2 is an open channel with a gradually varying width that is widest at the Mississippi River. The opening width at the upstream end of the walls is 605 feet, and the invert EL -40. Optimization 2 has a riprap channel between the gate piers and the riverside end of the intake.

Optimization 3 has a more gradual taper in the vertical walls of the open channel than Optimization 2. The opening width at the upstream end of the vertical walls is 642 feet and the invert EL -40. The bottom profile of Optimization 3 differs from the other models and is shown in Figure 8-8. The cross sectional area of Optimization 3 closely agrees with that of Optimization 2 (this was accomplished by matching cross sectional areas at the gated structure, Station 28+00, and Station 25+00). The width of the Optimization 3 section was increased as needed to equal the area of the deeper Optimization 2 section. Optimization 3 has a riprap open channel between the gate piers and the riverward end of the intake, whereas Optimization 1 and the base case have the open channel at the intake followed by a rectangular concrete section divided into three channels by vertical concrete walls.

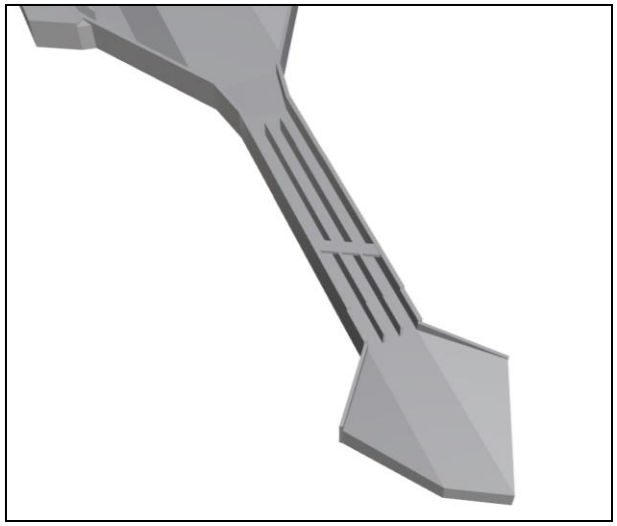


Figure 8-6: Open Channel EL -40 Invert Base Condition

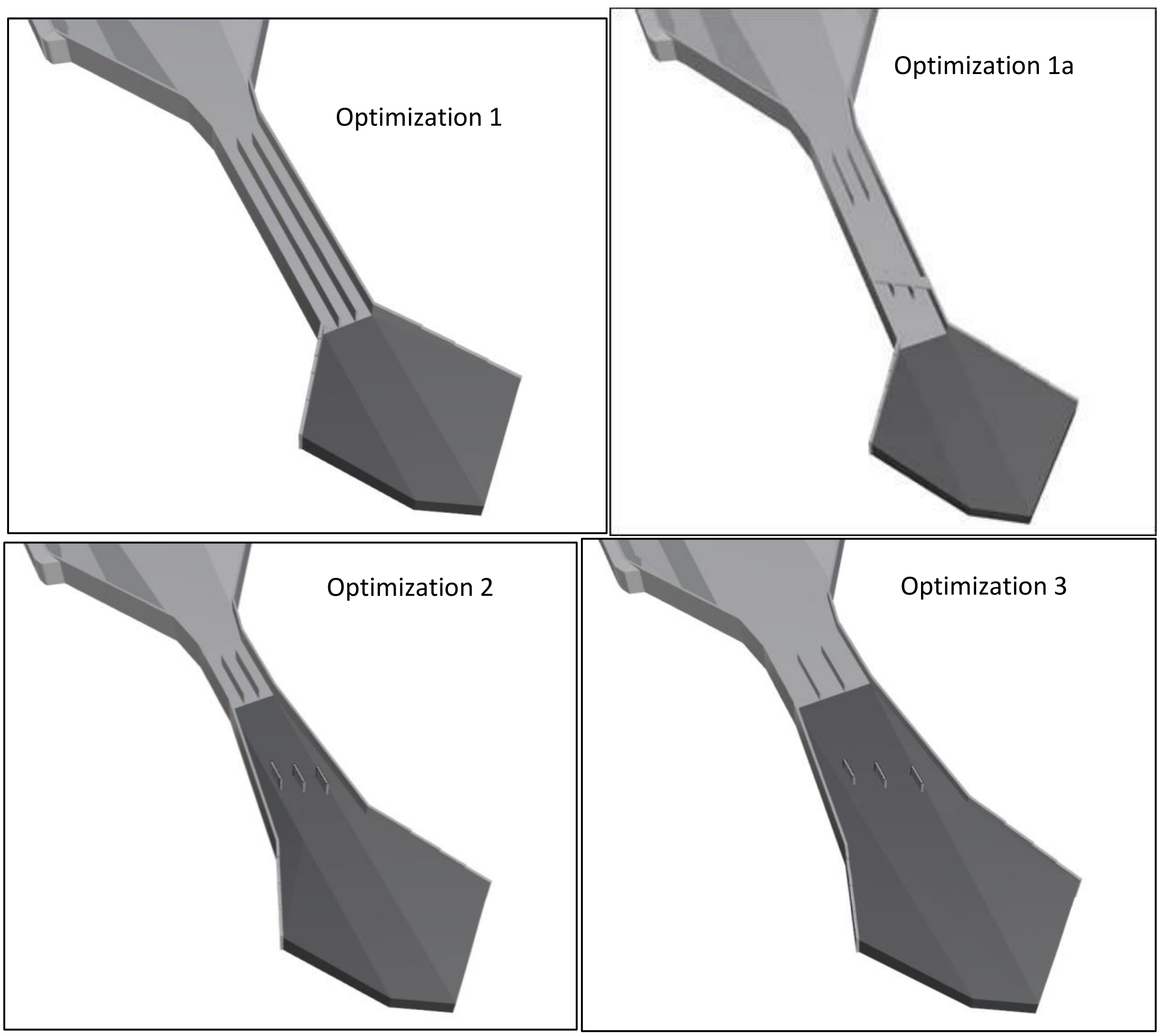


Figure 8-7: Open Channel EL -40 Invert Optimizations

A footprint comparison of the four alternatives is shown in Figure 8-8. The figure shows that each successive optimization provides a more gradual transition entering the diversion.

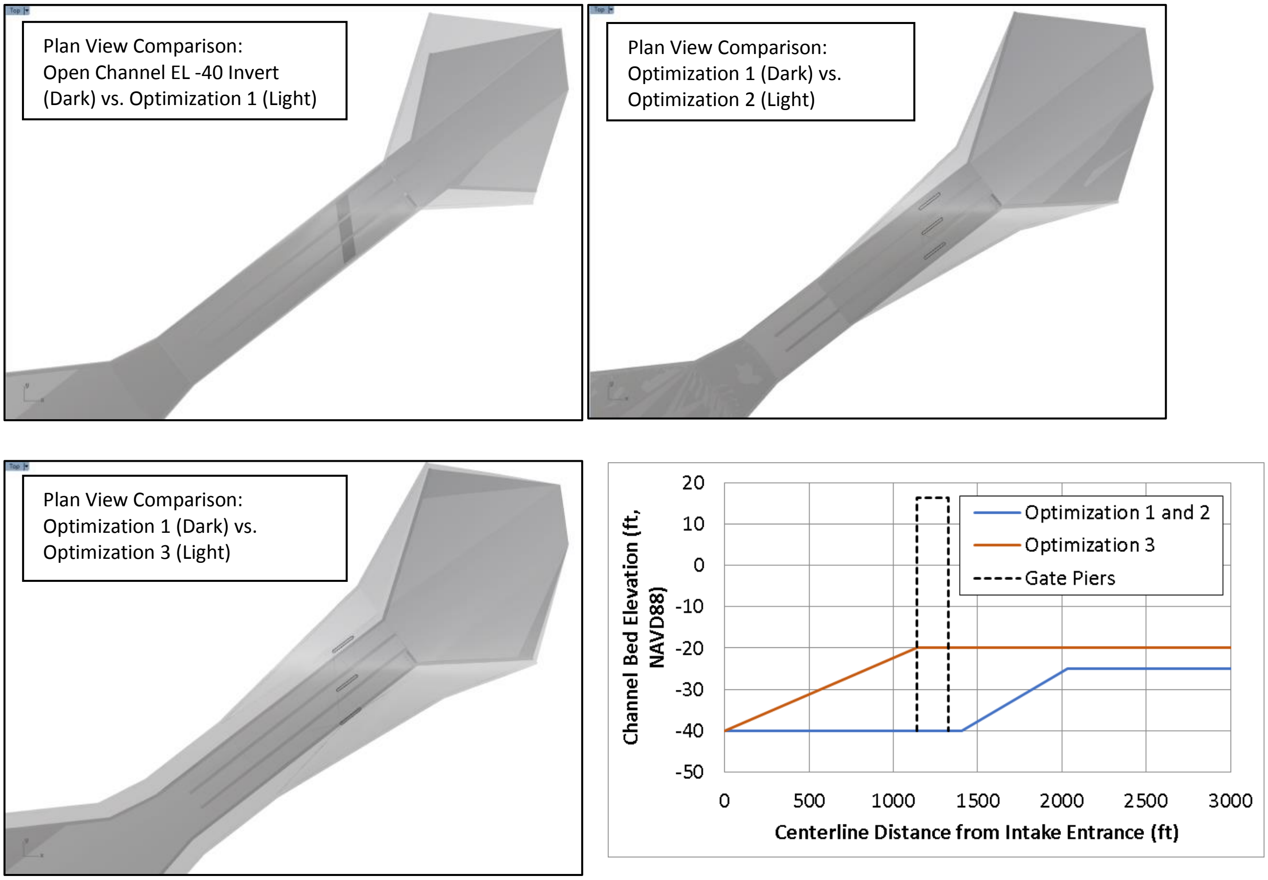


Figure 8-8: Footprint and Profile Comparison of Optimization Alternatives

Simulations were completed for low flow and high flow conditions. Boundary conditions for the model simulations were as shown in Table 8-5. The surface roughness for the model components is shown in Table 8-6.

Table 8-5: Model Boundary Conditions for FLOW-3D Optimization Simulations

Model Run	Upstream Flow Rate (cfs)	Diversion Flow Rate (cfs)	Downstream WSE (ft, NAVD88)
High Flow	1,000,000	75,000	7.81
Low Flow	600,000	48,000	3.48

Table 8-6: Roughness Heights used in FLOW-3D Model Optimization Simulations

Surface	Roughness Height (m)
River bed	0.600
Riprap	0.457
Concrete	0.006

Results
Each model was run until the hydrodynamic solver reach steady state flow. Particles were then added to the flow field and the simulation continued until the sediment water ratio reached steady state conditions. For each simulation, the total energy loss and the sediment water ratio (SWR) was determined. The SWR values are shown in Table 8-7 and the energy loss values are shown in Table 8-8. Water surface profiles are provided in **Appendix H.5**.

Table 8-7: Sediment to Water Ratio for Optimization Testing

Structure	SWR			
	Total Sand	250 µ Sand	125 µ Sand	83 µ Sand
Base Case	1.22	1.34	1.30	0.97
Optimization 1	1.10	1.07	1.23	0.96
Optimization 1a	1.13	1.10	1.25	0.97
Optimization 2	1.00	0.94	1.11	0.90
Optimization 3	0.78	0.66	0.92	0.72

Table 8-8: Total Energy Loss for Optimization Testing

Structure	High Flow Total Energy Head Loss (ft)	Low Flow Total Energy Head Loss (ft)
Base Case	2.32	1.27
Optimization 1	1.94	1.09
Optimization 1a	1.89	1.00
Optimization 2	1.90	0.95
Optimization 3	1.76	0.99

For each simulation the shear stress and depth averaged velocity was computed. Figure 8-9 shows contour plots of bed shear stress and Figure 8-10 shows depth averaged velocities for three of the optimizations. Optimization 1 has higher shear stress and depth averaged velocity extending further into the river than in Optimizations 2 and 3. Abrupt changes in the shear stress are attributable to changes in the surface roughness.

Optimizations 1 and 1A had the highest SWR and highest head loss of the three evaluated alternatives. Optimization 1 and 1A had a lower SWR than the base case. The more gradual contraction of Optimization 1 compared to the base case reduced the head loss, but also decreased the zone of influence of the intake. Optimizations 2 and 3 had even more gradual transitions to the concrete channel than Optimization 1, and had lower SWRs and head losses. The optimization geometries all had lower head losses than the base case because the expansion downstream of the gate piers was longer than in the base geometry and because the flared intake walls were lower in the optimization geometries.

Based on the FLOW-3D modeling, the preferred diversion is Optimization 1A. Optimization 1A has a SWR greater than 1.1 while realizing a significant reduction in head loss from the base condition. This conclusion may change once the Delft3D modeling has been completed, and it may also be influence by the numeric modeling of the upsizing condition. The preferred diversion stated here is based only on the hydraulic and sediment capture performance from the FLOW-3D modeling.

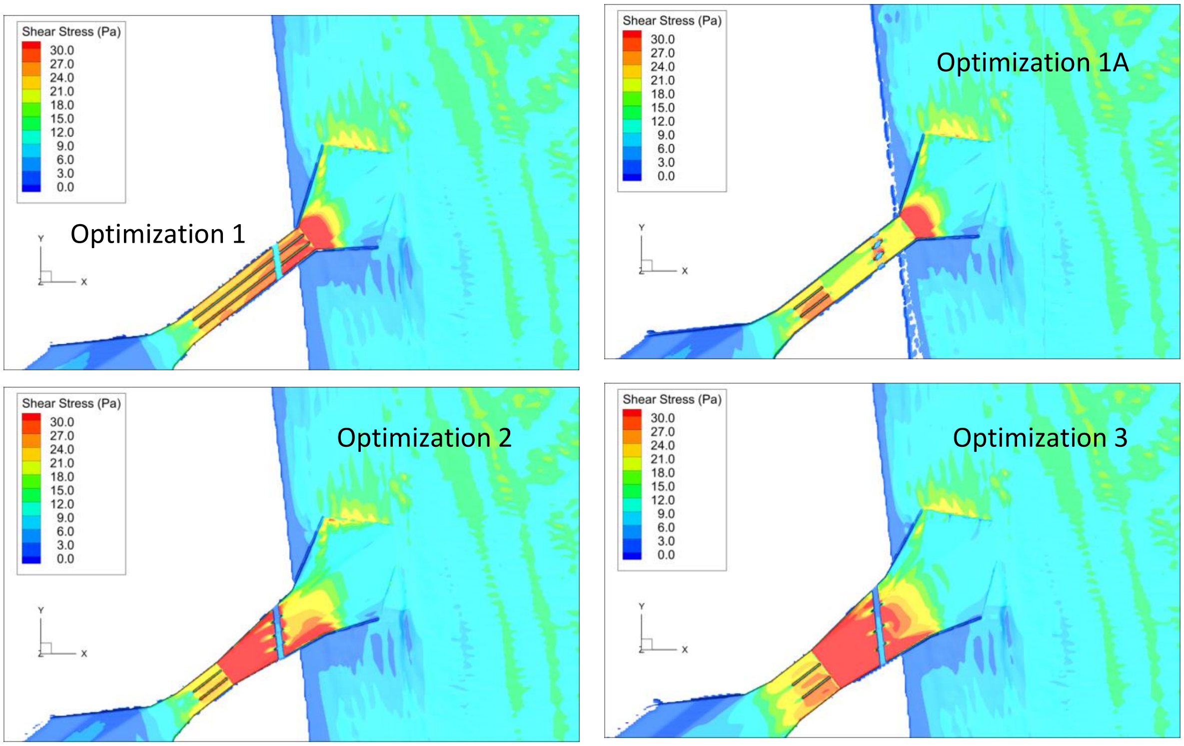


Figure 8-9: Shear Stress

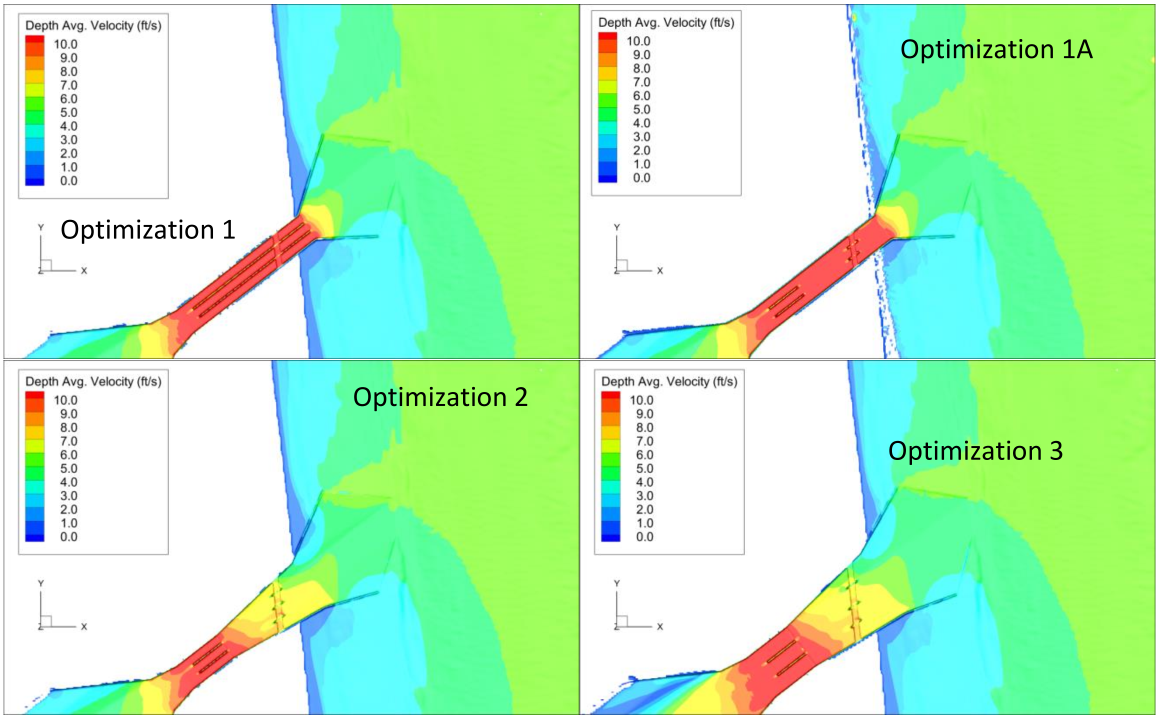


Figure 8-10: Depth Averaged Velocity Contours

8.6 Conveyance Channel Numerical Modeling

The purpose of the Channel is to convey the diverted water from the intake at the Mississippi River (MR) to the NOV Levee and into the Basin. The extension from the Intake Structure at the MR to the NOV Levee, which is approximately 2 miles, is necessary to prevent flooding of the infrastructure between the MR and NOV Levees.
Key design requirements of the channel are:

1) Convey design flow and SWR without any erosion or deposition in the channel.
2) Limit head loss along the channel – this provides the most flexibility for adjusting flows in the future, since the head loss can always be increased by reducing the Diversion Gate openings.
3) Limit armoring costs.
4) Limit degradation of water quality when diversion is not operational.

The first requirement is primarily a function of the flow speed, which is controlled by the channel-cross-section geometry. The flow speed needs to be sufficiently high such that it can support the sediment load coming though the diversion. A baseline design for the Conveyance Channel cross-section was provided in the 2014 Basis of Design Report (HDR, 2014). The cross-section geometry is shown in Figure 8-11 and consists of a 300-foot wide base at EL -25. The side slopes of 1:4 extend laterally until EL 2. At that point a berm extends laterally 97 feet increasing to EL 4. The berms are necessary to provide a stable platform for the channel guide levees. The total width of the Conveyance Channel is 734 feet.

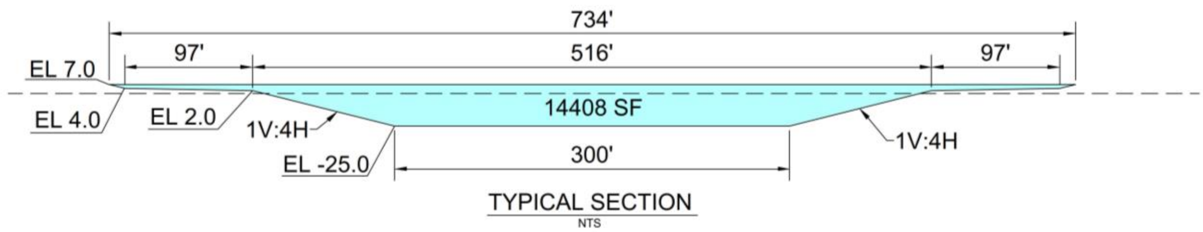


Figure 8-11: Conveyance Channel Cross-Section

A modeling analysis was conducted to determine the flow speed and sediment carrying capacity. A Delft3D model was developed to simulate the diversion flow and loads. The model configuration for the diversion is shown in Figure 8-12. The domain includes the Conveyance Channel starting downstream of the intake expansion ramp, the Outfall Transition Feature and the nearfield portion of the Barataria Basin. The appropriate downstream water elevation boundary conditions and basin bathymetry in the nearfield region were developed using data from TWIG's Basin Wide Model simulations. The details are provided in **Appendix H.2**. The Delft3D structured grid was used with a constant grid cell size of 32.9 by 65.6 feet (10 by 20 meters).

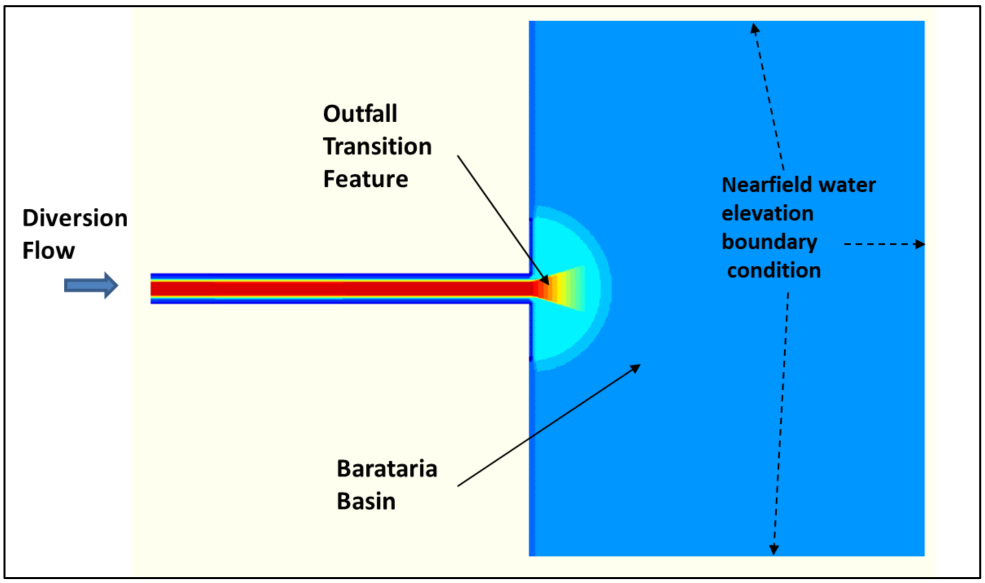


Figure 8-12: Delft3D Model Domain for Conveyance Channel Analysis

The sediment loads used in the modeling analysis that are associated the diversion flows are based on the Belle Chasse Sand Load and Belle Chasse Hysteresis Sediment Rating Curves rating curves developed from measured data in the MR. Details of their development are available in **Appendix H.2.**

For the design flow of 75,000 cfs discharge, the cross-section average flow speeds are on the order of 6 fps and were able to support the sediment load passing from the MR through the Intake Structure. The modeling analysis was also completed for a flow at the lower range of expected diversion flows, 40,000 cfs. The results also indicated that the lower flow could transport the sediment load from the MR to the basin without deposition in the channel.

Since the final relationship between the diversions flows and loads has not been established, these results are considered preliminary. However, it is expected that the current baseline design is close to the final design and no further analysis has been conducted at this time. When the final intake design is completed, and the diversion flow and load conditions are established, the cross-section geometry will be evaluated with the new data. However, it is not expected that the design will vary significantly from its current configuration.

The last requirement, limiting water quality degradation, is considered an operational objective, and does not impose design constraints on the Conveyance Channel geometry. Therefore, it has not been addressed in this alternatives analysis. Operational strategies for maintaining water quality objectives, such as periodic flushing of the channel will be evaluated in a subsequent Phase of the project.

The remaining two design requirements, minimizing head losses and minimizing armoring costs have been directly addressed in an alternatives analysis of the Conveyance Channel design. The channel, in addition to transport of flow and sediment from the MR past the NOV Levee, must accommodate the elevation change from the bottom elevation of the intake to the basin elevation. This analysis of the Conveyance Channel was completed in parallel with the intake analysis, and consequently the final selection of the intake invert was not made until after this analysis was completed. However, at the time of this analysis, two intake bottom elevations had become more plausible and those two are considered in this analysis. The intake bottom elevations for the two more likely designs are EL -40 and -20. Note that the EL -40 intake design currently includes an expansion ramp that both expands the intake cross-section from 148 feet to the channel width of 300 plus feet while simultaneously raising the bottom elevation from EL -40 to -25. This is again based on preliminary designs from the 2014 Basis of Design Report (HDR, 2014), and are retained in this analysis.

In summary, there are two intake configurations that are considered, herein referred to as:

a) EL -40 Intake Configuration
b) EL -20 Intake Configuration

Another feature of the diversion system that will impact the Conveyance Channel design is the Outfall Transition Feature. This feature is essentially a ramp that extends from the end of the Conveyance Channel into the basin with the role of gradually increasing the bottom elevation from the base of the Conveyance Channel to the basin elevation, which is nominally EL -4. The gradual transition is intended to reduce head losses as the flow accelerates across the Outfall Transition Feature. A separate analysis of the Outfall Transition Feature has been conducted (see Section 8.8). For the Conveyance Channel alternatives analysis discussed here, the Outfall Transition Feature was set at 1,500 feet and the slope was dictated by the Conveyance Channel elevation at the Outfall.

The Conveyance Channel alternatives analysis consisted of comparing the head losses and armoring requirements for three alternative channel planforms. The analysis was completed separately for the EL -40 Intake Configuration and the EL -20 Intake Configuration. A schematic of each alternative configuration is shown in **Appendix D**, and they are briefly summarized below.

The three configurations for the EL -40 Intake Configuration consisted of the following alternative planforms:

Alt1: Constant flat 300-foot wide bottom at EL -25.

Alt2: Two sections of continuously sloping bottom, the first covering 75% of the channel, starting at EL -25 and ending at EL -15. The second section covers the remaining 25% and starts at EL -15 and ends at EL -7 at the Outfall.

Alt3: Flat 300-foot wide bottom at EL -25, then changing to a constant slope over the last 25% of the channel, ending with EL -12 at the Outfall.

The three configurations for the EL -20 Intake Configuration consisted of the following alternative planforms:

Alt1: Constant flat 300-foot wide bottom at EL -20.
Alt2: Two sections of continuously sloping bottom, the first covering 75% of the channel, starting at EL -20 and ending at EL -12. The second section covers the remaining 25% of the channel, starting at EL -12 and ending at EL -7 at the Outfall.
Alt3: Flat 300-foot wide bottom at EL -20, then changing to a constant slope at EL -10 feet at the Outfall.

For each alternative Conveyance Channel configuration, the channel width was increased as the bottom elevation increased so that the cross-section area remained constant. This is necessary to assure that a sufficient flow speed is maintained to support the sediment load and prevent deposition. Also, the slope of the Outfall Transition Feature naturally changed as the bottom elevation of the channel at the Outfall changes (i.e., where the Outfall Transition Feature begins).
A model of the Conveyance Channel and nearfield basin was developed with the Coastal Modeling System (CMS) and used to evaluate the hydraulic performance of each alternative Conveyance Channel profile. The model domain is shown in Figure 8-13 and was configured to simulate a designated flow through the channel across the Outfall Transition Feature and into the basin. The flow and boundary conditions shown correspond to a 75,000 cfs diversion flow. The simulated head loss was measured from the upstream end of the Conveyance Channel out into the basin, so that the adjustments to the Outfall Transition Feature associated with each alternative were included in the assessment. Two flow rates of 75,000, and 40,000 cfs were used to span the range of expected diversion flows. Additional details of the model configuration and boundary conditions are available in **Appendix H.2**.

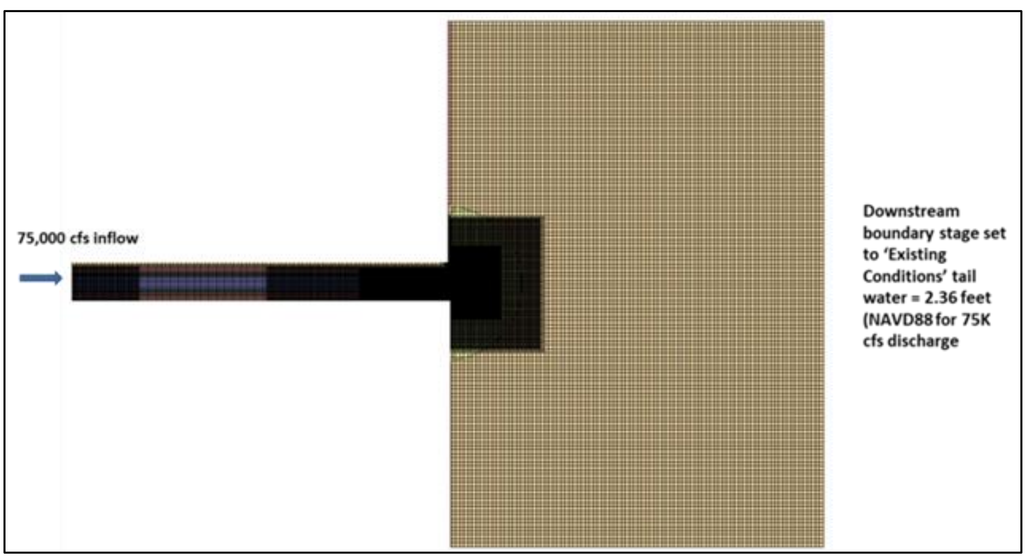


Figure 8-13: CMS Model Configuration For Evaluating Alternative Conveyance Channel Profiles

The results of the hydraulic analysis are shown in Table 8-9.

Table 8-9: Summary of Alternatives Analysis

Configuration	Flow Rate (cfs)	Head Loss (feet)		
		Alt1	Alt2	Alt3
-40 ft Intake	75,000	1.80	2.62	1.97
	40,000	0.92	1.28	1.00
-20 ft Intake	75,000	1.85	2.47	2.18
	40,000	0.96	1.18	1.14

For both intake configurations, Alternative 1 provides the minimal head loss.

8.7 Back Structure Numerical Modeling

The primary and initial motivation for the Back Structure, herein referred to as the "Back Gates", is to provide flood protection for the same flood and wave conditions as the NOV Levee. In concept, the Back Gates would be closed during extreme storm conditions, effectively continuing the NOV Levee protection across the Conveyance Channel outfall.

An alternative means for providing flood protection has been developed, which consists of designing the Conveyance Channel guide levees to the same flood protection standards as the NOV Levee. This approach would eliminate the need for the Back Gates as a flood protection feature. The approach would allow the flood waters and storm waves to enter the Conveyance Channel, and they would be prevented from impacting the area between the MR and NOV Levees by the Conveyance Channel guide levees. The costs of the Back Gates option is considered substantial relative to increasing the Conveyance Channel guide levee design to hurricane flood protection standards, and therefore an alternatives analysis has been conducted to determine the benefits and disadvantages of the two alternatives.

The two alternatives are herein referred to as the "Open Channel" and the "Back Gates". The "Open Channel" option would extend to the NOV Levee without changes to the cross-section. Flood protection would be provided by increasing the Conveyance Channel guide levees to hurricane grade. A representative sketch at the end of the Conveyance Channel is shown in Figure 8-14.

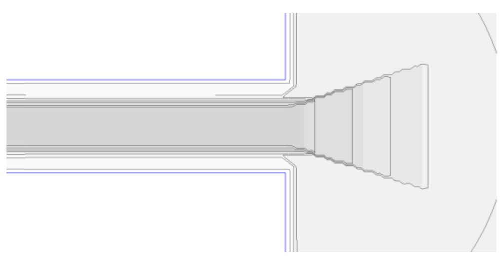


Figure 8-14: Open Channel Concept for Downstream End of Conveyance Channel

The "Back Gates" option includes a transition to a narrower cross-sectional area and then a 7-bay gate structure. A representative sketch at the end of the Conveyance Channel is provided in Figure 8-15. The Back Gates are integral with the existing hurricane protection levees, completing the flood protection system.

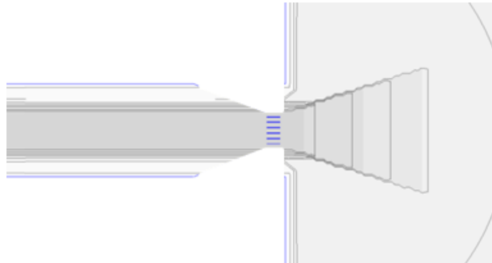


Figure 8-15: Back Gates Concept for Downstream End of Conveyance Channel

The Back Gate complex consists of two primary components. The first is training walls that funnel the flow from the side slopes and berms to the flat bottom section of the channel (approximately 300 feet wide). The Back Gate Structure then extends across the approximate 300 feet width with seven bays.

The DT, in conjunction with CPRA, has developed a set of performance measures for evaluating the two alternatives. They are:

1. Hydraulic head loss.
2. Sediment transport into the basin.
3. Management of siltation accumulating during non-operational periods.
4. Adaptive management.

Construction and maintenance costs are also a consideration but are not addressed here.

The concepts for adaptive management include three potential benefits that may be provided by the Back Gates:

- 4a. Flow jetting: by closing some of the gates (for example 5 of the 7 gates) the flow will be accelerated through the open gates. This "jetting" could be useful to periodically move sediment deposited in the Outfall Area further into the basin, potentially reducing dredging maintenance costs.
- 4b. Diversion flow management during opening and closing gates: During the opening and closing of the gates, the flow speeds in the Conveyance Channel may be slower than required to support the sediment load and deposition may occur. It may be possible to use the Back Gates to reduce the deposition.
- 4c. Radial gate configuration: The Back Gates could be oriented in a radial configuration and used to direct the diversion flow in different directions. This redirection of the flow may enhance the sediment dispersion in the basin.

Each of these seven performance measures (1, 2, 3, 4a, 4b, and 4c) was evaluated for both alternatives.

8.7.1 Head Loss

The head loss for each alternative was evaluated using the Coastal Modeling System (CMS) numerical model. The CMS model configuration for the "Open Channel" option is shown in Figure 8-16 to demonstrate the application of the boundary conditions. The head loss was evaluated for diversion flows of 75,000 cfs, 55,000 cfs and 35,000 cfs. The associated Mississippi River (MR) flows corresponding to these diversion flows are 1,000,000 cfs, 650,000 cfs and 500,000 cfs.

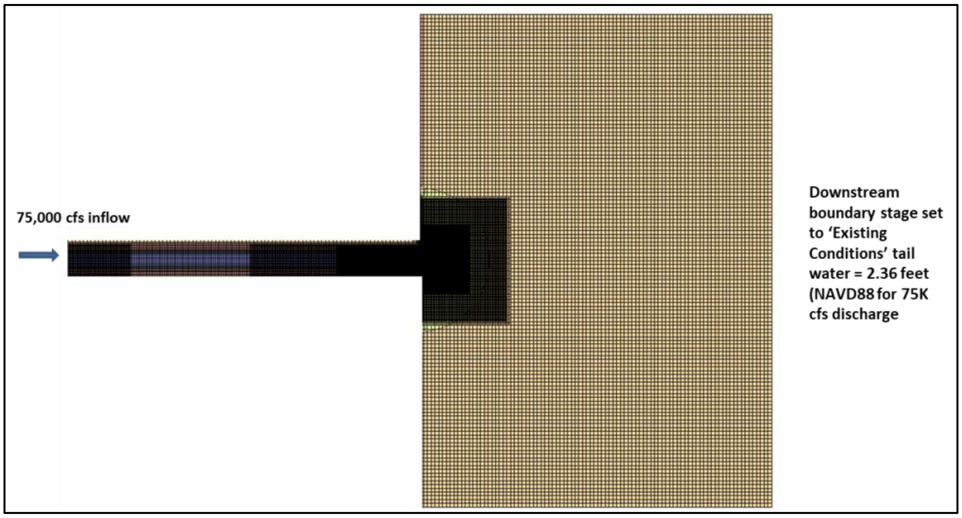


Figure 8-16: Model Grid Domain for Evaluation of Head Losses

The configuration in Figure 8-16 is for a diversions flow of 75,000 cfs. The water level at the downstream boundary is dependent on the diversion flow. Appropriate values were determined from an analysis of the existing conditions water levels from the TWIG's Basin Wide Model PR15. The TWIG Basin Wide Model simulation starts with existing conditions, and the first few years of simulation do not include land building. Therefore their simulated water elevations in the vicinity of the outfall represent the influence of the diversion flows on the water for existing conditions. The tail water elevation for 75,000 feet is 2.36 feet (0.72 meters), for 55,000 cfs diversion flow it is 2.1 feet (0.65 meters) NAVD88 and for the 35,000 cfs diversion flow the downstream water surface elevation is 1.8 feet (0.56 meters) NAVD88. Details of the model boundary conditions and bathymetry are available in **Appendix H.3.**

The hydraulic grade line (HGL) or water surface elevation for the Open Channel and Back Gate alternatives is shown in Figure 8-17 for the 75,000 cfs flow scenario. In the plot, the distance axis (horizontal) value of 4,250 feet corresponds to the end of the Intake Structure ramp/expansion and the beginning of the Conveyance Channel. The Conveyance Channel ends at 14,000 feet.

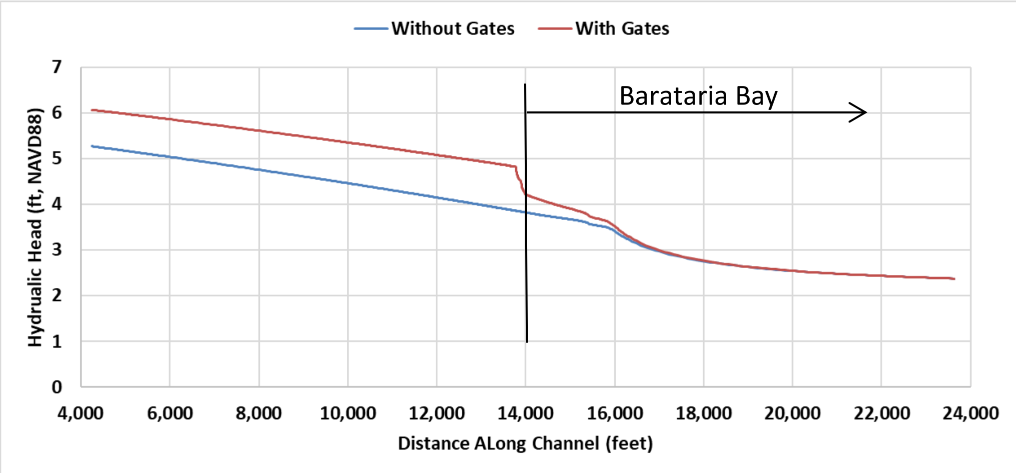


Figure 8-17: Hydraulic Grade Line Along the Channel and into the Basin (75K cfs Diversion Flow)

For all scenarios, the Back Gate alternative required a larger hydraulic head (i.e. upstream stage) due to the energy losses associated with the restricted flow cross-section (i.e., training walls), higher flow speeds, and gate bay walls. The increased hydraulic head required for the Back Gates (relative to the Open Channel alternative) are summarized in Table 8-10.

Table 8-10: Summary of Additional Head Loss for Range of Flow Rates

Flow (cfs)	Additional Head Loss due to Back Gate (ft)
75,000	0.83
55,000	0.49
35,000	0.20

These results indicate that a larger Intake Structure will be required if the Back Gates are included, to meet the design requirements of 75,000 cfs when the MR is flowing at 1,000,000 cfs. The relationship between intake size and head loss has not been established, and therefore these results cannot currently be interpreted in terms of cost associated with the increased intake design.

8.7.2 Sediment Delivery into the Basin

Conceptually, the increased flow speeds generated with the Back Gate alternative will enhance sediment transport into the basin. The enhancement consists primarily of transporting the sediment further into the basin, providing less risk of sediment accumulating in the Outfall Area and subsequently reducing the requirement for maintenance dredging.

A set of numerical model simulations was completed to evaluate the sediment transport and deposition characteristics for the two alternatives. The specific scenarios simulated are summarized in Table 8-11.

Table 8-11: Summary of Sediment Transport Model Simulations

Scenario	Alternative	Diversion Flow (cfs)	Sediment Inputs
1	Open Channel	75,000	MR Loads consistent with 1,000,000 cfs
2	Back Gates	75,000	MR Loads consistent with 1,000,000 cfs
3	Open Channel	48,000	MR Loads consistent with 600,000 cfs
4	Back Gates	48,000	MR Loads consistent with 600,000 cfs

A Delft3D model was configured for the analysis. The basic model domain is shown in Figure 8-18.

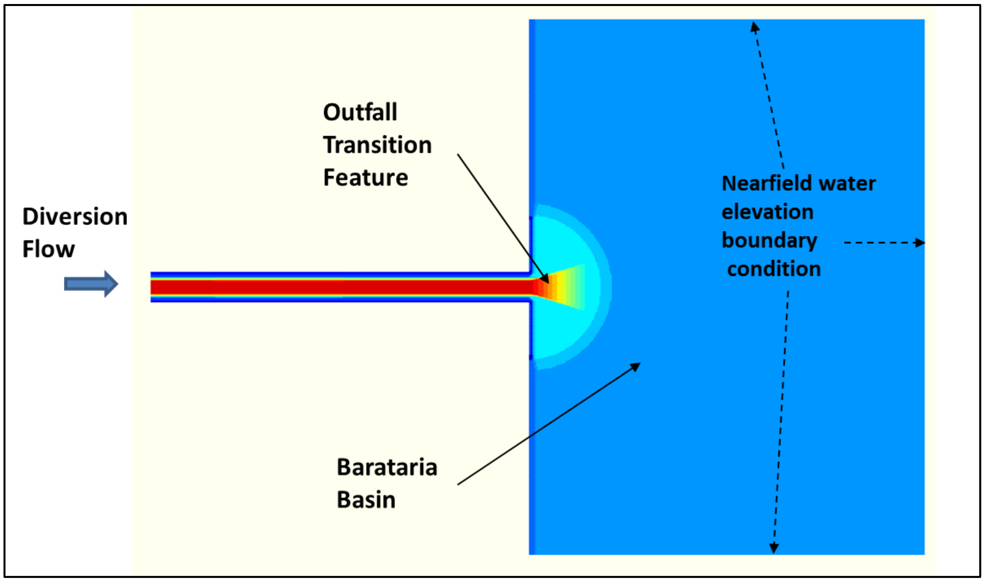


Figure 8-18: Delft3D Model Domain for Sediment Transport Simulations

It is assumed in this analysis that the diversion system will be designed (i.e., "sized") to provide 75,000 cfs for both alternatives when the MR is flowing at 1,000,000 cfs. (Thus it will be slightly larger if back gates were included in the design). The 48,000 cfs diversion flow is expected to occur when the MR flow is at 600,000 cfs. This is based on previous analysis of the diversion but may change during the design process. The suspended sediment concentration entering the Conveyance Channel was determined for 1,000,000 and 600,000 cfs diversion flow from the Belle Chasse Sand Load and Belle Chasse Hysteresis Sediment Rating Curves. Details of these the sediment input conditions is available in **Appendices H.2 and H.3**. The values used are summarized in Table 8-12.

Table 8-12: Summary of Sediment Concentrations Used in the Modeling Analysis

Flow (cfs)	Clay (mg/L)	Silt (mg/L)	0.83 mm Sand (mg/L)	0.125 mm Sand (mg/L)	0.250 mm Sand (mg/L)
48,000	37.5	112.5	7.92	8.88	7.2
75,000	50	150	19.8	22.2	18

The silt and clay erosion and settling properties were adopted for the values used in the TWIG's Basin Wide Model PR15 and are shown in Table 8-13.

Table 8-13: Parameters Characterizing the Fine Sediment Classes

Parameter	Silt	Clay
Settling Speed (mm/s)	0.1	0.001
Critical Shear Stress (Pa)	0.15	0.01
Erosion Rate (kg/m2-s)	0.001	0.001

Each scenario was simulated for 9 hours with a morphologic acceleration of 10, with a 3-hour delay in recording morphology (i.e. a spin-up period), yielding an effective simulation time of 60 hours. The results were analyzed by calculating the final deposit thickness. An example plot for Scenario 1 (open channel alternative) and Scenario 2 (with gate alternative) is shown in Figure 8-19. As the flow entered the basin the flow speeds dropped due to lateral spreading of the flow and sediment began to deposit.

There is some deposition along the berm in the Conveyance Channel, but the primary deposition occurs in the basin area outside of the ramp area. There is also significant deposition on the outer edges of the flow as it exits the channel.

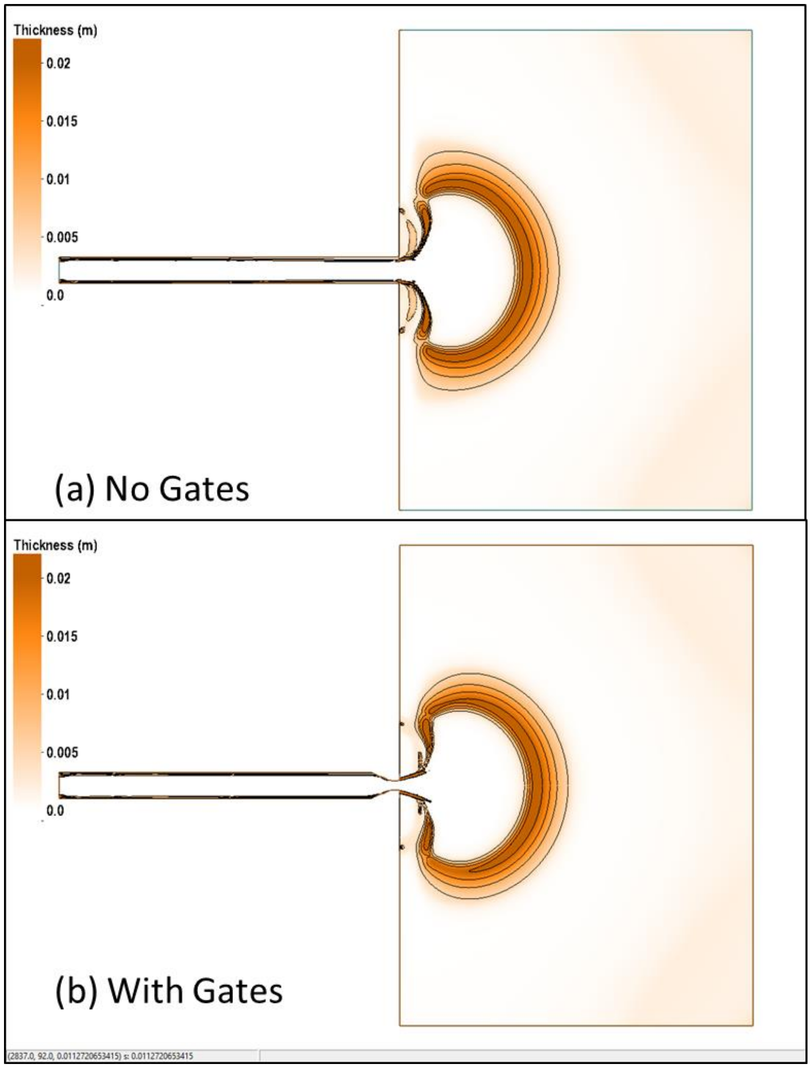


Figure 8-19: Depositional Patterns for Scenario 1 (a) and Scenario 2 (b)

The sediment deposits were recorded and their location for the Outfall determined. An example plot of the deposition along a transect aligned with the channel and extending into the basin is shown in Figure 8-20.

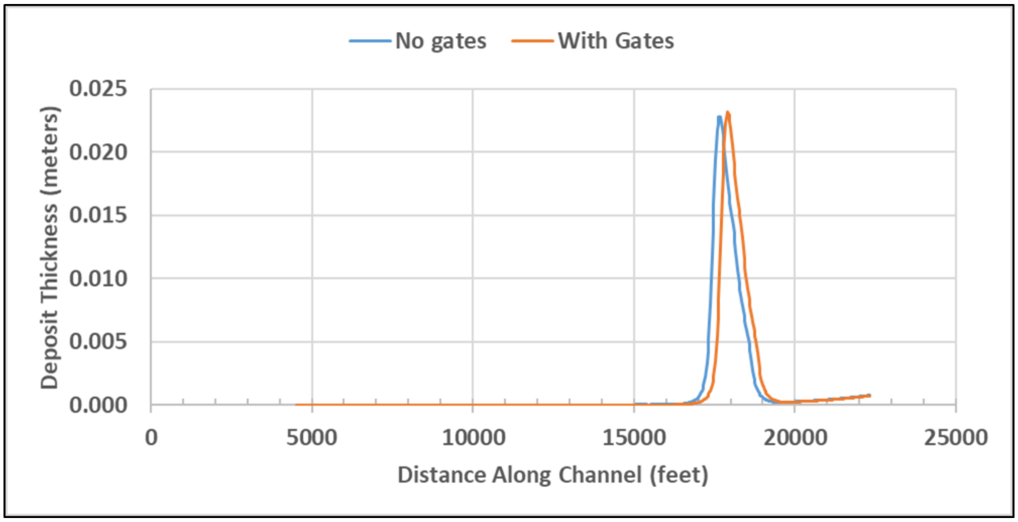


Figure 8-20: Example of Sediment Deposition in Basin for the Two Alternatives (Channel Outfall is at 14,000 Feet)

The distance from the end of the Outfall to the peak of the deposit is 3,636 feet for the "Open Channel" option and is 3,898 feet for the "Back Gates" option. For the 48,000 cfs flow scenario, the depositional peak for the "open channel" alternative is 3,060 feet from the Outfall, and 3,300 for the "Back Gates" alternative.

8.7.3 Management of siltation accumulating during non-operational periods

During non-operational periods, storm events affecting the basin may induce sediment transport, potentially causing sedimentation near the diversion outfall. The siltation analysis consists of determining the ability of the diversion flow to flush sedimentation that occurred during non-operational periods. The "Back Gates" alternative has the benefit preventing sediment accumulation in the Conveyance Channel, though accumulation in Barataria Bay will continue to occur. For the "Open Channel" alternative, sediment accumulation may propagate into the Conveyance Channel.

The analysis is comprised of two parts. The first is an estimate of reasonable siltation patterns that may occur. The second part is a modeling analysis to determine if the assumed siltation can be flushed, and if so, the time periods need to flush the deposits.

8.7.3.1 Estimate of Siltation Volumes

Reliable estimates of siltation have been developed from hydrographic surveys of the Barataria Water Way (BAWW). A set of survey data was identified and acquired for the Barataria Water Way, in response to Hurricane Rita, which provides insight into potential siltation rates related to storm activity in the basin.

Hurricane Rita made landfall on September 24, as a Category 3 hurricane at Johnson's Bayou, Louisiana, between Sabine Pass, Texas and Holly Beach, Louisiana, with winds of 115 mph. The Barataria Water Way is 12 feet deep and 125 wide. An estimate of the siltation depth was developed by comparing the two surveys. The results of the comparison are shown in Figure 8-21. A location map of the channel station is show in Figure 8-22.

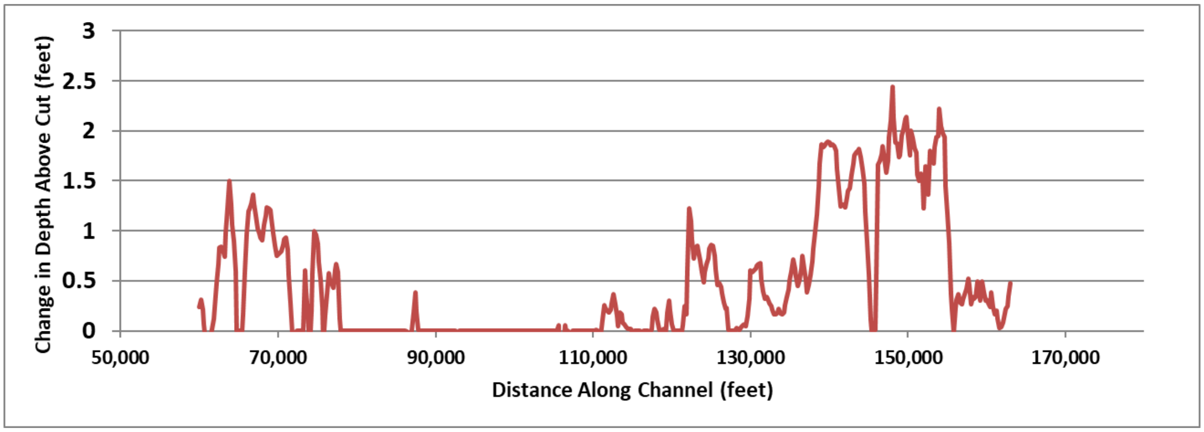


Figure 8-21: Estimated Siltation Depths Along the BAWW

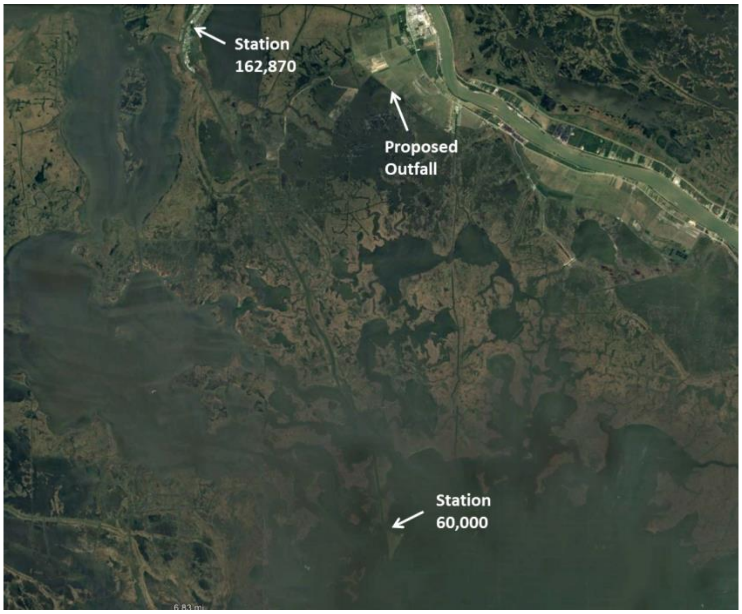


Figure 8-22: Station Location Map for the BAWW

The maximum siltation near the Outfall is approximately 2 feet. This data provides a quantitative basis for expected siltation in the basin due to extreme storm events. However, in addition to using these levels of siltation, other siltation depths and foot prints have been considered, due to the uncertainty in the expected siltation volumes. These additional volumes are considered very conservative and provide a rigorous test for evaluating the alternatives.

The siltation surface and footprint for the "Open Channel" alternative is prescribed as a surface elevation and a distance to which the surface extends into the channel. The volume also includes any portion of the ramp that is below the siltation surface elevation.

For the "Back Gates" alternative, the siltation volume and footprint are specified as a surface elevation extending over the ramp. The initial deposit is the volume above the ramp elevation and below the siltation surface elevation. These configurations are depicted in Figure 8-23 and Figure 8-24.

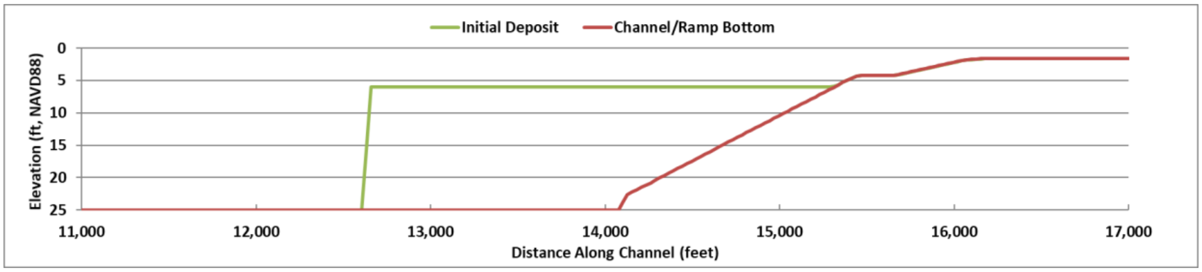


Figure 8-23: Initial Siltation Deposit for the "Open Channel" Alternative for Scenario 2 in Table 8-14

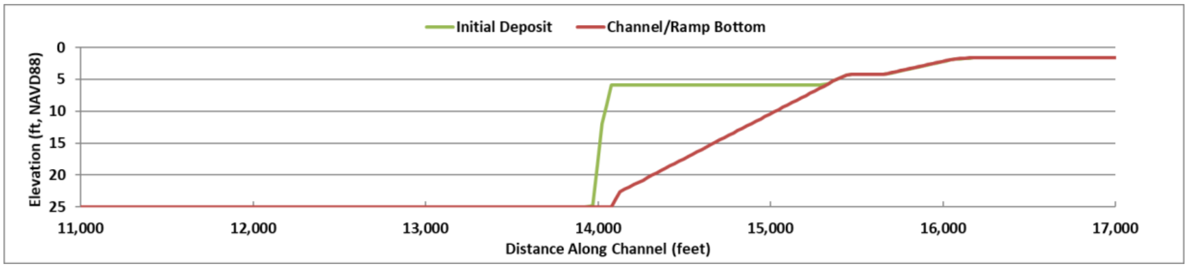


Figure 8-24: Initial Siltation Deposit for the "Back Gates" Alternative for Scenario 2 in Table 8-14

A summary of the modeling scenarios for the "Open Channel" and "Back Gates" alternatives are summarized in Table 8-14.

*Table 8-14: Summary of Modeling Scenarios for "Open Channel" and "*Back Gates*" Alternatives*

Scenario	Deposit Surface Elevation (ft, NAVD88)	Extension into Channel (feet)	No Gate Volume (cy)	Back gates Volume (cy)
1	-23	10,000*	184,789	5,489
2	-6	1,425	624,676	259,775
3	-12	2,100	454,048	88,768
4	-18	3,900	382,180	15,800

*entire length of channel

The initial deposits were assumed to be entirely composed of silt.

8.7.3.2 Model simulations of flushing

A Delft3D model simulation of the channel, ramp and basin sediment transport was completed for each of the 4 scenarios for both the "Open Channel" and "Back Gates" alternatives. The standard grid configuration was used for the analysis, with one modification. The upstream boundary condition was changed to a stage boundary condition. The value of the stage was determined through a series of model simulations of the open channel configuration (with no initial deposit) such that a 28,000 cfs flow was obtained. It was necessary to use a stage boundary condition so that any additional energy loses due to the presence of the deposits (and the Back Gates) would be reflected in the simulation. The flow of 28,000 cfs was selected to represent flow rates expected when the diversion is first operated at the beginning of each season (corresponding to 450,000 cfs in the MR). The actual initial diversion flow rate has not been determined at this time, and therefore 28,000 cfs was adopted. Details of the modeling analysis conducted for setting the stage boundary conditions are described in **Appendix H.3.**

The selected suspended concentrations selected for the 28,000 cfs flow rate were developed using the same approach as described in Section 8.8.2 and are summarized in Table 8-15.

Table 8-15: Upstream Suspended Sediment Concentrations

Flow (cfs)	Clay (mg/L)	Silt (mg/L)	0.83 mm Sand (mg/L)	0.125 mm Sand (mg/L)	0.250 mm Sand (mg/L)
28,000	31.25	93.75	4.95	5.55	4.5

For each simulation the change in the depositional surface and volume within the channel/ramp area was recorded. An example of the output for Scenario 2 for the "Open C" and "Back Gates" alternatives are shown in Figure 8-25 and 8-26. The entire deposit has not been eroded during the simulation for some of the scenarios, but the rates of volume change are established and can be used as a basis of comparison.

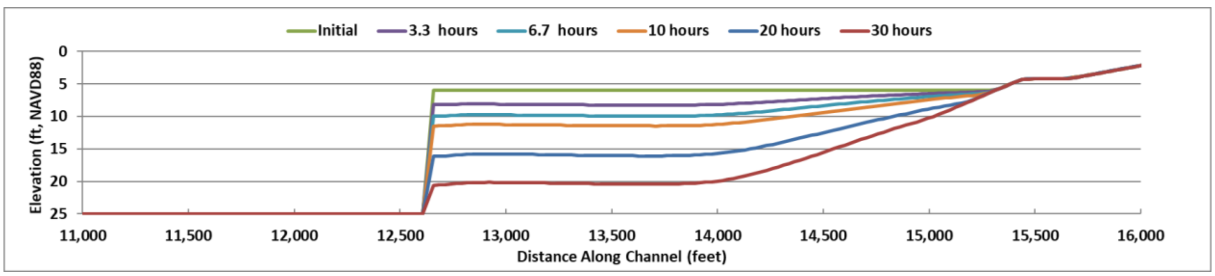


Figure 8-25: Erosion of the Initial Deposit for the "open channel" alternative

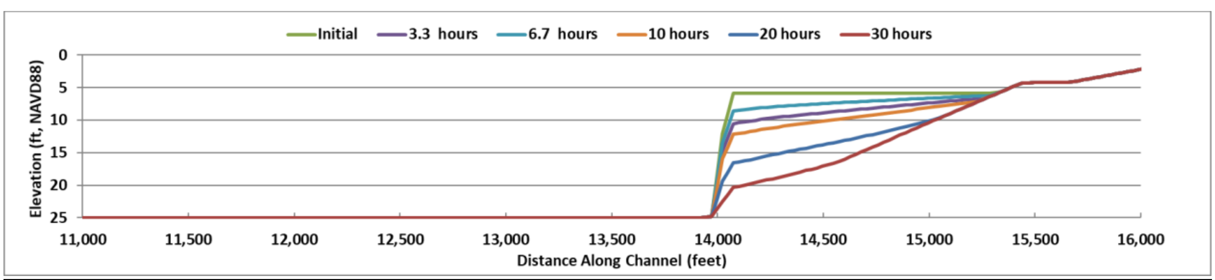


Figure 8-26: Erosion of the Initial Deposit for the "Back Gates" alternative

The deposits generally eroded downward from the upper surface, indicating that the silt deposits were easily eroded into the water column. The results for all of the scenarios listed in Table 8-14 showed similar results. A summary of the time evolution of the deposit volumes is presented in Section 8-16.

Table 8-16: Summary Deposit Volumes

Scenario	Open channel 1	Open channel 2	Open channel 3	Open channel 4	Back Gates 1	Back Gates 2	Back Gates 3	Back Gates 4
Initial Volume (cy)	184,789	624,676	454,048	382,180	5,489	259,775	88,768	19,847
Hours	***Percentage of Deposit Remaining***							
10	15.0	63.5	52.7	9.3	0.0	46.8	32.8	22.5
20	0	31.2	17.1	3.9	0.0	24.9	17.5	9.4
30	0	8.2	0.8	0.7	0.0	5.3	12.2	0.0
40	0	1.4	0.2	0.0	0.0	4.0	7.7	0.0
50	0	0.3	0.0	0.0	0.0	0.5	0.0	0.0

The "Back Gates" alternative has a slightly slower rate of erosion, based on the simulated percent-volume reduction rates. This is due to the reduced flow caused by the deposit blocking a portion of the channel cross-section. The flow for the "Open Channel" option is also reduced, but the combined effect of the deposit and the training walls for the "Back Gates" alternative is more severe, especially for the larger deposit (i.e. Scenarios 2 and 4). However, both alternatives will flush the deposit from the channel and Outfall Area within one to two days.

Additional analysis was conducted using a sand sized sediment for the initial deposit. Deposits consisting of sand will be much less mobile and it is possible the nozzle effect will increase the flushing rate significantly for sand relative to the "Open Channel" alternative, yielding a more favorable result for the "Back Gates" alternative. The simulation was repeated for Scenario 2, and the results indicated that approximately 50% of the initial deposit was removed after 20 days for the open channel alternative and 60% of the deposit was removed for the "Back Gates" alternative. Both results are likely not acceptable, and if a storm induced deposit contains significant amounts of sand sized material, then dredging would be required before the diversion was operated. However, the dredging costs would be lower for the "Back Gate" alternative. The storm deposit would be limited in size by the presence of the back gates, which prevent sediment from depositing in the conveyance channel.

8.7.4 Adaptive Management Opportunities

The three adaptive management opportunities developed with CPRA have been evaluated to determine any potential benefits. The first two potential benefits are solely attributed to the Back Gates alternative as they are not achievable with the open channel alternative.

8.7.4.1 4a: Flow Jetting

The jetting concept consists of closing some of the gate bays, resulting in a higher velocity through the remaining gates. The jet provides increased scouring potential to erode sediment that accumulated during normal operations. For this alternatives analysis, it was assumed that five of the seven bays would be closed.

A Delft3D model was developed and used to evaluate the potential benefits of the jetting. The model used is the same as described in Section 8.7.2. Prior to conducting the sediment transport modeling analysis, a hydrodynamic analysis was conducted to determine the flow reduction due to the gate closing. The closing of five gates will add additional flow resistance and since the diversion flow is gravity driven, the flow through the diversion will be reduced. The analysis indicated that when MR and basin conditions will yield the design flow of 75,000 cfs with all gates open, the flow will be reduced to 32,000 cfs when 5 of the 7 gates were closed. This is an important characteristic of the jetting operations, since the sediment load will be consistent with the 75,000 cfs diversion flow, and likely will not be kept in suspension along the channel when the flow is reduced to 32,000 cfs. Details of the flow reduction analysis are provided in **Appendix H.3**.

Two flow and sediment transport scenarios were used to evaluate the jetting concept and they are summarized in Table 8-17.

Table 8-17: Summary of Transport Modeling Scenarios

Scenario	Gate Configuration	Diversion Flow (cfs)	Sediment Inputs
1	5 Gates closed	32,000	MR sediment concentrations consistent with 1,000,000 cfs
2	5 Gates closed	20,000	MR sediment concentrations consistent with 600,000 cfs

An example plot of the simulated deposition along a transect aligned with the channel and extending into the basin is shown in Figure 8-27.

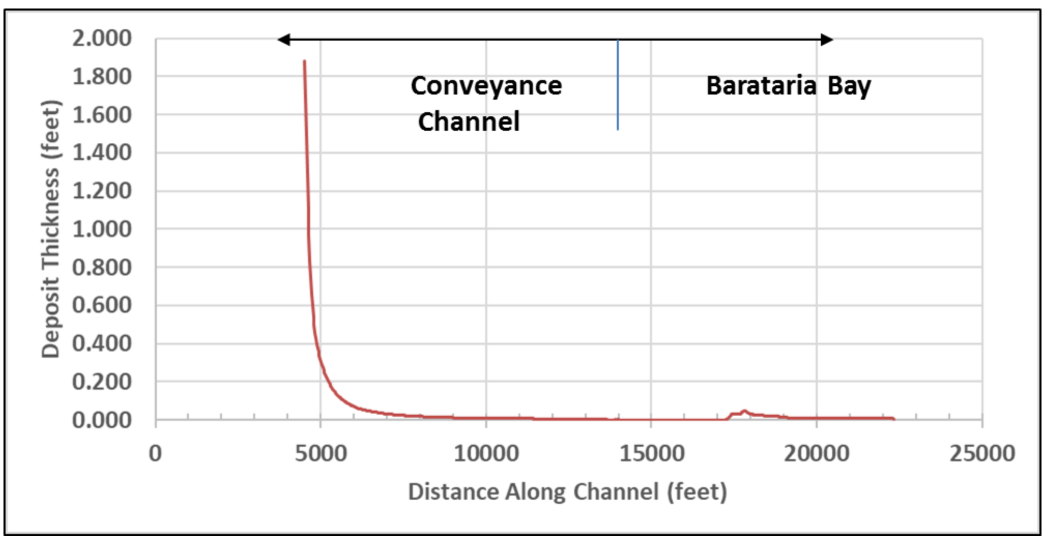


Figure 8-27: Deposits along channel and in the basin for jetting for Scenario 1 (channel Outfall is at 14,000 feet)

The patterns are similar for both scenarios. The most striking result is the large deposition at the upstream end of the Conveyance Channel. This occurs because the partially closed gates restrict the Conveyance Channel flow and velocity. Although the velocity through the gates is accelerated and on the order of 9 fps, it is typically below 2 fps in the Conveyance Channel. The flow entering the diversion through the intake is carrying the same suspended sediment concentration associated with normal operations, consistent with flow speeds on the order of 6 fps in the Conveyance Channel. At the reduced flow and velocity, the sediment transport capacity of the Conveyance Channel is reduced and sediment immediately begins to accumulate in the area of the intake.

At the Outfall the jet is formed yielding higher velocities, and the remaining suspended load is carried into the basin until the flow velocity decreases sufficiently for sediment deposition to occur. Based on the deposit in the basin shown in Figure 8-27, the deposit begins about 4,000 feet into the basin. This is similar to the length into the basin for the case when all gates are open. The accelerated flow due to the jetting is much narrower and despite its higher local velocity, it is spreads out quicker, and subsequently loosing speed, and does not carry sediment further into the basin. The jetting does have more “power” to flush sediment in the region from the Outfall out to about 4,000 feet into the basin. However, based on the analysis in performance Section 8.7.2 (sediment delivery), deposition of sediment in this region is not expected for both the open channel and Back Gate alternatives.

The potential benefits of the jetting can be summarized as providing additional flushing power in the near field region adjacent to the Outfall. However, the results of the sediment delivery analysis (Section 8.7.2) indicate that there will not likely be any deposition in the nearfield region adjacent to the outfall. Thus the potential benefit of extra flushing power is not helpful. Furthermore, it has the potential disadvantage of increasing sedimentation at the beginning of the Conveyance Channel, near the diversion Intake Structure.

8.7.4.2 4b: Diversion flow management during opening and closing gates

The use of the Back Gates to aid in adaptive management has been promoted as a potential benefit of the Back Gate alternative. However, the DT has not been able to develop any clear benefits to adaptive management. It is expected that the flow rates through the diversion can be controlled by the Diversion Gates and there is no additional benefit to using the Back Gates to provide additional control.

There is one potential benefit of the Back Gates while the Diversion Gates are being closed at the end of an operational period. When the MR stage falls below the operational range, the Diversion Gates will be close to prevent flow from the MR into the basin. During the gate closing, which may take up to 10 minutes, the flow speeds in the channel will be reduced (eventually to zero), but the flow will be carrying a sediment load that is consistent with diversion flow speeds. The sediment load during this period will deposit into the channel. A conservative estimate of the depth of the deposit is less than 1mm, (see **Appendix H.3** for the basis of this estimate) and it is expected that this deposition can be flushed by the diversion flow when the diversion is opened during the next operational season.

It is possible that the Back Gates could be used to reduce the volume of water flowing through the channel while the system is being closed. By simultaneously closing the Diversion Gates and the Back Gates, additional flow resistance will be incurred and the total flow going through the conveyance channel will be reduced. Subsequently, the volume of deposited sediment will be reduced. However, since the expected deposit thickness is on the order of 0.1 mm or less, the benefit is not significant.

8.7.4.3 4c: Radial gate configuration

The radial gate concept has been developed to change the general orientation of the diversion. The general premise is that the distribution of sediment into the Barataria Basin can be enhanced if the direction of the diversion flow emanating from the Outfall is periodically changed. For instance, the flow may initially be directed westward, consistent with the current design, but then changed to a southwesterly direction, and eventually a northwesterly direction. This redirection of the flow and sediment may widen the area impacted by the diversion, spreading the land building over a larger area.
A conceptual design of such a system capable of redirecting the flow, as well as maintaining the multiple gate complex for each orientation is shown in Figure 8-28.

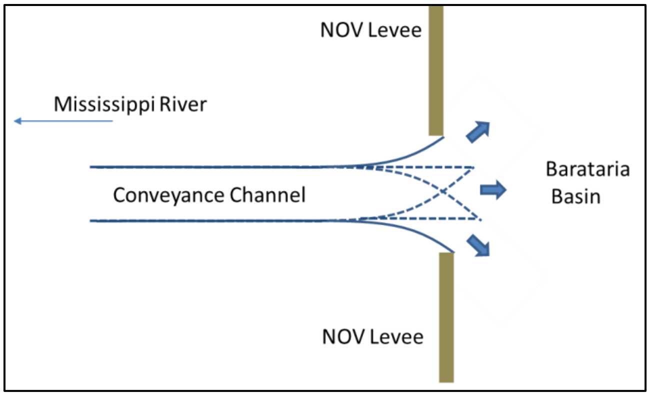


Figure 8-28: Concept Drawing for Radial Gate System

The mechanism needed to guide the flow through one of the three Outfalls shown in Figure 8-28 is not considered here. The design of such a mechanism is not a simple task, as the hydraulic efficiency of an adaptable system must remain high to maintain the design flows. Furthermore the cost of this type of system is expected to be relatively high. The 7-bay gate system that has been used in analysis in this section is expected to cost over $300 million.

Another alternative is to retain the single Outfall design and use channel dredging and possibly temporary walls to redirect the flow after it exits the Outfall. A concept drawing is shown in Figure 8-29 for diverting the flow in one direction.

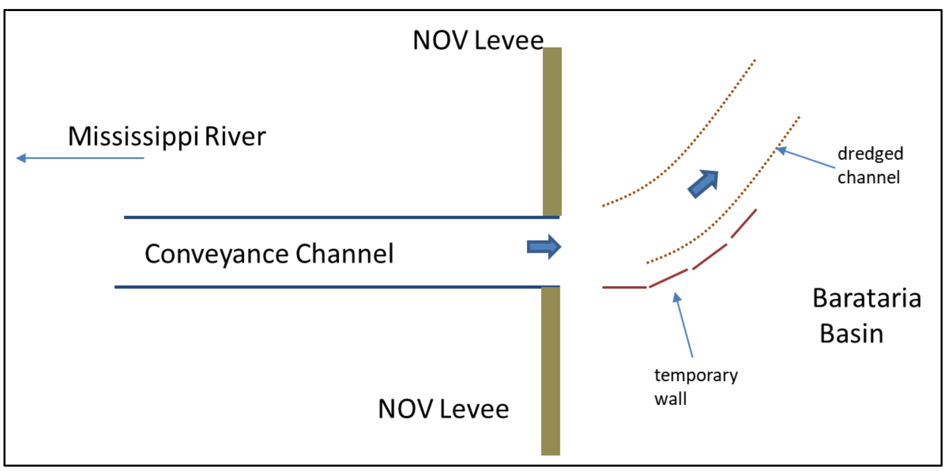


Figure 8-29: Concept Drawing for Flow Diverting Approach

The premise that reorienting the diversion flow to the north or south will improve land building over the Barataria Basin (relative to not changing the orientation) has not yet been demonstrated. The diversion flow analysis conducted for this and other alternatives analysis indicate that most of the momentum associated with the diversion flow decays within approximately a mile of the Outfall, at which point the diversion water moves with the ambient wind and tide driven flow. As the Barataria Basin is much larger, extending up to 20 miles from the Outfall, it is not clear if the flow reorienting impacts confined to one mile from the Outfall will have impacts over the entire basin.

Therefore, no additional analysis has been applied to the radial gate alternative as an adaptive management benefit. The concept does have merit, but the potential beneficial impacts on improved sediment dispersion and increased land building should be demonstrated before further consideration is given to the concept. The land building analysis is beyond the existing scope but it is recommended that it be pursued during subsequent design work.

8.8 Outfall Transition Feature Numerical Modeling

An alternatives analysis of the Outfall Transition Feature has been conducted to guide the selection of the final transition design. The primary function of the Outfall Transition Feature is to provide a gradual transition from the Conveyance Channel to the basin. The invert of the Conveyance Channel is on the order of EL -25 and the basin elevation near the Outfall is on the order of EL -4. The Outfall Transition Feature is intended to be a temporary component of the design. The results of the TWIG's Basin Wide Model and Outfall Management Models indicate that a channel will be eroded through the area of the Outfall Transition Feature and further into the basin. Thus, the role of the Outfall ramp is to provide an initial transition during the first few years of operation, until a channel is eroded.

The basic configuration of the Outfall Transitions Feature is shown in Figures 8-30 and 8-31. The Outfall Transition Feature begins at the end of the Outfall where the channel bottom width is approximately 300 feet wide and at EL -25. The feature will slope upwards as it extends into the basin, until it reaches the nominal basin elevation of EL -4. The ramp will expand laterally (defined by the half-flare angle) and at the lateral edges, it will also slope upwards to the basin elevation of EL -4.

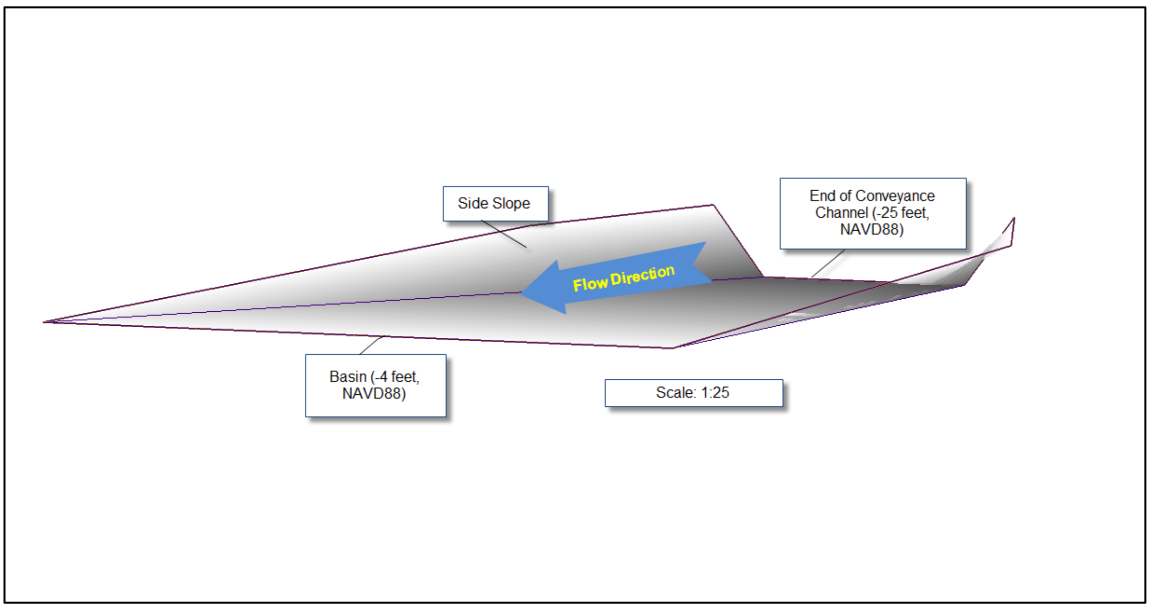


Figure 8-30: Three-dimensional view of the Outfall Transition Feature

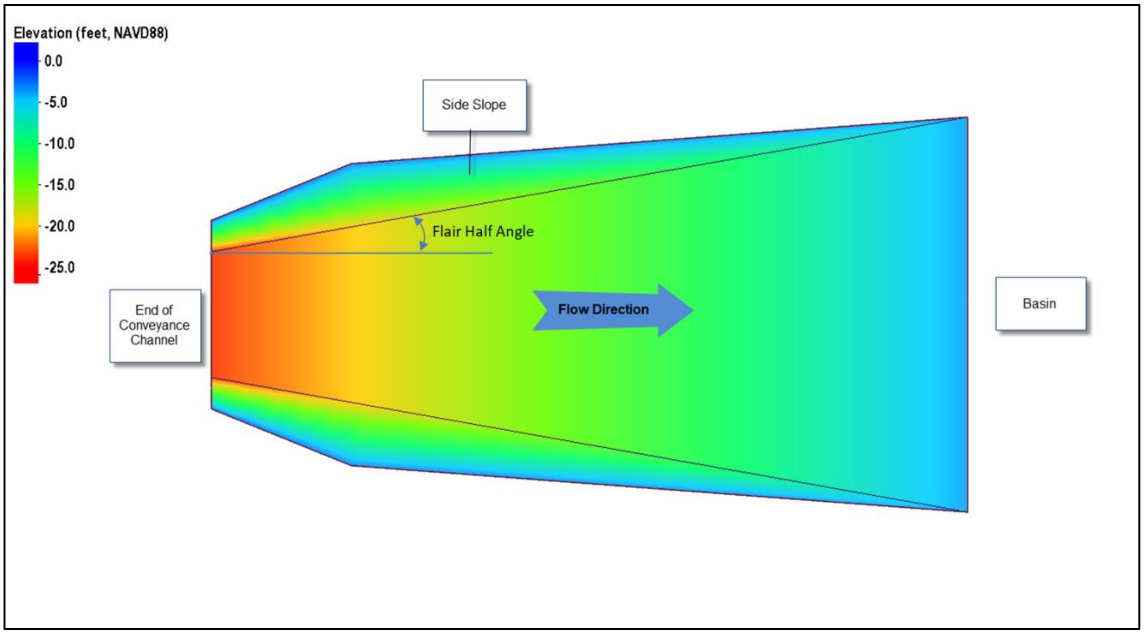


Figure 8-31: Map view of the Outfall Transition Feature Configuration

A Delft3D model was configured to evaluate the alternatives. The portion of the model domain encompassing the Conveyance Channel, the Outfall Transition Feature and the near field part of the Barataria Basin is shown in Figure 8-32.

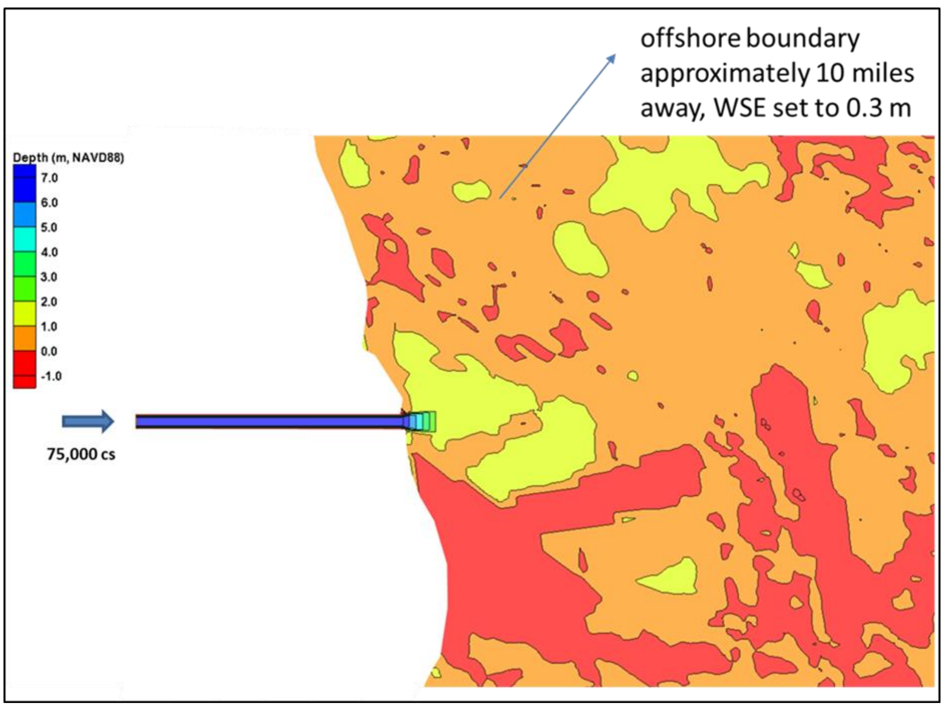


Figure 8-32: Delft3D Model Domain and Bathymetry for Outfall Transition Feature Analysis

The primary metrics in the evaluation of the alternatives are:

a) the hydraulic head loss, and
b) the total volume of material that will need to be dredged to form the feature.

The alternatives analysis was conducted in two phases. In the first phase, four ramp lengths (1,000, 2,000, 3,000, and 4,000 feet) and three flare half angles (10, 15, and 20 degrees) were considered.

The water elevation along the centerline of the Conveyance Channel and ramp was extracted for each alternative ramp configuration. A plot of the results for the 4 lengths using a flare half angle of 10 degrees is shown in Figure 8-33.

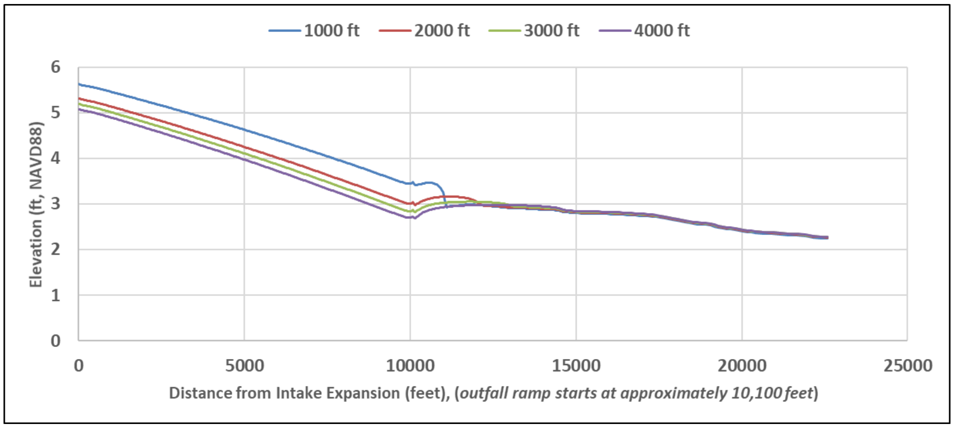


Figure 8-33: Water Elevation Profiles for Ramp Alternatives (10 degree half angle)

The results for all the alternatives are summarized in Table 8-18, which show the upstream stage elevations for each configuration. The results show very little sensitivity to the flare half-angle with the differences in stage on the order of 0.09 feet or less. The upstream stage decreases as the ramp length increases for all flare angles, with diminishing impacts as the ramp is lengthened.

Table 8-18: Summary of Ramp Upstream Stages

Angle/ Distance	10 (deg)	15 (deg)	20 (deg)
1000 (ft)	5.63	5.58	5.54
2000 (ft)	5.31	5.27	5.23
3000 (ft)	5.19	5.14	5.11
4000 (ft)	5.08	5.05	5.05

Subsequently, additional evaluation of a 500, 1500, and 5,000-foot Outfall Transition Feature was completed using the 10-degree flare half-angle to provide more resolution on the variation of the head loss with the transition feature length.

The results of these additional analysis and the original analysis (with a 10 degree flare half angle) are summarized in Table 8-19. A tailwater stage was selected at about 14,500 feet along the transect, which represents a point where all the stage profiles have the same value (within 2%). The tailwater EL there is 2.84 and was used to quantify the stage differences (i.e. head losses) for the different ramp configurations.

Table 8-19: Summary of Stage Impacts

Ramp Length (feet)	Upstream Stage (ft, NAVD88)	Tailwater Stage (ft, NAVD88)	Head Loss* (ft, NAVD88)	Relative Difference** (feet)
500 ft	6.13	2.84	3.30	1.06
1000 ft	5.63	2.84	2.79	0.55
1500 ft	5.42	2.84	2.58	0.34
2000 ft	5.31	2.84	2.48	0.23
3000 ft	5.19	2.84	2.36	0.11
4000 ft	5.08	2.84	2.24	0.00
5000 ft	5.08	2.84	2.24	0.00

*Head Loss does not include velocity (difference in stage only)
**Compared to Head Loss for the 5000-foot ramp length

A graphical representation of the relative differences is shown in Figure 8-34.

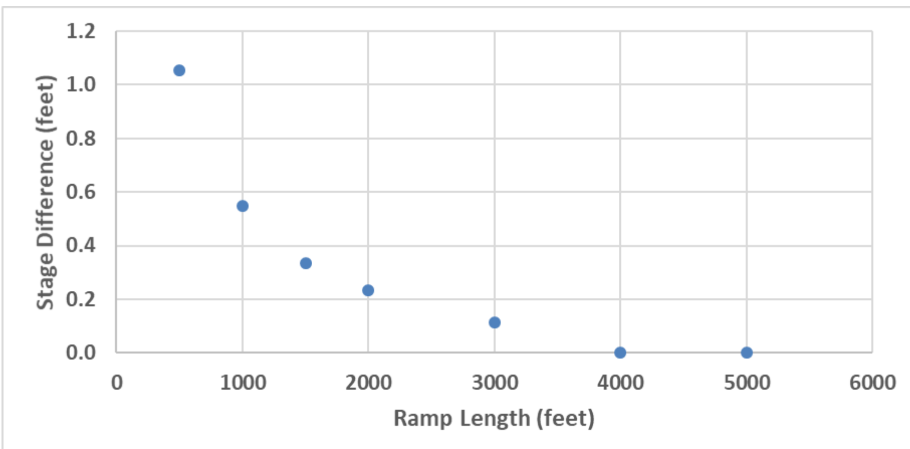


Figure 8-34: Difference in Head Loss (compared to 5000-foot ramp length)

The footprint of each ramp alternative and the dredge volume required to construct each ramp configuration are provided in Table 8-20.

Table 8-20: Summary of Head Loss and Dredging Requirements

Length (ft)	Flare Half-Angle (deg)	Relative Difference (feet)	Footprint Area (ft^2)	Dredge Volume (cy)
500	10	1.06	321,000	89,900
1000	10	0.55	679,000	195,300
1500	10	0.34	1,163,000	335,100
2000	10	0.23	1,693,000	483,300
3000	10	0.11	3,096,000	866,900
4000	10	0.00	4,826,000	1,329,900
5000	10	0.00	6,891,000	1,874,700

The DT recommends that the 1,500-foot-long Outfall Transition Feature be selected as the preferred alternative. Numerical modeling results indicate that the 1,500-foot-long ramp will produce an energy loss of four inches. Reducing the energy loss to where it approaches zero requires extending the ramp 2,500 feet, which requires dredging an additional 994,800 cubic yards of in-situ soils. The DT estimates the unit cost to be $15/cubic yard for Outfall dredging (see **Appendix O**), inclusive of piping it to the designated fill area near Bayou Dupont. This equates to $14,992,000 of additional construction cost. The four-inch energy loss is a consideration for the initial period of the diversion's operational life because that is when the Outfall Ramp's constructed geometry affects the distribution of the sediment-laden discharge flows into the Basin. During the initial operational period, a four-inch energy loss will not impede distribution. The ramp's geometry will evolve as the discharge flows erode in-situ material and deposit conveyed sediments, and it is this evolved geometry that will affect sediment distribution into the Basin during the remainder of the diversion's operational period. Numerical modeling to be performed during the 30% Phase will model the evolution of the Outfall Ramp's geometry, and the effectiveness of the 1,500-foot-long ramp design will be evaluated as part of that effort. This will be documented in the BODR Update. In any case, with monitoring and adaptive management, the ramp area can be dredged later to promote conveyance and distribution, if monitoring determines this necessary. For all these reasons, the DT recommends the 1,500-foot-long Outfall Transition Feature Alternative as the basis for the Outfall Transition Feature's detailed design.

8.9 Performance of the Current Conditions Diversion System under Future Conditions

The basin-side water surface elevation is expected to rise in the future due to a combined effect of the Relative Sea Level Rise (RSLR) (TWIG-SLR-Memo, 2018) and land building as a direct result of sediment delivery to the basin during the diversion life-cycle. TWIG's Basin Wide and the OMBA land-building models show that a typical deltaic system with well-defined channels develops in the vicinity of the Outfall. This results in a significant impact on the tailwater and reduces the diversion capacity. Further, TWIG's PR15 basin-wide model (Meselhe et al., 2015) used an internal boundary connection between the river and the diversion intake (defined as a fixed mathematical relation that prescribes the diversion discharge as a proportion of the river discharge), which disregarded the actual head difference available in order to draw the prescribed diversion flow. Therefore, the DT developed a Delft3D model (FTNOMBA) consisting of the intake, the Conveyance Channel, the Outfall region and the Barataria Basin up to the Gulf of Mexico. The model bathymetry was developed using land-building predicted at year 49 by the TWIG's PR15m 1.5m SLR Basin Wide Model.

To simulate the one-year hydrograph run, the 49th year MR hydrograph would have been required. However, the 49th year MR hydrograph does not reach the required design condition in the MR of 1,000,000 cfs. Therefore, the 44th year MR hydrograph (Figure 8-35) was used for this one-year simulation. The peak discharge is seen to reach over 1,200,000 cfs. The southern Gulf of Mexico boundary was kept at a constant water surface elevation (WL) of approximately 1 foot corresponding to Mean Tidal WL data from TWIG's Basin Wide Model at Port Fourchon. Figure 8-35 (in red) also shows the diverted discharge hydrograph. As seen from the figure the diverted discharge does not reach 75,000 cfs at 1,000,000 cfs in the MR under future conditions if the current conditions diversion system design is used. Figure 8-36 shows the discharge rating curve between the MR and the Outfall discharge and indicates that the currently designed system can convey only approximately 55,000 cfs under future conditions. A redesign of the sizing of the intake and/or Conveyance Channel is necessary to meet the

75,000 cfs target flow. Figure 8-37 shows the basin-wide water surface elevations at time when MR reaches 1,000,000 cfs during the one-year simulation.

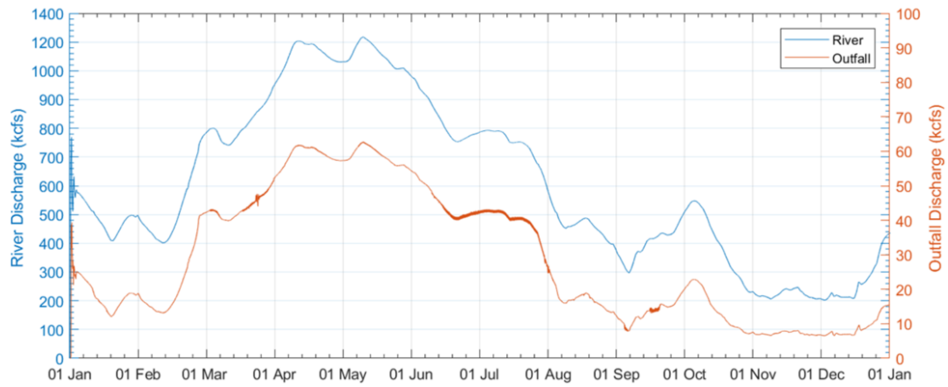


Figure 8-35: MR discharge hydrograph for future condition (44th year conditions is shown here as the 50th year hydrograph did not reach design condition of 1,000,000 cfs in MR) from TWIG PR15 1.5m SLR model (blue) on left axis and corresponding discharge at the diversion outfall (red) is plotted on the right axis

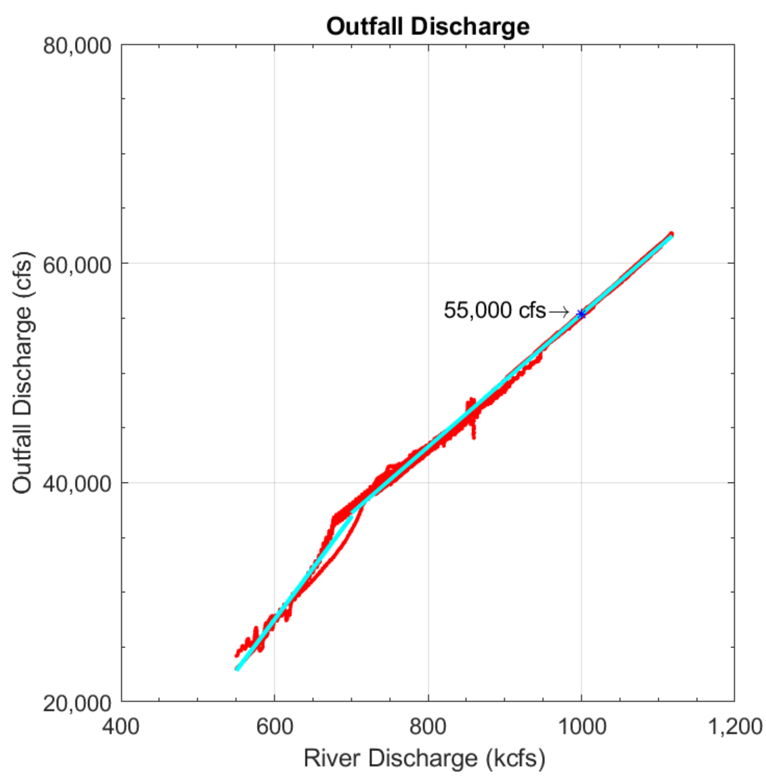


Figure 8-36: MR Discharge vs Outfall Discharge under future conditions with curent diversion system size. At 1,000,000 cfs in the MR river the current design allows only approximately 55,000 cfs discharge at the outfall under future conditions.

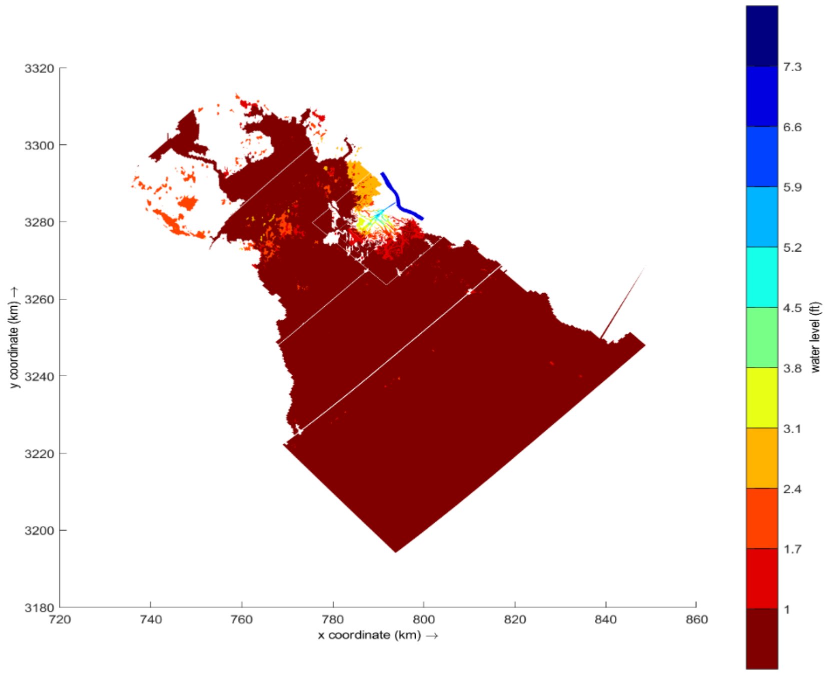


Figure 8-37: FTNOMBA Model simulated Water surface elevations when MR reaches 1,000,000 cfs.

Table 8-21: Sensitivity of diversion discharge at the Outfall to the Conveyance Channel roughness, Manning's n .

Manning's roughness coefficient (n) for Conveyance Channel	River Discharge (cfs)	Diversion Discharge at Outfall (cfs)
0.024 (unlined earth channel)	1,000,000	65,500
0.035 (rip-rapped channel)	1,000,000	55,800
0.050 (natural, vegetated, channel with pools)	1,000,000	48,000

Modeling simulations showed that, for a given system dimension, the diversion system discharge capacity depends on the the choice of Manning's roughness. A limited sensitivity analysis using three steady state runs at 1,000,000 cfs MR discharge and with the currently designed three-component system (combining the headworks, the conveyance channel and the outfall transition) showed (Table 8-21) that considerable diversion discharge variation is possible based on the type of channel lining or the level maintenance. In order to accurately estimate the three-component diversion losses, the FLOW-3D model should be used to model the complex 3D turbulence, frictional and contraction/expansion losses through this complex system. The development of FLOW-3D modeling of the three-component system is currently underway as a next step to determine the required increase in the intake conveyance and calibrate the Delft3D model for further tasks for this project.

8.10 Physical Modeling

The numeric modeling program is also supported with a physical modeling program. A physical model plan was developed for a 1:65 scale model. The physical modeling will investigate the effectiveness of the diversion and the performance of the Conveyance Channel. Two physical models will be constructed: One model that includes about 12,500 feet of the Mississippi River and the diversion. A second model will include about 7,000 feet of the Conveyance Channel and about 2,000 feet of the basin to determine the sediment transport characteristics in the channel and near field deposition in the basin. Figure 8-38 shows the physical model domain.

Figure 8-38: Mississippi River Physical Model Domain

The physical model is a live bed model that includes sediment and captures both bedload and suspended load transport processes. A detailed discussion of the physical model and the physical model scaling is presented in **Appendix H.6**.

Part of the model scaling, was confirmation that the selected model sediment will move as bedload and suspended load. A small flume test was conducted to determine the incipient motion characteristics of the sediment and confirm that it will move in suspension. A 20 feet long by 2 feet wide flume was used for the test. The center 10 feet of the flume was filled with about 2 inches of sediment. Upstream and downstream of the sediment, a false floor was installed making the floor of the flume and the top of the sediment level. Figure 8-39 shows the model flume with sediment. The flume was tested at three water depths and three velocities. The flume depths correspond to prototype water depths of 19.5, 39 and 78 feet and the water velocities corresponded to prototype velocities of 1, 3, and 5 ft/s. Prototype velocities range from about 1 ft/s to 7 ft/s depending on the river flow and location in the cross section. Mid channel velocities are 4.5 to 7 ft/s. Appendix H.6 (Figure 5-4) shows a plot of depth averaged water velocity as a function of distance from left bank for flows of 712,000 cfs and 959,000 cfs.

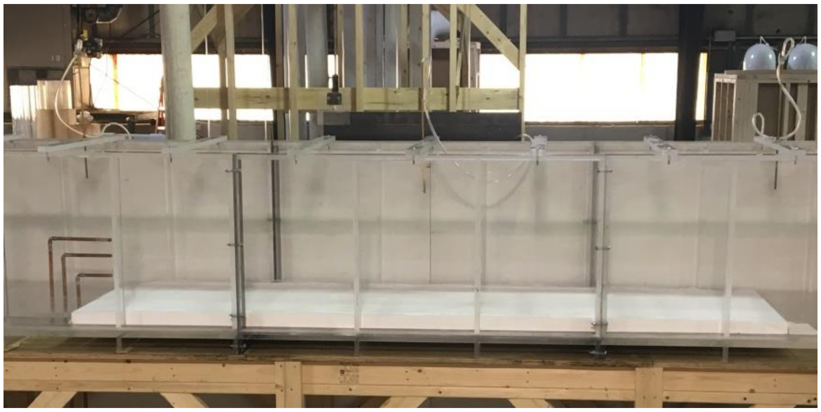


Figure 8-39: Sediment Test Flume

During each test, isokinetic samples were collected at three depths at the downstream end of the live bed. The data shows distinct sediment concentration profiles at higher velocities with near bed concentrations near 1000 mg/l. Figure 8-40 shows the measured sediment concentration profiles from the flume test. In addition to the measured sediment concentration profiles, photographs during testing showed the formation of bedforms. The geometric similarity of the flume bedforms to the Mississippi River bedforms is not yet known, however, it is known that bedforms exist in the MR for some of the flows tested. Figure 8-41 shows the bed forms observed at a prototype velocity of 5 ft/s and a prototype depth of about 19.5 feet.

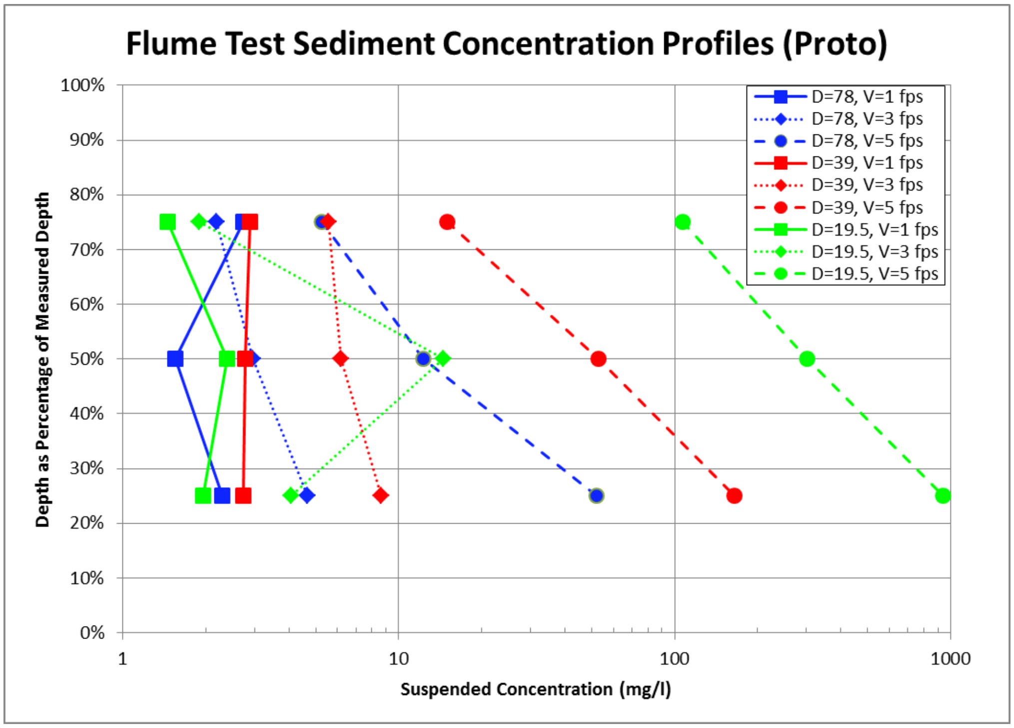


Figure 8-40: Measured Sediment Concentration Profiles in Small Flume

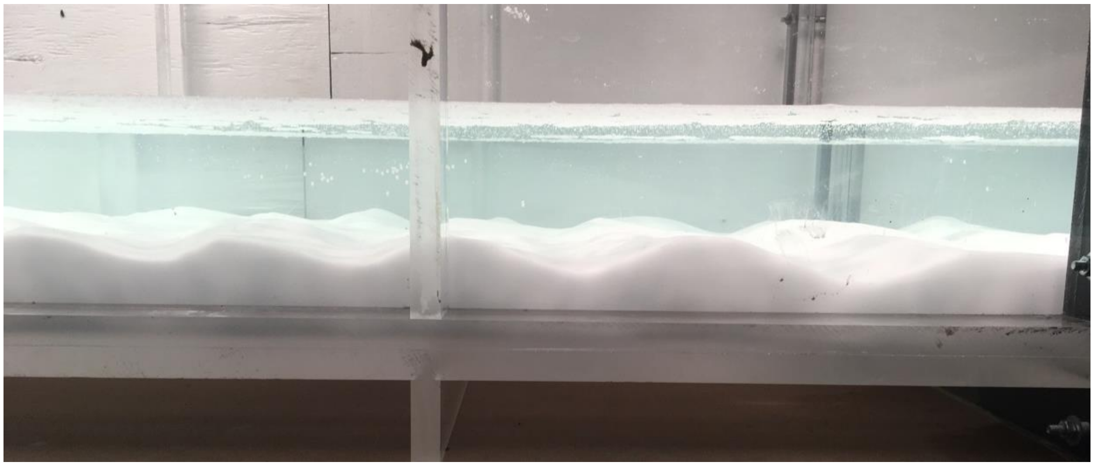


Figure 8-41: Bedforms Observed in the Small Flume Test

The observed bedforms were a plain bed (no bedforms) for a velocity of 1 ft/s at all depths. At a velocity of 3 ft/s ripples were observed and at a velocity of 5 ft/s dunes were observed. The largest dunes were observed for the lowest water depth.

The Rouse number is a dimensionless number that describes the uniformity and shape of the vertical sediment concentration profile model report. The Rouse number was estimated for the Mississippi River at the diversion site and compared with the Rouse number computed for the flume based on the sediment characteristics of the sediment that is planned for use. Both the prototype and the model have a Rouse number near one for flows of about 1,000,000 cfs. A detailed description is provided in **Appendix H**.

A detailed report on the model scaling and the flume test results is included in **Appendix H**.

8.11 Interior Drainage and Siphon Design

This subsection documents the work completed to date and the work planned for development of the BOD for Interior Drainage improvements. The key design element of the Interior Drainage improvements is the inverted Siphon, the conduit that will connect the drainage area bisected by the sediment diversion channel.

8.11.1. Data Gap Analysis

The DT's first step in developing the BOD for Interior Drainage was to take inventory of the available information, and to identify data gaps. These identified data gaps were documented in the January 30, 2018 Data Gap Analysis Report. Though some of these data gaps have been resolved, the following gaps remain:

8.11.1.1 Topographic Surveys

The DT is in the process of performing topographic surveys. Once complete, these surveys will allow the DT to update the existing HEC-HMS and HEC-RAS models to reflect current conditions and to confirm existing drainage features.

8.11.1.2 Access to Wilkinson Pump Station

Though not a specific data gap, the DT has not been authorized access to the Wilkinson Pump Station nor allowed coordination with the station's operations staff. Once access and coordination are granted, the DT will calibrate the existing conditions model utilizing data gathered on site, including but not limited to, pump start/stop times, run times and suction bay elevation readings. The time sequence of this data would ideally begin several hours prior to a significant rainfall event and continue to a time after the event when pumping ends. The calibrated existing conditions model will be used as the foundation of the existing conditions models and be further developed to reflect the improved conditions for each of the alternatives.

8.11.1.3 Wilkinson Pump Station Construction Drawings and Operation Data

As the installation of an inverted Siphon will increase the system headwater elevation, the DT must evaluate the extent to which tailwater can be lowered at the Wilkinson Pump Station. However, the DT does not have as-built drawings of the Wilkinson Pump Station, nor operation and maintenance data reflecting the standard operation procedures. Once provided, this information will inform the DT the degree to which operating levels of the pump station can be lowered through operational modifications, and the cost of structural and equipment changes necessary to further lower operating levels.

8.11.2. Design Criteria

The criteria dictating the design of the Interior Drainage improvements, given in **Appendix I**, establish the design basis for the surface drainage features, the hydraulic design of the inverted Siphon, and the design of the Inverted Siphon's inlet and outlet structures. The design criteria also establish the applicable USACE, State of Louisiana and Plaquemines Parish codes and standards that apply to the design of the Interior Drainage improvements.

8.11.3. Design Assumptions

The evaluation of hydraulic conditions and the subsequent design of hydraulic features to maintain Interior Drainage upon construction of the diversion channel will be based on a level of service consistent with a 25-Year, 24-Hr storm event. The anticipated longevity and estimated net present value of the operation and maintenance of new drainage features will be based on a useful life of 50 years.

It is also assumed that a zero net increase of water levels in the existing drainage system upstream of the inverted siphon must be maintained and that any additional head imparted into the drainage system by the installation of an Inverted Siphon can be operationally mitigated at the Wilkinson Pump Station by lowering the suction bay water surface elevation by an amount equal to the head added by the Inverted Siphon along with some minor mechanical modifications at the station. These modifications are assumed to include i) replacement/re-trimming of pump impellers, ii) removal and replacement of existing 800 hp diesel drives with new 900 hp drives, iii) removal and replacement of or modifications to the existing right angle gears to accommodate the new drives and iv) modifications to existing fuel oil, compressed air, cooling and other process piping and control wiring as well as reprogramming of controls as needed.

8.11.4. Existing Conditions Drainage Model

The DT has reviewed and will update the existing HEC-HMS model to determine storm quantities and the existing HEC-RAS model to determine water surface elevations, both under the 25-Year, 24-Hr storm event. The DT has not yet updated the models as topographic surveys of the area are not yet complete and data describing the Wilkinson Pump Station's operation are not yet available. The DT will initiate updating the models once the survey and operations data are available.

The HEC-HMS model update will verify the digital elevation model describing the drainage basin, as well as the sub-basin delineations and characterizations. The updated unsteady state HEC-RAS model will incorporate the operation of the Wilkinson Drainage Pump Station, and flows generated by the updated HEC-HMS model. Using the updated data, the DT will validate the sub-basin discharge quantities and identify the Outfall locations of each. To calibrate the models, the DT will monitor the channel elevation at its most downstream point, the Wilkinson Pump Station, and correlate flow rates through the channel with station's pumping performance. With the calibration of the models, the DT will develop a post-model map and compile the results to reflect the current performance of the system.

A detailed description of the procedures for updating and calibrating the existing conditions models will be provided in **Appendix I** of the updated BODR which will be included as part of the 30% phase of work.

8.11.5. Siphon Conceptual Sizing

As previously stated, the DT has not been allowed access to the Wilkinson Pump Station, and has been unable to calibrate the existing conditions drainage basin model. Therefore, the DT has not been able to independently establish the required capacity of either a pump station alternative or inverted siphon alternative at the time of this submittal. In an effort to establish a valid comparison between the Inverted Siphon and the pump station alternatives with the limited information currently available, it was decided to compare a pump station sized to 740 cfs as presented in the 2014 Base Design, with an Inverted Siphon of the same capacity. Further, a statistical analysis of five-years of rainfall data collected from the Belle Chasse Naval Air Station north of the project site reveals a low-flow condition of 35 cfs at the new Siphon structure. Considering a minimum Siphon velocity of 2.5 fps (to mitigate sedimentation) and the low flow condition the DT preliminarily recommends a combination of three 48-inch and five 60-inch Siphon tubes. This configuration includes a single redundant tube of each diameter. Maintenance of the minimum flow velocity within the inverted siphon tubes during pumping events will be accomplished through the design of a stepped weir system that will only allow flow into a predetermined number and combination of tubes depending on the amount of flow, and therefore, the elevation within the channel. Mechanical equipment requiring operation during a storm event to maintain minimum velocities is not a consideration for the design. Final sizing of the Siphon can only be completed once the HEC-HMS and RAS models are checked in detail, adjusted as needed and calibrated. A detailed description of the Siphon sizing effort is given in **Appendix I**.

8.11.6. Alternate Intake Design for the Inverted Siphon

As a potential measure to reduce the amount of head introduced by the drainage siphon, the DT will also consider, as part of the 30% design, an alternative siphon intake bay design. The concept driving the alternative intake design is to utilize the nearly unlimited amount of water available in the diversion channel for periodic siphon cleaning in lieu of achieving scour velocities for cleaning during normal operation.

Having such a reliable water supply available may give the DT the ability to increase the size of the siphon tubes, thereby lowering design flow velocities to a level below the recommended normal operating siphon velocities, which were developed by the relevant Agencies to achieve scour velocity.

This would result in a significant decrease in the head losses through the siphon during normal operations, which would in turn reduce the amount that the tailwater would have to be lowered at the Wilkinson Pump Station to mitigate for the head introduced by the siphon.

The physical concept of the alternate siphon intake bay includes construction of the bay in close proximity to the diversion channel levee with the ability to be isolated from the upstream drainage channel. This would be accomplished through the installation of a control gate structure at the upstream portion of the bay. Isolation gates would also be installed on each of the siphon tubes themselves. The concrete walls and/or earthen berm defining the intake basin walls will be built to an elevation at or near the elevation of the top of the diversion levee. A pump or true siphon will be installed between the diversion and siphon intake bay. Periodically, as defined in an operation and maintenance protocol to be developed by the DT, or as required due to current conditions, the intake bay isolation gate will be closed along with the siphon tube gates. The intake bay would then be filled with water from the diversion channel via the pump or true siphon. Once the intake bay is filled to a predetermined elevation, related to velocity requirements within the drainage siphon tubes to promote scouring, the drainage siphon tube gates would be opened, allowing for flow equal to or above the scour velocities required for cleaning. This process could be repeated as many times as necessary to complete siphon cleaning by virtue of the water available in the diversion. This would also require coordination with the operation of the Wilkinson Pump Station to pump out the water used for cleaning of the siphons.

8.11.7. Modeling of Proposed Alternatives

Once the exiting conditions models have been updated and calibrated, the DT will evaluate the alternative configurations by which an inverted Siphon system can maintain drainage in conjunction with the sediment diversion channel. The models will consider the drainage basins yielded by two candidate NOV Levee alignments: along the existing back levee alignment and along Timber Canal further inland. A detailed description of the procedure for developing these models of proposed alternatives will be provided in the Site Drainage Report Outline in **Appendix I** of the updated BODR, which will be included in the 30% phase of work.

9. GEOTECHNICAL EXPLORATION AND ENGINEERING

9.1 General

The DT performed the geotechnical engineering for the project's permanent structures. Temporary structures will be designed by the CMAR utilizing the exploration data developed for the project and the DT's preliminary analyses from the 15% design effort. The CMAR will also require additional geotechnical data (e.g., pump test). The DT will provide technical review of the CMAR's design efforts where appropriate.

The DT retained subject matter experts for seismic faulting evaluations, Outfall erodibility, and independent technical review. Dr. George Filz has been designated a subject matter expert and will provide consultation on settlement induced bending moment on pile supported features, and deep mixing method (DMM), and soil structure interaction numerical modeling. Subject matter experts are in the process of being retained for consult on Outfall channel erodibility and seismic considerations (Risk of Faulting). Outfall erodibility will be addressed by Dr. Kehui Xu, Associate Professor, Louisiana State University, as the subject matter expert. His work will be primarily reviewed by Dr. Nina Stark, Assistant Professor AY, Virginia Polytechnic University. A seismic subject matter expert is currently being identified among several experts.

9.2 Design Approach

Design standards outlined in the Hurricane and Storm Damage Risk Reduction System Design Guidelines (HSDRRSDG), Interim, Revisions through June 2012 and Louisiana Flood Protection Design Guidelines (LFPDG), Geotechnical Section Version 1.0 are the standards referenced for geotechnical design of flood protection. The "LADOTD Bridge Design and Evaluation Manual" (which defers to the AASHTO LRFD Bridge Design Specifications) will be the design standard for the Hwy 23 Bridge. Refer to the Project DCD (**Appendix U**) for detailed discussion of all geotechnical criteria.

9.3 References and Publications

- AASHTO LRFD Bridge Design Specifications, 8th Edition.
- Cofferdams, 2nd Edition, Columbia University Press, New York, L. White, and E. A. Prentis, 1950.
- Comments to the U.S. Army Corps of Engineers, New Orleans Division in reference to The Environmental Impact Statement for the Mid-Barataria Sediment Diversion, McClindon, C. et al., September 2017.
- Dewatering Cofferdam for Construction of Olmsted Locks, Journal of Geotechnical and Environmental Engineering, ASCE, Volume 126, No. 6, June 2002.
- EM 1110-2-1913, Design and Construction of Levees, USACE, April 2000.
- EM-1110-2-2503, Design of Sheet pile Cellular Structures, Cofferdams, and Retaining Structures, September 1989, USACE.
- Fine-Grained Alluvial Deposits and Their Effects on Mississippi River Activity, War Department, Corps of Engineers, Mississippi River Commission, Vicksburg Mississippi, Harold Fisk, July 1947.
- Finite Element Analysis of Lock and Dam 26 Cofferdam, Journal of Geotechnical and Environmental Engineering, ASCE, Volume 111, No. 4, G.W. Clough, Thangavelu Kuppusamy, April 1985.

- Geological Investigation, Mississippi River Deltaic Plain, Distribution of Deltaic and Marine Deposits, Quadrangle, Pointe A La Hache, U.S. Army Corps of Engineers, 1987.
- Geotechnical Data Report for 30% Design, Mid Barataria Diversion Project (BA-153), Plaquemines Parish, La., January 24, 2014.
- Hurricane and Storm Damage Risk Reduction System Design Guidelines, Revised June 2012, including references.
- Louisiana Department of Transportation and Development, Bridge Design and Evaluation Manual, including AASHTO Standards.
- Louisiana Flood Protection Design Guidelines Version 1.0, July 16, 2015, including references.
- Mid-Barataria Sediment Diversion, Geotechnical Report, HDR Engineering, Inc., July 2014.
- TM 3-424, Investigation of Underseepage and Its Control, Lower Mississippi River Levees, Volume 1, Waterways Experiment Station, USACE, 1956.
- TM 5-818-5, CI, Dewatering and Groundwater Control, Department of the Army, the Navy, and the Air Force, 27 June 1985.
- TO15/16: Sediment Erodibility in Outfall Areas of Barataria and Breton Sound, Geotechnical Field Investigation, The Water Institute of the Gulf, June 2016.
- U.S. Army Engineer Waterways Experiment Station, CE, Distribution of Soils Bordering the Mississippi River From Donaldsonville to Head of Passes, C.R. Kolb, TR No. 3-601, June 1962.
- U.S. Army Engineer Waterways Experiment Station, CE, Geology of the Mississippi River Deltaic Plain, Southeastern, Louisiana, C.R. Kolb and J.R. Van Lopik, TR No. 3-483, Volume 1, 1958.

9.4 Available Investigation Summary

9.4.1 Available Boring and In-Situ Data

Available geotechnical data include data gathered from 11 borings made by the USACE. Three borings were 5-inch diameter fixed piston sample borings made to depths between 50 and 82 feet. The remaining eight borings were 3-inch diameter general type borings sampled with a Shelby tube sampler. The 3-inch diameter borings vary in depths between 27 and 149 feet. Three of these borings were made along the alignment of the MRL. GeoEngineers, in association with HDR Engineering, completed the preliminary geotechnical exploration. This preliminary geotechnical exploration supplemented the USACE borings with 19 borings obtaining 5-inch diameter fixed piston sampler borings, five individual 3-in. diameter general type Shelby tube sample borings made in the Mississippi River, 20 cone penetration tests (CPTs), and four field vane (FV) tests made adjacent to the 3-in. diameter Shelby tube borings. In addition, two pump tests (PTs) were conducted and monitored with 16 piezometers. The PTs were also sampled with 3-in. diameter borings. One PT was performed near the NOV Levee within predominantly fine-grained deposits and is not relevant for the BOD. The other PT was performed in shallow silt deposits, through which the excavation for the intake gate at the HW will be completed landward of the MRL. We provide detailed discussion of recommended - additional PTs in Section 9.14. Together with the USACE borings, a total of 66 exploration points were available from the existing and preliminary explorations, east of the NOV levee that borders Barataria Bay, and 21 additional 3-inch diameter borings in the Barataria Bay marsh, west of the NOV Levee. Existing exploration points are shown on the drawings in **Appendix D**. These exploration points are concentrated in or very near to the MRL.

9.4.2 Available Laboratory Data

The USACE's borings and borings from the 2014 Baseline Study provided samples for laboratory tests. These tests were supplemented by the results of CPTs and FV shear tests obtained during the 2014 Baseline Study. Besides classification tests, laboratory tests consisted of numerous unconsolidated undrained triaxial shear (UU) three-point tests, unconfined compression (UC) tests, grain size analyses, and -#200 particle size sieve determinations. The 2014 Baseline Study also included flexible wall permeability tests and 51 consolidation tests. However, of the 51 consolidation tests, 31 tests were performed on samples obtained from borings made to the west of the NOV Levee in the Barataria Bay marsh. Four consolidated undrained (CU) triaxial tests were performed on samples in a single boring between the ground surface and 10-foot depths. As a result, the data are isolated and in areas of the subsurface that do not fully support the geotechnical design.

9.5 Site Geology Based on Existing Data and Information

The site can be divided into several major depositional units including a complex point bar deposit at the Mississippi River. This point bar deposit is overlain by natural levee deposits extending into the marsh area to the west of the project's intake at the Mississippi River. Both the marsh and natural levee deposits overlie undifferentiated interdistributary/intradelta sequences lain in brackish water environments and, in turn, nearshore Gulf and prodelta deposits lain in salt water environments. The deltaic deposits are incised by two abandoned distributary channels identified in the preliminary exploration. These abandoned channels are shown in the USACE's geologic study as part of the Cheniere Traverse Bayou entrenchment and deposition. Studies by the USACE indicate these abandoned channels may be interconnected extending westward toward the remnant abandoned distributaries of Bayou Barataria. The surface of deposits from the Pleistocene Epoch appears to be between EL -100 and EL -125 (referenced to the MSL Datum) at the Mississippi River with a general trend at approximate EL -110 along the proposed Conveyance Channel alignment. Area geology is shown in plan and cross-sections shown in **Appendix D**.

9.6 Supplemental Geotechnical Exploration Program

9.6.1 General

The goal of the supplemental geotechnical exploration program is to provide deeper exploration in the vicinity of the structural features of the project and sufficient area coverage along the guide levees and Conveyance Channel, highway bridge, tie-ins to the NOV Levee, near-field Outfall basin, and potential back structure and Siphon locations. Undisturbed borings will obtain samples from borings using 5-inch diameter fixed piston samplers and general type borings will obtain 3-inch diameter Shelby tube samples. CPTs and small diameter direct-push borings will be used to supplement the other boring data. Exploration points and depths are summarized in **Appendix D**. The field program began in July 2018 and will be completed in November 2018. The field program has been and will continue to be performed in accordance with the Quality Control Plan for the project dated November 2017.

9.6.2 Headworks

The Headworks (HW) structures will be installed or partially installed within dry excavations requiring dewatering and hydrostatic pressure relief. These excavations will also require cofferdams for construction. Preliminary engineering in this 15% design effort have cofferdams comprising cellular type and earthen structures. The earthen structures will eventually be guide levees for the Conveyance Channel. Data will be obtained to evaluate pile capacity, lateral stability of the HW structures, settlement, seepage, slope stability of tie-in flood protection, and conceptual design requirements for dewatering, pressure relief, stability, and seepage for the temporary works (cofferdams). Additional explorations for the cellular structures (i.e., protective cellular structures in the River), structural cofferdams, earthen cofferdams, and dewatering and pressure relief will be performed after the 15%

design as the designs of permanent works progresses and when the CMAR starts designs of the temporary works.

Point bar deposits comprise two predominant units and are a significant concern for design. The lower unit comprises coarser and more uniform sands and extends from the river bottom at approximate EL -50 to EL -130 (reference to NAD 83/WGS 84 Data). Pressure relief in this stratum will likely be feasible using relatively widely spaced pumped wells around the perimeter of the headworks excavation. Landward point bar deposits comprise interbedded fine grained silts, silty sands, and clay. These deposits extend from approximately EL -10 to EL -110 and overlie the coarser point bar sands. The upper point bar deposits will be difficult to dewater; closely spaced wells along the top of sloped excavation will likely be necessary to lower the phreatic surface to several feet below planned excavation subgrade elevation. It also may be necessary to seal the perimeter wells and either pump them with jet eductors or with submersible pumps supplemented with vacuum pumps to achieve vacuum inside of the well casings. Where the stratum of coarse point bar sand exists below the fine point bar silt and clay, groundwater in the higher point bar deposit may drain into the lower point bar sands when this stratum is pumped and provide adequate lowering of the phreatic surface in the point bar silt. Conceptual recommendations for pumping tests in both the lower coarse point bar sand and the upper point bar silt are presented in Section 9.14. The results of such testing are needed to complete the design of temporary groundwater control systems for the headworks excavation. Unprotected slopes of open excavations in the fine point bar deposits will erode readily. Even if the phreatic surface in the fine point bar deposit is lowered several feet below the planned excavation bottom, these soils will still be almost fully saturated and will be easily disturbed under construction traffic. It is expected that the upper point bar silt will drain slowly; it is possible that additional wells inside of the excavation may be necessary to lower the phreatic surface in the fine point bar if the drainage to a perimeter well system is too slow.

Supplemental exploration for the HW structures and earthen structures include 10 undisturbed borings obtaining 5-inch diameter fixed piston samples seven CPTs. Borings and CPTs have been or will be made to depths of 140 feet below the existing ground surface or mudline in the river to investigate the HW structures. These borings will penetrate the point bar deposits and extend into the Pleistocene formation. One additional undisturbed boring was made to 200 feet below the existing ground surface to further investigate the nature of the Pleistocene deposits. Additional deeper explorations (to EL -130, or 140 feet deep) will be necessary in future design phases to better delineate the extent and thickness of the coarse point bar sand where the dewatering wells/drains are to be installed around the perimeter of the planned HW excavation.

9.6.3 Conveyance Channel and Guide Levees

Data will be obtained to evaluate slope stability, settlement, and underseepage. The USACE and the CPRA require exploratory points at 500-foot center-to-center spacings along levee structures. In this regard, we will utilize a combination of CPTs and 5-inch diameter fixed piston undisturbed sample type borings made at 500-foot center-to-center spacings along the north and south levee alignments. In general, the CPT locations and the undisturbed boring locations alternate. These exploration points will be made to 80 and 100-foot depths. We have supplemented these borings with 3-inch diameter Shelby tube sampled borings made along the centerline of the Conveyance Channel. The purpose of these borings is to evaluate near-surface borrow material for use in the levees, and to complement the borings made along the levee centerline for stability analysis purposes. The borings will be made to 60-foot depths considering we anticipate the Conveyance Channel will be as deep as EL -25.

9.6.4 Siphon

Data will be gathered to support analyses for bearing capacity and settlement of the Siphon structure. Seepage analyses will also be required. One row of three borings will be located along the centerline alignment of the Siphon. Depending upon the Siphon's location (and if more than one Siphon will ultimately be required), north and south guide levees, and conveyance centerline borings will be adjusted to accommodate the Siphon location(s). One boring will be a 5-inch diameter undisturbed boring, one boring will be a 3-inch diameter general type boring, and one CPT will be made to depths of 140 feet.

9.6.5 Outfall Structure

Data will be obtained to evaluate pile capacity, lateral stability of the Outfall structures, settlement, slope stability of tie-in flood protection, and conceptual requirements for excavations. Additional explorations necessary for excavation (if any) will be included with the CMAR contracts. The Outfall structure may be located at the extreme western terminus of the guide levees, or may be located within the Conveyance Channel as the USACE is considering relocating the NOV Levee inland to reduce the overall length of the flood protection. Two additional undisturbed borings will be made at the structure and Outfall channel. Two CPTs will be made to assist design of the tie-in to the existing back levee. These borings and CPTs will be made to 140-foot depths.

9.6.6 Hwy 23 and Approaches

Geotechnical analyses for the bridge will focus on pile capacity and settlement for piers. Special consideration will be given to floodwalls (pile supported T-Walls) beneath the bridge along the guide levee alignments. Data must be gathered to evaluate pile capacity, lateral stability, settlement, settlement induced bending moment at the floodwalls, and seepage. Proposed locations of the exploration points for the bridge and approaches are shown in **Appendix D**.

Discussions have been undertaken with the State of Louisiana, Department of Transportation and Development (LADOTD). LADOTD has indicated they require borings or CPTs made at every bent or pier supporting the bridge. With the bridge design being in preliminary stages and bent/pier locations not established, borings and CPTs will be made at approximate, alternating 100-foot center-to-center spacings and at the currently planned bent/pier locations. These borings/CPTs will be made to 170-foot depths. We propose to perform seven 3-inch diameter Shelby tube sample borings and eight CPTs at 15 bent locations. Borings at two bents will be slightly relocated and positioned at T-Wall features below the bridge. At these locations, two 5-inch diameter undisturbed borings will obtain fixed piston samples extending to 140-foot depths. These borings will be completed to 170-foot depths obtaining 3-inch diameter Shelby tube samples. LADOTD also requires shallow borings to characterize subgrade materials along approaches. Six approach borings will be sampled with an auger and sampled continuously to 10-foot depths outside of the approach ramps. Two additional 3-inch diameter borings will be made to 120-foot depths at the ramps. These borings in association with the 3-inch diameter borings at the edges of the bridge are intended to support design of the ramps.

9.6.7 Point Bar Sampling and Outfall Channel Sampling

General type borings obtaining standard penetration tests (SPTs) are planned to investigate the erodibility characteristics of the Mississippi River point bar deposits at the project's intake and the Barataria Bay marsh deposits at the project's Outfall. Six exploration point locations are planned for each of these two areas, and will be established by the project's hydraulic engineers.

9.7 Supplemental Laboratory Testing Summary

9.7.1 General

Soil laboratory testing on samples obtained from the borings follows the same schedule as the field program (began in July 2018) and will finish a few weeks after completing the field program (approximately November 2018). The soil laboratory testing program has been and will continue to be performed in accordance with the Quality Control Plan for the project dated November 2017. We are providing a testing protocol consistent with current USACE, CPRA, and LADOTD standards for samples obtained from the borings. We will also perform consolidation tests, enhance and expand CU tests (including CKoTXC), and provide direct simple shear (DSS) tests to compliment UU and UC tests. To assist in classification and the evaluation of the drainability of the fine point bar silts, silty sands, and clays, both field and laboratory visual descriptions will include dilatancy (reaction to shaking) observations for all samples of these fine soils.

HW features, and guide levees parallel to the HW, will be located in point bar deposits of interbedded sands and silts for the region river side of the abandoned distributary shown in **Appendix D.** The remaining features will be located in primarily natural levee clay; abandoned distributary sequences of clays, organics and silts; and backswamp/marsh clay; and organic clay in deltaic interdistributary deposits. The underlying Pleistocene deposits are also primarily clay-type soils.

9.7.2 Undisturbed Borings

USACE and CPRA testing protocols require most samples be subjected to UU tests. In this regard, we will provide a UU test at every 10-foot depth of cohesive deposits. UC tests will alternate with UU tests at every 10 feet thus providing undrained shear strength tests for every 5 feet of sample. The USACE and CPRA also require Atterberg limits determinations for each UU test. This requirement will be part of Eustis Engineering's testing protocol.

Special concern will be given to the nature of point bar deposits in the HW area. These deposits do not lend themselves well to undisturbed sampling and shear strength testing. We anticipate standard penetration testing (SPT) to obtain samples of these point bar deposits and grain size analyses on the -#200 sieve. We will also perform hydrometer dispersion tests on silt and sand deposits to characterize these deposit's propensity to be drained by pumping. Clay deposits encountered with the upper point bar deposits will be subjected to the testing protocols previously described for cohesive materials. Dilatency testing is also being performed to characterize the ability of clay and silt soil samples to drain. Given the heterogeneous nature of point bar deposits, our testing protocols will be flexible and adjusted based on sample recovery.

Consolidation tests obtained for the 2014 Baseline Study, were primarily concentrated in the vicinity of the MRL or in the Barataria Bay marsh borings west of the NOV Levee. Only 11 consolidation tests were available along the levee alignments. Eustis Engineering will supplement these consolidation tests near the vicinity of the HW in the MRL and focus on obtaining additional consolidation tests along the Conveyance Channel guide levees, Siphon structure, and Outfall canal structure.

Point bar deposits (sands and silts) are predominate in the HW structure and MRL tie-in areas. The USACE evaluates undrained shear strength parameters using CU triaxial shear tests (three-point) with pore pressure measurements. Representative samples will be subjected to these tests for verification of parameters typically assumed in silt materials. Shear strength parameter selection will depend highly on a critical evaluation of UU tests. Sampling and testing techniques introduce potential disturbance that affect the test results. CU triaxial testing can mitigate sample disturbance using normalized testing methods according to the SHANSEP. We will evaluate normalized parameters for the various geologic units along the Conveyance Channel guide levees to verify typically assumed strength to effective stress ratios. We will use perform CU and CKoU triaxial shear tests, consolidated and sheared at various pressures to represent normally consolidated behavior to obtain representative parameters for SHANSEP evaluations of strength gain during stage loading of the levees. We will similarly perform DSS tests in the SHANSEP framework to further aid in parameter selection and help define design strengths for soils sheared in the DSS failure mode.

9.7.3 General Type Borings

In cohesive materials, we will obtain one-point UU tests at 10-foot depths and alternate these with UC tests at 10-foot depths resulting in shear testing every 5 feet. Atterberg limits determinations will be performed for each UU test. Grain size analyses to the -#200 sieve will be performed on any cohesionless material encountered. Of notable concern will be the near surface natural levee backswamp/marsh and undifferentiated interdistributary/intradelta deposits. The general type borings are also planned to investigate these materials as a potential borrow source. In this regard, we will perform moisture content, organic content, and Atterberg limits determinations to establish material quality and constructability.

9.7.4 Small-Diameter, Direct Push Borings

Small-diameter, direct push borings will extend to 20-foot depths to investigate the extent of natural levee deposits and potentially underlying interdistributary/intradelta deposits. Moisture contents will be obtained at 2.5-foot intervals and Atterberg limits determinations at 5-foot intervals. Organic content tests will be established for each sample that has a moisture content in excess of 80%.

9.8 Description of Subsurface Conditions Based on Existing Geotechnical Data

9.8.1 General

The Delineation of Soil Parameters Report presents the DT interpretation of soil reaches and soil design parameters as they interrelate with the proposed project features and general design requirements for MBSD. The Delineation of Soil Parameters Report builds on the Data Gap Analysis Report that was published by the DT in February 2018 and the 2014 Baseline Study documents prepared by HDR Engineering, Inc. and GeoEngineers, Inc. Considering all available information, we designated nine design reaches. Please refer to **Appendix D** for descriptions and extents of the reaches. We developed stratigraphy and parameters for each reach and have based the analyses for the 15 percent design effort on these assumptions. We developed data plots for moisture content, unit weight, undrained shear strength, standard penetration tests, and D10 sizes. We selected soil design parameters based on the plots that are included in the Delineation of Soil Parameters Report. We also designated consolidation parameters in the Soil Delineation Report. We describe the nine soil design reaches in the following sections.

9.8.2 Reaches 1 and 2

Reaches 1 and 2 extend from the riverside extreme limit to Station 25+00 and comprise the river point bar deposits at the Intake Structure. Reach 1 includes locations of the two easternmost borings made in the deeper river and was separated from Reach 2 to investigate potential differences due to location.

Reaches 1 and 2 were subsequently judged to have similar characteristics and may be consolidated after the final exploration. In these reaches, point bar deposits extend to the Pleistocene surface at EL -128. Point bar deposits are coarser sand deposits and the Pleistocene deposits are pre-compressed clays. The deepest exploration point extends to EL -200.

9.8.3 Reaches 3 and 4

Reaches 3 and 4 represent the continuation landward of the point bar deposits between Station 25+00 and Station 35+00. They are overlain by natural levee deposits and the MRL. The deeper point bar deposits have similar characteristics as those in Reaches 1 and 2, i.e., coarser sand deposits but they are overlain at shallower depths by fine sand, silt, and clay deposits. The MRL fill and natural levee deposits are clay soils, more competent below the levee centerline (Reach 3). Natural levee deposits extend to EL -10 and underlying point bar deposits extend to EL -132. Upper point bar deposits between EL -10 and EL -80 are interbedded silts and clays. Separate parameters were selected for these deposits and used for analyses to investigate sensitivity to these variations.

9.8.4 Reach 5

Reach 5 comprises the shallow point bar deposits between Station 35+00 and Station 48+00 and extend to EL -106. These deposits are interbedded clays, sands, and silts that underlie natural levee deposits and interdistribuary deposits. The natural levee and interdistributary deposits are primarily clays and silty clays from the existing ground surface to EL -37. An abandoned distributary indicated by geologic mapping may extend into these natural levee deposits but was not encountered by the preliminary field exploration. Point bar deposits interface with Pleistocene Age clay deposits at EL -104.

9.8.5 Reach 6

Occurring between Station 48+00 and 53+00, Reach 6 is characterized by an abandoned distributary incised into the natural levee and interdistributary deposits that comprise Reach 5. The abandoned distributary deposits are interbedded clays and silts with organic matter. The clays and silts are extended to approximate EL -48 and overlie prodelta clay deposits. Pleistocene clays are encountered at EL -120.

9.8.6 Reach 7

Reach 7 extends from Station 53+00 to 85+00 and comprises natural levee deposits from the existing ground surface extending to EL -10 and interface with deltaic deposits that continue to the Pleistocene interface at EL -120. Two subreaches, Reach 7A and Reach 7B were identified as abandoned distributaries incising the deltaic deposits to approximate EL -42. The deltaic deposits are an interdistributary unit extending to EL -50 and a prodelta unit extending below the interdistributary deposits to EL -115. A sand deposit was encountered between EL -115 and the Pleistocene unit at EL -120. Deltaic deposits are primarily clay with interdistributary deposits containing silt lenses and layers. Abandoned distributary deposits are interbedded clays and silts with organic matter. Reach 7A extends between Station 53+00 and Station 59+00 and Reach 7B extends between Station 78+00 and Station 83+00.

9.8.7 Reaches 8 and 9

Reaches 8 and 9 are similar in geology but differ in land use. Reach 8 is inside (i.e., protected side) of the line of the levee flood protection. Reach 9 is outside (i.e., flood side) of the protection and within Barataria Bay. Both reaches are characterized by surficial marsh deposits underlain by deltaic deposits of interdistributary and prodelta units. Marsh deposits in Reach 9 are weaker and extend to deeper depths. These deposits extend to EL -10 in Reach 8 and EL -15 in Reach 9. The extent of marsh deposits will be a significant design consideration effecting both stability and settlement. In addition, marsh deposits are not suitable levee fill requiring their delineation in the borrow areas. Pleistocene deposits were encountered at EL -120 in Reach 8 but explorations in Reach 9 were not deep enough to establish the Pleistocene surface.

9.9 Mississippi River Flood Protection

9.9.1 Levee Stability and Seepage

At the 15% level, the DT researched the appropriate flood side analysis of the MRL that was performed by the USACE, New Orleans District. The USACE performed a flood side analysis of the MRL using the LMVD Method of Planes and considered a LWL of EL 0.0 (NGVD). The USACE established a stability control line along which all safety factors for levee stability toward the river were at least 1.30. The DT referred to that stability control line when considering various scenarios of excavation (e.g., in-the-wet, in-the-dry, varying intake elevations). The DT ensured that excavations did not encroach upon the stability control line so that contemplated excavations were considered safe with respect to MRL stability.

The existing MRL is underlain by vast point bar deposits of varying sands and silts. Excavations in these deposits present challenges for dewatering and pressure relief. However, with the existing grades on the protected side of the MRL near EL 2 to EL 5 and considering a SWL of EL 12.6, these deposits have shown to have suitable clay blankets overlying the point bar deposits. We conclude that adequate safety factors for heave and exit gradient have been achieved.

9.9.2 Bank Stability

Similar to the levee stability, the DT researched at the 15% level the appropriate flood side analysis of the bank adjacent to the MRL that was performed by the USACE, New Orleans District. The USACE established a stability control line along which all safety factors for bank stability toward the river were at least 1.30. This control line extends from approximately EL 2 along a 4.5H:1V slope down to EL -50, then along a 2H:1V slope down to EL -120. The DT referred to that stability control line when considering various scenarios of excavation (e.g., in-the-wet, in-the-dry, varying intake elevations).

9.10 Mississippi River Scour Protection

The Mississippi River scour protection was not considered in the geotechnical analysis/design at the 15% level. The DT will consider the presence of scour protection along the proposed banklines for flood side analysis of the MRL stability.

9.11 Mississippi River T-Wall Design

The Mississippi River T-Walls will consist of six monoliths (T-1 through T-6) on each side of the U-Frame at Station 29+00 and will connect to the existing MRL. The ground surface on the protected and flood sides is EL 2 at Monoliths T-1 through T-5 and EL 10 at Monolith T-6. Top of wall grade is EL 16.4. Braced excavations will be used to construct the T-Walls and these stability analyses will be performed after the T-Wall construction sequence is developed with the contractor.

The DT performed stability and seepage analyses on select T-Wall monoliths with the flood side water level at EL 16.4 to evaluate unbalanced loads and required sheetpile tip elevations using methods outlined in Section 3.5.11 of the Project DCD using design parameters for Soil Reach 4. A summary of the stability and seepage results performed for the T-Walls in Table 9-1 and the supporting calculations are provided in **Appendix G**.

Table 9-1: Stability and Seepage Results for Mississippi River T-Walls

Monolith No(s).	Protected and Flood Side Ground Surface EL	Base Width (feet)	Bottom of Base Design EL [with 2-feet Working Pad]	Required Sheetpile Tip for Seepage	Stability Factor of Safety	Unbalanced Load (lbs)
T-1	2	32	-49	-111	2.61	0
T-2	2	32	-39	-101	2.71	0
T-3	2	24	-27	-80	2.15	0
T-4	2	15	-17	-80	1.57	0
T-5	2	15	-7	-80	1.44	0
T-6	10	15	-7	-80	3.41	0

Allowable pile load capacities for the Mississippi River T-Walls were computed using methods outlined in Section 3.4.3 of the Project DCD. Various sizes of open end pipe piles with the top of piles at EL -3, -25, and -47 were analyzed using design parameters for Soil Reach 4. Estimates of allowable pile load capacities and supporting calculations are provided in **Appendix G**.

9.12 Headworks Excavation Design and Groundwater Control during Construction

9.12.1 Recommendations for Pumping Test in Clean Point Bar Sand and Overlying Point Bar Silt

The DT recommends that a carefully planned pumping test be performed and analyzed to support final design engineering by the CMAR for the excavations for the HW. The following discussion assumes that an adequate supplemental subsurface investigation with laboratory testing will be completed before the location and design of the test pumping program is started.

9.12.1.1 Purposes of Test and Conceptual Installation, Pumping, and Monitoring Plan

One of the purposes of the pumping test will be to evaluate the actual hydrogeological properties of the clean point bar sand stratum, the distance to the effective source of steady state seepage at the conclusion of the test, the efficiency and safe collection capacity of the test well, and the storativity of the clean point bar sand disclosed by non-steady flow. Although it is useful to evaluate these parameters, a pumping test will elucidate the drainability of the overlying point bar silt and silty fine sand. Advance knowledge of the drainability of the silt will be essential to the timely, effective design and installation of a successful groundwater control system for the HW excavations. It is contemplated that the test well will consist of 10- or 12-inch stainless steel continuous slot pipe size screen and Sch 80 or SDR 21 PVC riser pipe installed in a 24-inch diameter hole drilled using either the flooded reverse circulation or bucket auger method using water or a polymer for the drilling fluid. The well will be screened in the lower 30 to 60 feet (depending on its location) of the clean point bar sand stratum and the screen will be surrounded by a high quality, commercially available uniform silica sand filter graded using appropriate filter design criteria. Because the clean point bar sand is fine and uniform, it is likely that the filter will be either 20/40[1] or 16/30 sand and that the required well screen slot size for a uniformly graded filter will be about 0.020 in. A tentative location for the test well is the north side of the excavation opposite about baseline Station 32+00. Piezometric head and pore pressure monitoring will include 2 radial lines of piezometers at radii of about 25, 50, 100, and 200 feet from the test well. Each piezometer will be equipped with a non-vented pressure transducer with either an onboard datalogger or connected to a master datalogger. The test well flow will be monitored with a flow meter that also includes a datalogger. River stages and barometric pressures will be monitored before, during, and after the pumping test either manually or automatically using level (or pressure) transducers. One little more than half of these piezometers will be installed at two levels in the silt stratum, and the remainder will be installed in the clean point bar sand. One test boring will be drilled and sampled at 5-foot centers full depth in advance close to the proposed test well. At least two tensiometers will be installed in the silt stratum close to the test well at depths of 5 feet and 10 feet below the static phreatic surface for the purpose of estimating the degree of saturation before and during the test.

It is possible that the point bar silt and silty sand will drain vertically into the underlying clean point bar sand stratum by simply lowering the piezometric head in the underlying clean point bar sand formation. Pore pressures in piezometers installed in the overlying point bar silt will be monitored as well as piezometric levels in the underlying clean point bar sand when the test well is pumped. The required test duration is uncertain; the duration should be sufficient to evaluate the time required for 90% drainage of the fine point bar deposits. A reasonable tentative estimate for the pumping test duration is two weeks, followed by two weeks of recovery monitoring. Such a test is necessary to evaluate whether or not gravity drainage of the silt will occur, and if so, what pumping duration is needed for 90% drainage.

However, if clay lenses or layers within the point bar silt stratum prevent vertical drainage of the silt into the point bar sand, additional (2-inch completed diameter, un-pumped) low capacity wells will be needed to induce vertical drainage of this stratum into the underlying clean point bar sand stratum when it is pumped. It is possible that the silt will not drain vertically by gravity even with the addition of closely spaced smaller sized wells around the perimeter of the excavation. To attempt to overcome this potential problem, a vacuum pumping system will be installed and operated with a manifold to produce a small relative vacuum (5 to 10 inches of mercury, or Hg) in the 2-inch low capacity well casings, which will be sealed. The effectiveness of 2-inch un-pumped low capacity wells in achieving drawdown in the point bar silt will be evaluated by installing a 400-foot (total length) section of 2-inch completed diameter wells screened through the both the silt and at least 15 feet into the underlying clean sand stratum. To evaluate the need for and the effectiveness of low capacity wells in expediting drainage of the point bar silt, 17 low capacity wells will be installed in 10-inch diameter jetted or drilled holes 25 feet apart, centered on the high capacity test well. These wells can either be installed concurrently with the installation of the high capacity test well or after the initial pumping indicates that such wells either are or may be necessary. During the installation of the 17 low capacity wells, a vacuum pump and manifold will be installed to connect the pump to the sealed low capacity well casings. The vacuum

[1] These numbers indicate the range of US Standard sieve sizes for the gradation of commercially available filter sands.

pump will be started after an elapsed test pumping time of a few days and the application of vacuum to the low capacity wells will continue until the end of test pumping. Recovery of water levels in the piezometers installed in both the point bar silt and in the underlying point bar sand will be monitored after pumping for at least the same duration as the active pumping. All piezometers, the barometric pressure at the site, and the river stage at the site will be monitored at least 4 times per day for two weeks before the test, hourly during active pumping until 24 hours following the end of pumping, then at least 4 times per day for another two weeks. Instantaneous and cumulative flow measurements will be accurate to within 1% of the measured flow and shall be monitored continuously throughout active pumping. The accuracy of automated instruments (except for the flow meter) will be checked at least twice per day) during active pumping using suitable manual measurement methods. The flow meter will be new or calibrated by the manufacturer within 3 months before its use onsite. Water temperature, pH, conductivity, and oxidation-reduction potential will be monitored at least once per day during active pumping and again one to two weeks after pumping is stopped.

Groundwater samples will be taken at the end of active pumping and one week after the end of pumping and shipped to an approved laboratory for a battery of tests recommended by the laboratory to determine inorganic water chemistry, organic content, the presence and identification of microbiological organisms (bacteria), and the probability of well/pump/pipe fouling or corrosion in pumped well systems and other drainage systems. The laboratory will prepare a report summarizing the test results and its opinions of the potential for well and pump clogging and/or corrosion of metallic well screens and discharge piping. The laboratory will have a successful experience record of preparing such interpretive reports for well and piping systems on a minimum of 10 projects in the preceding 10 years and the report shall be reviewed and co-signed by a subject matter expert in well fouling and corrosion.

The DT will summarize the results of the pumping test in an engineering report, including all collected data, groundwater testing and interpretative report by the well fouling / corrosion subject matter expert, estimations of transmissivity and storativity for the clean point bar sand stratum, and the drainability of the silt stratum under gravity conditions as well as under a small relative vacuum.

9.12.2 Conceptual Designs for Groundwater Control during Construction

Groundwater control during construction was evaluated conceptually for four in-the-dry and one in-the-wet alternative designs, all for the intake gate located at baseline Station 33+50 (450 feet from the MRL):

1. U-Frame intake in-the-dry with invert at EL -40[2]
2. Open channel intake in-the-dry with invert at EL -20
3. Open channel intake in-the-dry with invert at EL -50
4. Submerged culvert intake in-the-dry with invert at EL -50
5. U-Frame in-the-wet cofferdam with invert at EL -40

Summaries of the elements of the five designs are discussed in Sections 9.12.2.1 through 9.12.2.5. In all five cases a (redundant) seepage barrier between EL -60 and EL -135 was included in the conceptual designs and cost estimates as described below to reduce seepage through the clean point bar sand stratum. The dewatering systems were designed independent of the seepage barrier (i.e., assuming

[2] All elevations cited in this report section are in feet and refer to the North American Vertical Datum of 1988, 2009.55 epoch.

that the seepage barrier is not installed). Conceptual designs and corresponding cost estimates for groundwater control during construction include the following common components:

- single panel[3] jet grouted cutoff extending from EL -60 to 5 feet below the Pleistocene clay stratum, completely surrounding the planned excavations where they are underlain by the clean point bar sand stratum, or riverward of approximately baseline Station 38+00, where the clean point bar sand is assumed to pinch out;
- high capacity 10-inch completed diameter pumped wells screened in the clean point bar sand stratum for pressure relief with 300-gpm submersible electric pumps and motor controls;
- low capacity 2-inch diameter un-pumped wells screened in both the upper point bar silt and the underlying clean point bar sand, supplemented if necessary by applying low vacuum (5 to 10 inch Hg) to sealed well casings to induce drainage of the silt;
- low capacity 4-inch completed diameter wells screened only in the upper point bar silt to at least 10 feet below excavation subgrade, sealed and pumped using 4-inch parallel pipe jet eductors to achieve a small relative vacuum (5 to 10 inch Hg) in the wells to induce drainage of the silt, or sealed and pumped using fractional horsepower 4-inch submersible pumps supplemented by an electric vacuum pumping system sized to produce the same small relative vacuum in each of the sealed well casings;
- low capacity 2-inch completed diameter un-pumped wells in each cofferdam cell screened full depth through the cell backfill, natural point bar silt, and the underlying clean point bar sand, supplemented if necessary by a vacuum pumping system to induce a small relative vacuum in the individual well casings;
- system for controlling precipitation and surface runoff that collects within the excavations, including sumps, pumps, piping, and ditches;
- primary and secondary 3-phase electrical distribution, motor controls and monitoring devices, provisions for automatically switched standby power;
- instrumentation for system monitoring (piezometers, flow meters, drawdown in wells, coupons in pumped wells to monitor encrustation, discharge water quality, relative vacuum, current, voltage, frequency, and motor status);
- operation and monitoring, including pump replacement, periodic exercise of standby power generators, sump cleaning, sand content measurements, manual checks of transducer data, plotting, and reporting performance data for systems;

Design calculations and working sketches of conceptual dewatering designs for these alternative cases are included in **Appendix G**. Summaries of the designs are discussed in the following sections, as well as tabulations of assumed design parameters and the results of analytical calculations. Design assumptions/parameters common to all cases analyzed are given in the Table 9-2. A summary of the conceptual designs and cost estimates is presented in Table 9-3.

[3] A more positive jet grouted seepage barrier would comprise double panels that are cris-crossed between grout injection points. Such a barrier would cost approximately twice as much as a single panel barrier.

Table 9-2: Design Assumptions Common to All Cases Analyzed[4][5]

Parameters	Value
Design River Stage (ft, NAVD88)	17.5
Average K_h of Clean Point Bar Sand (cm/sec)	0.015
Average Thickness D of Clean Point Bar Sand below excavation (ft)	60
Average Well Collection Capacity Q_w (gpm)	300
Bottom of Clean Point Bar Sand (ft, NAVD88)	-130
Azimuth and Station of Intersection of Line Source of Seepage with Baseline (degrees / Station)	349 / 15+75

Table 9-3: Summary of Conceptual Design Options and Cost Estimates

Option	Q_t=Flow in Clean Point Bar Sand (gpm)	No. of 10-inch High Capacity Wells	No. of 2-inch Low Capacity Wells (Un-Pumped)	No. of 4-inch Low Capacity Wells (Pumped)	Length of Seepage Barrier (ft)	Cost Estimate With Seepage Barrier	Cost Estimate Without Seepage Barrier
U-Frame Intake In-The-Dry Invert at EL -40	4,000	19	128	37	4,350	$32,275,000	$12,700,000
Open Channel Intake In-The-Dry Invert at EL -20	2,200	7	133	29	3,250	$26,642,500	$12,197,500
Open Channel Intake In-The-Dry Invert at EL -50	4,600	15	102	62	3,580	$28,325,000	$12,215,000
Submerged Culvert Intake In-The-Dry Invert at EL -50	5,200	17	132	53	5,000	$34,410,000	$13,260,000
U-Frame Intake In-The-Wet Invert at EL -40	3,000	11	101	122	2,230	Not Estimated	Not Estimated

9.12.2.1 U-Frame In-the-Dry Intake with Invert at EL -40

9.12.2.1.1 High Capacity Well System

The purpose of the high capacity well system is to depressurize the clean point bar sand stratum beneath the excavations, lowering the piezometric head below the excavation to at least 5 feet below

[4] For the in-the-dry submerged culvert intake at EL -50, the intersection of the assumed line source of seepage with the project baseline is Station 14+40.

[5] For the in-the-dry open channel intake at EL -40, the intersection of the assumed line source of seepage with the project baseline is Station 21+20, azimuth 345°.

planned subgrade (or to EL -55). See **Appendix G** for dewatering design calculations and sketches showing the design assumptions discussed below. Wells will be installed to 5 feet into the Pleistocene clay underlying the clean point bar sand, or to about EL -135. The well borehole diameter will be about 24 inches and the finished well diameter will be 10-inch pipe size, which will allow 300-gpm capacity pumps to be installed in them. Wells riverward of the MRL will be installed on the inboard side of the cellular or the combi-wall cofferdam. Each well will be screened completely through the clean point bar sand stratum. The actual hydraulic conductivity of the clean point bar sand stratum is estimated to be somewhere between 0.015 and 0.05 cm/sec, based on experience and the USACE K_h vs. D_{10} correlation[6], which was used to estimate K_h for representative samples from (Geotechnical Reach 2) Borings R-1A through R-6A. Because the lower two-thirds of the point bar sand is very dense, based on Standard Penetration resistances and the DT's experience with fine sand formations in Louisiana having similar average D_{10} values (about 0.08 to 0.10 mm), the average K_h assumed for all dewatering flow calculations was 0.015 cm/sec. The average stratum thickness at the river end of the cofferdam is estimated to be 83 feet. The borings indicate that the clean point bar sand stratum extends from its outcrop in the river channel landward to the "pinch-out" in the vicinity of boring NL-9A, or at about baseline Station 38+00. The average thickness *D* of the clean point bar aquifer in the area of the excavation riverward of Station 38+00 was assumed to be 60 feet. The effective source of seepage was assumed to be an infinite fully penetrating slot in the river channel about 300 feet (or more) riverward of the river end of the well system (intersecting baseline at Station 15+75, azimuth 349 degrees). The total system flow is estimated to be 4,000 gallons per minute (gpm) using the equation for steady combined artesian-gravity flow to an equivalent well with a radius r_e of 536 feet, as described in **Appendix G**, drawdown inside of the ring of wells to 5 feet below subgrade (or to EL -55), the common assumptions listed in Table 9-2, and the case-specific assumptions listed in Table 9-3. As estimated in **Appendix G**, the estimated average well capacity is about 300 gpm assuming an average formation K_h of 0.015 cm/sec along the well screens, an effective individual well diameter of 1.5 feet, 10 feet of incremental drawdown at individual wells due to well interference, and a wetted screen length of 65 feet at each well. Using a uniform well spacing of 200 feet, 19 wells are required, and for a total system flow of 4,000 gpm, the average flow per well is a little more than 200 gpm. Therefore 300-gpm pumps and appurtenant discharge piping have a Factor of Safety of about 1.5. The required head capacity of each pump is about 93 feet, comprising the sum of the lift [17.5-(-65) = 82.5 feet] and friction and minor losses [allow 10 feet]. For a 300-gpm pump capacity and assuming 2-pole, 460-volt, 60-Hz, 3-phase submersible motors, the pump bowl diameter will be between 6 and 8 inches (inches), and 10-inch-pipe-size wells are appropriate and conservative (robust) for that range of bowl diameters.

9.12.2.1.2 Low Capacity 2-inch Un-pumped Well System Screened in Point Bar Silts and Underlying Clean Sand Stratum

The purpose of the low capacity 2-inch un-pumped well system, which would be screened in both the silt and in the underlying sand on a close (25-foot) center-to-center spacing around the perimeter of the intake excavation landward of the cellular cofferdam is to lower the phreatic surface in the point bar silts to at least the approximately planned subgrade level (EL -50). The total number of these wells is about 98. Because of the fineness of this formation, it is known from experience that the individual well flows and aggregate system flow will be very small and have not been estimated.

[6] USACE (2000) Engineer Manual 1110-2-1913, Design and Construction of Levees, Figure 3.5b, page 3-10

9.12.2.1.3 Low Capacity 2-inch Un-pumped Well System Screened in Point Bar Silts and Underlying Clean Sand Stratum in Cofferdam Cells

The stability of the cofferdam cells requires that the phreatic surface in the individual cells be lowered to the elevation of the inboard stability berm, or to about EL -20. In the DT's judgment, the phreatic surface inside each cofferdam cell can be lowered and maintained at or below EL -20 using one 2-inch diameter un-pumped well in each cell that is screened through the cell backfill, natural levee, fine point bar, and extending 10 feet or more into the underlying clean point bar sand, in conjunction with pumping the high capacity well system to lower the head in the clean point bar sand to EL -55 or deeper. As indicated in **Appendix G** for this design case, 30 of these wells will be required. It will also be necessary to produce a small relative vacuum in the casings to induce drainage of fine grained silts.

9.12.2.1.4 Low Capacity 4-inch Diameter Low Capacity Pumped Well Screened in Point Bar Silt to at Least 10 feet Below Planned Subgrade

Landward of the pinch-out at about baseline Station 38+00, the clean point bar sand does not exist below the point bar silt and lowering the phreatic surface will probably require installing and pumping closely-spaced (25-foot) low capacity wells in the point bar silts. This design spacing will require approximately 37 low capacity pumped wells. Pumping the anticipated small flow from the silt and simultaneously producing a vacuum in the sealed well casings can be accomplished using either 4-inch diameter parallel pipe jet eductors, which will pump both air and water, or by installing small 4-inch diameter submersible pumps in the wells to pump water and using vacuum pumps to produce a small relative vacuum in the sealed well casings. The principal advantage of using submersible pumps rather than jet eductors is that the air-handling capacity of the vacuum pump is much higher.

9.12.2.1.5 Length and Face Area of Seepage Barrier

As indicated in **Appendix G**, the length of the jet grouted seepage barrier will be about 4,350 feet. For treatment between EL -60 and EL -135, the calculated seepage barrier face area is 326,250 square feet.

Table 9-4: Dewatering System Design Summary for U-Frame Intake In-the-Dry with Invert at EL -40

Parameters	Value
Q_t=Flow in Clean Point Bar Sand (gpm)	4,000
r_e = radius of equivalent well (ft)	536
L = Distance to Line Source of Seepage	1,177
No. of 10-inch High Capacity Wells	19
Length of Seepage Barrier (ft)	4,350
No. of 2-inch diameter low capacity un-pumped wells including cell wells	128
No. of 4-inch low capacity pumped wells	37

9.12.2.2 Open Channel Intake In-the-Dry with Invert at EL -20

9.12.2.2.1 High Capacity Well System

The high capacity well system is designed to depressurize the clean point bar sand stratum beneath the excavations, lowering the piezometric head below the excavation to at least 5 feet below planned subgrade (or to EL -35). See **Appendix G** for dewatering design calculations and sketches showing the design assumptions discussed below. Wells will be installed to 5 feet into the Pleistocene clay underlying the clean point bar sand, or to about EL -135. The well borehole diameter will be about 24 inches and the finished well diameter will be 10-inch pipe size, which will allow 300-gpm capacity pumps to be installed in them. Wells riverward of the MRL will be installed on the inboard side of the cellular or the combi-wall cofferdam. Each well will be screened completely through the clean point bar sand stratum. The total system flow was estimated to be 2,200 gpm using the equation for steady combined artesian-gravity flow to an equivalent well with a radius of 534 feet, as described in **Appendix G**, drawdown to EL -35, and the assumptions listed in Table 9-2. Using a uniform well spacing of 200 feet, 7 wells will be required, and for a total system flow of 2,200 gpm, the average required pump capacity per well is about 300 gpm. The required head capacity of each pump is about 93 feet, as calculated in the previous Section (9.12.2.1).

9.12.2.2.2 Low Capacity 2-inch Un-pumped Well System Screened in Point Bar Silts and Underlying Clean Sand Stratum

The purpose of the low capacity 2-inch un-pumped well system, which would be screened in both the silt and in the underlying sand on a close (25-foot) center-to-center spacing around the perimeter of the intake excavation landward of the cellular cofferdam is to lower the phreatic surface in the point bar silts to at least the approximately planned subgrade level (EL -30). Because of the fineness of this formation, it is known from experience that the individual well flows and aggregate system flow will be very small and have not been estimated. As indicated in **Appendix G**, 121 of these wells are required at this spacing.

9.12.2.2.3 Low Capacity 2-inch Un-pumped Well System Screened in Point Bar Silts and Underlying Clean Sand Stratum in Cofferdam Cells

The stability of the cofferdam cells requires that the phreatic surface in the individual cells be lowered to the elevation of the inboard stability berm, or to about EL -20. In the DT's judgment, the phreatic surface inside each cofferdam cell can be lowered and maintained at or below EL -20 using one 2-inch diameter un-pumped well in each cell that is screened through the cell backfill, natural levee, fine point bar, and extending 10 feet or more into the underlying clean point bar sand, in conjunction with pumping the high capacity well system to lower the head in the clean point bar sand to EL -55 or deeper. As indicated in **Appendix G** for this design case, 12 of these wells will be required. It has been assumed that it will be necessary to produce a small relative vacuum in these casings to induce drainage of the silts.

9.12.2.2.4 Low Capacity 4-inch Diameter Low Capacity Pumped Well Screened in Point Bar Silt to at Least 10 feet Below Planned Subgrade

Landward of the pinch-out at about baseline Station 38+00, the clean point bar sand does not exist below the point bar silt and lowering the phreatic surface will probably require installing and pumping closely spaced (25-foot) low capacity wells in the point bar silts. This design spacing will require approximately 29 low capacity pumped wells. Pumping the anticipated small flow from the silt and simultaneously producing a vacuum in the sealed well casings can be accomplished using either 4-inch diameter parallel pipe jet eductors, which will pump both air and water, or by installing small 4-inch diameter submersible pumps in the wells to pump water and using vacuum pumps to produce a small relative vacuum in the sealed well casings.

9.12.2.2.5 Length and Face Area of Seepage Barrier

As indicated in **Appendix G**, the length of the jet grouted seepage barrier will be about 3,370 feet, and for treatment between EL -60 and EL -135, the barrier face area is 252,750 square feet.

Table 9-5: Dewatering Summary for Open Channel Intake In-The-Dry with Invert at EL -20

Parameters	Value
Q_t=Flow in Clean Point Bar Sand (gpm)	2,200
r_e = radius of equivalent well (ft)	534
L = Distance in Feet to Line Source of Seepage (300 ft outboard of well system)	1,350
No. of 10-inch High Capacity Wells	7
Length of Seepage Barrier (ft)	3,250
No. of 2-inch diameter low capacity un-pumped wells (including cell wells)	133
No. of 4-inch low capacity pumped wells	29

9.12.2.3 Open Channel Intake In-the-Dry with Invert at EL -50

9.12.2.3.1 High Capacity Well System

The high capacity well system is designed to depressurize the clean point bar sand stratum beneath the excavations, lowering the piezometric head below the excavation to at least 5 feet below planned subgrade (or to EL -65). See **Appendix G** for dewatering design calculations and sketches showing the design assumptions discussed below. Wells will be installed to 5 feet into the Pleistocene clay underlying the clean point bar sand, or to about EL -135. The well borehole diameter will be about 24 inches and the finished well diameter will be 10-inch pipe size, which will allow 300-gpm capacity pumps to be installed in the wells. Wells riverward of the MRL will be installed on the inboard side of the cellular or combi-wall cofferdam. Each well will be screened completely through the clean point bar sand stratum. The total system flow was estimated to be 4,600 gpm using the equation for steady combined artesian-gravity flow to an equivalent well with a radius of 620 feet, as described in **Appendix G**, drawdown to EL -65, and the common assumptions listed in Table 9-2.

Using a 300-gpm well capacity, 15 wells will be required, and the calculated total system flow is 4,600 gpm. The required head capacity of each pump is estimated to be about 93 feet, as calculated in the previous Section (9.12.2.1).

9.12.2.3.2 Low Capacity 2-inch Un-pumped Well System Screened in Point Bar Silts and Underlying Clean Sand Stratum

The purpose of the low capacity 2-inch un-pumped well system, which would be screened in both the silt and in the underlying sand on a close (25-foot) center-to-center spacing around the perimeter of the excavation landward of the cellular cofferdam is to lower the phreatic surface in the point bar silts to at least the approximately planned subgrade level (EL -50). Because of the fineness of this formation, it is known from experience that the individual well flows and aggregate system flow will be very small and have not been estimated. As indicated in **Appendix G**, 88 of these wells are required at this spacing.

9.12.2.3.3 Low Capacity 2-inch Un-pumped Well System Screened in Point Bar Silts and Underlying Clean Sand Stratum in Cofferdam Cells

The stability of the cofferdam cells requires that the phreatic surface in the individual cells be lowered to the elevation of the inboard stability berm or to about EL -20. In the DT's judgment, the phreatic surface inside each cofferdam cell can be lowered and maintained at or below EL -20 using one 2-inch diameter un-pumped well in each cell that is screened through the cell backfill, natural levee, fine point bar, and 10 feet or more into the underlying clean point bar sand, in conjunction with pumping the high capacity well system to lower the head in the clean point bar sand to EL -65 or deeper. As indicated in **Appendix G** for this design case, 14 of these wells will be required. It has been assumed that it will also be necessary to produce a small relative vacuum in the casings to induce drainage of fine grained silts.

9.12.2.3.4 Low Capacity 4-inch Diameter Low Capacity Pumped Well Screened in Point Bar Silt to at Least 10 feet Below Planned Subgrade

Landward of the clean point bar sand pinch-out at about baseline Station 38+00, that stratum does not exist below the point bar silt and lowering the phreatic surface will probably require installing and pumping closely spaced (25-foot) low capacity wells in the point bar silts. This design spacing will require approximately 62 low capacity pumped wells. Pumping the anticipated small flow from the silt and simultaneously producing a vacuum in the sealed well casings can be accomplished using either 4-inch diameter parallel pipe jet eductors, which will pump both air and water, or by installing small 4-inch diameter submersible pumps in the wells to pump water and using vacuum pumps to produce a small relative vacuum in the sealed well casings.

9.12.2.3.5 Length and Face Area of Seepage Barrier

As indicated in **Appendix G**, the length of the jet grouted seepage barrier will be about 3,580 feet, and for treatment between EL -60 and -135, the barrier face area is 268,500 square feet.

Table 9-6: Dewatering Summary for Open Channel Intake In-the-dry with Invert at EL -50

Parameters	Value
Q_t=Flow in Clean Point Bar Sand (gpm)	4,600
r_e = radius of equivalent well (ft)	622
L = Distance to Line Source of Seepage	1,420
No. of 10-in. High Capacity Wells	15
Length of Seepage Barrier (ft)	3,580
No. of 2-in. dia. low capacity un-pumped wells (including cell wells)	102
No. of 4-in. low capacity pumped wells	62

9.12.2.4 Submerged Culvert Intake In-The-Dry with Invert at EL -50

9.12.2.4.1 High Capacity Well System

The high capacity well system is designed to depressurize the clean point bar sand stratum beneath the excavations, lowering the piezometric head below the excavation to at least 5 feet below planned subgrade (or to EL -65). See **Appendix G** for dewatering design calculations and sketches showing the design assumptions discussed below. Wells will be installed to 5 feet into the Pleistocene clay underlying the clean point bar sand, or to about EL -135. The well borehole diameter will be about 24 inch and the finished well diameter will be 10-inch pipe size, which will allow 300-gpm capacity pumps to be installed in the wells. Wells riverward of the MRL will be installed on the inboard side of the cellular or the combi-wall cofferdam. Each well will be screened completely through the clean point bar sand stratum. The total system flow was estimated to be 5,200 gpm using the equation for steady combined artesian-gravity flow to an equivalent well with a radius of 751 feet, as described in **Appendix G**, drawdown to EL -65, and the common assumptions listed in Table 9-2.

Using a 300-gpm well capacity, 17 wells will be required. The required head capacity of each pump is estimated to be about 93 feet, as calculated in the previous section (9.12.2-1).

9.12.2.4.2 Low Capacity 2-inch Un-pumped Well System Screened in Point Bar Silts and Underlying Clean Sand Stratum

The purpose of the low capacity 2-inch un-pumped well system, which would be screened in both the silt and in the underlying sand on a close (25-foot) center-to-center spacing around the perimeter of the excavation landward of the cellular cofferdam is to lower the phreatic surface in the point bar silts to at least the approximately planned subgrade level (EL -50). Because of the fineness of this formation, it is known from experience that the individual well flows and aggregate system flow will be very small and have not been estimated. As indicated in **Appendix G**, 96 of these wells are required at this spacing.

9.12.2.4.3 Low Capacity 2-inch Un-pumped Well System Screened in Point Bar Silts and Underlying Clean Sand Stratum in Cofferdam Cells

The stability of the cofferdam cells requires that the phreatic surface in the individual cells be lowered to the elevation of the inboard stability berm or to about EL -20. In the DT's judgment, the phreatic surface inside each cofferdam cell can be lowered and maintained at or below EL -20 using one 2-inch diameter un-pumped well in each cell that is screened through the cell backfill, natural levee, fine point bar, and 10 feet or more into the underlying clean point bar sand, in conjunction with pumping the high capacity well system to lower the head in the clean point bar sand to EL -65 or deeper. As indicated in **Appendix G** for this design case, 36 of these wells will be required. It has been assumed that it will also be necessary to produce a small relative vacuum in the casings to induce drainage of the point bar silts.

9.12.2.4.4 Low Capacity 4-inch Diameter Low Capacity Pumped Well Screened in Point Bar Silt to at Least 10 feet Below Planned Subgrade

Landward of the clean point bar sand pinch-out at about baseline Station 38+00, that stratum does not exist below the point bar silt and lowering the phreatic surface will probably require installing and pumping closely spaced (25-foot) low capacity wells in the point bar silts. This design spacing will require approximately 62 low capacity pumped wells. Pumping the anticipated small flow from the silt and simultaneously producing a vacuum in the sealed well casings can be accomplished using either 4-inch diameter parallel pipe jet eductors, which will pump both air and water, or by installing small 4-inch diameter submersible pumps in the wells to pump water and using vacuum pumps to produce a small relative vacuum in the sealed well casings.

9.12.2.4.5 Length and Face Area of Seepage Barrier

As indicated in **Appendix G**, the length of the jet grouted seepage barrier will be about 5,000 feet, and for treatment between EL -60 and -135, the barrier face area is 375,000 square feet.

Table 9-7: Dewatering Summary for Open Channel Intake In-the-Dry at EL -50

Parameters	Value
Q_t=Flow in Clean Point Bar Sand (gpm)	5,200
r_e = radius of equivalent well (ft)	751
L = Distance to Line Source of Seepage	1,300
No. of 10-inch High Capacity Wells	17
Length of Seepage Barrier (ft)	5,000
No. of 2-inch diameter low capacity un-pumped wells (including cell wells)	132
No. of 4-inch low capacity pumped wells	53

9.12.2.5 U-Frame Intake In-The-Wet with Invert at EL -40

9.12.2.5.1 High Capacity Well System

The high capacity well system is designed to depressurize the clean point bar sand stratum beneath the excavations, lowering the piezometric head below the excavation to at least 5 feet below planned subgrade (or to EL -55). See **Appendix G** for dewatering design calculations and sketches showing the design assumptions discussed below. Wells will be installed to 5 feet into the Pleistocene clay underlying the clean point bar sand, or to about EL -135. The well borehole diameter will be about 24 inches and the finished well diameter will be 10-inch pipe size, which will allow 300-gpm capacity pumps to be installed in the wells. Wells riverward of the MRL will be installed on the inboard side of the cellular or the combi-wall cofferdam. Each well will be screened completely through the clean point bar sand stratum. The total system flow was estimated to be 3,000 gpm using the equation for steady combined artesian-gravity flow to an equivalent well with a radius of 378 feet, as described in **Appendix G**, drawdown to EL -55, and the common assumptions listed in Table 9-2.

Using a 200-foot well spacing, 11 wells will be required. The required head capacity of each pump is estimated to be about 93 feet, as calculated in the previous Section (9.12.2.1).

9.12.2.5.2 Low Capacity 2-inch Un-pumped Well System Screened in Point Bar Silts and Underlying Clean Sand Stratum

The purpose of the low capacity 2-inch un-pumped well system, which would be screened in both the silt and in the underlying sand on a close (25-foot) center-to-center spacing around the perimeter of the excavation landward of the cellular cofferdam is to lower the phreatic surface in the point bar silts to at least the approximately planned subgrade level (EL -50). Because of the fineness of this formation, it is known from experience that the individual well flows and aggregate system flow will be very small and have not been estimated. As indicated in **Appendix G**, 88 of these wells are required at this spacing.

9.12.2.5.3 Low Capacity 2-inch Un-pumped Well System Screened in Point Bar Silts and Underlying Clean Sand Stratum in Cofferdam Cells

The stability of the cofferdam cells requires that the phreatic surface in the individual cells be lowered to the excavation subgrade elevation (EL -50). In the DT's judgment, the phreatic surface inside each cofferdam cell can be lowered and maintained at or below EL -50 using one 2-inch diameter un-pumped well in each cell that is screened through the cell backfill, natural levee, fine point bar, and 10 feet or more into the underlying clean point bar sand, in conjunction with pumping the high capacity well system to lower the head in the clean point bar sand to EL -55 or deeper. As indicated in **Appendix G** for this design case, 13 of these wells will be required. It has been assumed that it will also be necessary to produce a small relative vacuum in the casings to induce drainage of the point bar silts.

9.12.2.5.4 Low Capacity 4-inch Diameter Low Capacity Pumped Well Screened in Point Bar Silt to at Least 10 feet Below Planned Subgrade

Landward of the clean point bar sand pinch-out at about baseline Station 38+00, that stratum does not exist below the point bar silt and lowering the phreatic surface will probably require installing and pumping closely spaced (25-foot) low capacity wells in the point bar silts. This design spacing will require approximately 122 low capacity pumped wells. Pumping the anticipated small flow from the silt and simultaneously producing a vacuum in the sealed well casings can be accomplished using either 4-inch diameter parallel pipe jet eductors, which will pump both air and water, or by installing small 4-inch diameter submersible pumps in the wells to pump water and using vacuum pumps to produce a small relative vacuum in the sealed well casings.

9.12.2.5.5 Length and Face Area of Seepage Barrier

As indicated in **Appendix G**, the length of the jet grouted seepage barrier will be about 2,230 feet, and for treatment between EL -60 and -135, the barrier face area is 167,250 square feet.

Table 9-8: Dewatering Summary for U-Frame Intake In-The-Wet with Invert at EL -40

Parameters	Value
Q_t=Flow in Clean Point Bar Sand (gpm)	3,000
r_e = radius of equivalent well (ft)	378
L = Distance in Ft to Line Source of Seepage (300 ft outboard of well system)	1,432
No. of 10-inch High Capacity Wells	11
Length of Seepage Barrier (ft)	2,230
No. of 2-inch dia. low capacity un-pumped wells (including cell wells)	101
No. of 4-inch low capacity pumped wells	122

9.12.3 Seepage Cutoff Evaluations

No seepage cutoff is required for the HW excavation, in the DT's opinion. Dewatering the fine point bar deposit by pre-drainage using widely-spaced deep wells tapping the underlying coarse point bar sand could well be all that is required for adequate groundwater control during construction. In the worst case, closely spaced wells that completely penetrate the fine point bar and are pumped with or without applied vacuum may be required in addition to the coarse point bar deepwell system. Installing a seepage barrier is not required for the success of this method of groundwater control. Although it is theoretically possible to dewater the fine point bar soils by open sumping, the excavation slopes would necessarily have to be very flat, even assuming that a fully penetrating seepage barrier were installed in advance of excavation. If the fine point bar deposit does not drain vertically because of layer of clay, there will also be seepage stability problems at such interfaces if open sumping with no pre-drainage is the dewatering method. The need for a seepage barrier will be evaluated again during the 30% design for the post-construction case of a high river stage in conjunction with a closed intake. It is likely that hydrostatic pressure relief may be necessary immediately landward of the intake gate for that case. There may be other cases requiring permanent seepage control measures in the HW area that will also be evaluated during the 30% design phase.

9.12.4 Combi Walls/Cellular Structures

9.12.4.1 Cellular Structures

Construction of the "in-the-dry" options involves cellular cofferdams extending from approximately 150 feet east of the MRL centerline into the river. The distances that the cells extend into the river differ between the EL -20 and EL -40 options as shown in **Appendix D**.

The DT sized the cofferdams for the 15 percent level of design initially based on published case histories for two riverine cofferdams of roughly similar height in similar soil conditions. These two case histories were the cofferdams for Locks and Dam 26 in the Mississippi River near St. Louis, Missouri[7] and cofferdam for Olmsted Lock on the Ohio River near Olmsted, Illinois.[8] Basic details of these cofferdams and the selected dimensions for the MBSD cofferdam are summarized in Table 9-9 below and drawings are provided in **Appendix D**.

Table 9-9: Attributes of Referenced Cofferdams and Those Selected for MBSD Cofferdam

Attribute	LD 26	Olmsted	Selected for MBSD
Diameter (ft)	63	62.7	63
Maximum height (Top of cofferdam elevation-mudline elevation)	60	69	65*
Maximum Head Difference (Design river elevation - dewatered design elevation on land side)	83	104	65*
Width of Top of Landside Berm (ft)	20	20	20
Slope of Landside Berm and Soil Type of Berm	5H:1V sand	3H:1V, sand	3:1 riprap
Distance from Top of Cofferdam to top of Berm (ft)	35	39	35*
Foundation Soil Below Cofferdam	Sand	Sand with stiff clay	Sand (east end) Sand, silt,clay (west end)
Cofferdam Dewatered	yes	yes	yes
Penetration of Sheet pile Below Mudline	35	40	35

*Assumed top of cofferdam at EL 15 which was later changed to EL 17.5

After sizing the MBSD cofferdam based on similar case histories, rough calculations were made to confirm that the size selected was reasonable. Calculations generally followed the USACE guidelines in EM 1110-2-2503, "Design of Sheet Pile Cellular Structures, Cofferdams, and Retaining Structures," 29 September 1989. This method differs slightly from others in the references cited below which were also reviewed.

[7] Clough, G.W.,Kuppusamy,Thangavelu,"Finite Element Analyses of Lock and Dam 26 Cofferdam", Journal of Geotechnical and Environmental Engineering, American Society of Civil Engineers, Volume 111, No. 4, April 1985, pages 521-540.

[8] Mansur, C.I., Durrett, S.G.,"Dewatering Cofferdam for Construction of Olmsted Locks", Journal of Geotechnical and Environmental Engineering, American Society of Civil Engineers, Volume 126, No. 6, June 1, 2002, pages 496-510.

Two different subsurface profiles are applicable to design of the cofferdams, one at the east end of the cofferdam furthest in the river, and a second near the MRL. For the invert EL -40 option, the cofferdam extends approximately 900 feet from the MRL into the river. Subsurface conditions there are represented by Reaches 1 and 2 conditions from the Soil Delineation Report. Subsurface conditions in Reaches 1 and 2 are essentially identical, i.e. coarse point bar deposits in the river bed to at least EL -85.

Further west, near the existing MRL, soil conditions are less well defined because no borings are located in the river near the levee. The closest borings in the river are about 650 feet east of the MRL. The closest profile is at Reach 3 along the center of the MRL which was used for evaluation. An east-west subsurface profile is shown in **Appendix D**. As noted in the figure, subsurface conditions at the east end of the cofferdam consist of sand fill within the cofferdam over a clean coarse sand foundation (coarse point bar deposits). These conditions are preferable to the west end of the cofferdam near the MRL where soil conditions consist of silts, silty sand, and clay (fine point bar deposits) from surface grade (EL -6) to about EL -90. Below EL -90 coarse point bar sands are generally present, similar to the east end of the cofferdam.

For the EL -20 invert, the entire cofferdam is within about 500 feet of the MRL and soil conditions for calculations were assumed to be represented by only Reach 3 conditions.

Analysis of Cells at the East End of the MRL (Reach 1 and 2 Soil Conditions), Invert EL -40.

Analysis of this cofferdam using only drained (S-case) conditions because foundation soils and cell fill will be sand. Additional assumptions for this case are:
Top of cofferdam is EL 17.5 with river at EL 17.5

Wall friction was ignored.

Seepage was assumed controlled to EL -50 on the protected side of the cofferdam and to EL -16.25 inside the cell (halfway between the river elevation and dewatered level inside the cofferdam) assuming the cells are dewatered.

The cofferdam was analyzed with no penetration below the mudline and therefore results calculated and summarized below are conservative since the actual cofferdam extends 35 feet below the mudline.

The preliminary calculations confirmed that key factors of safety were met. Therefore the dimensions of the cofferdam assumed based on published case histories was reasonable for Reach 1 and 2 soil conditions in the river near where boring information is available.

Analysis of Cells near the MRL, (Reach 3 Soil conditions), Invert EL -40

By inspection, bearing capacity at EL -85 for the Reach 3 soil conditions showed it was inadequate. Calculations indicated a Factor of Safety on bearing capacity less than 1.0 and well below the 3.0 value recommended by the USACE.

Therefore the cells were deepened to EL -100 to bear in the dense which is present near EL -90. Deepening the cofferdam will also help with sliding, overturning and vertical shear that would likely be an issue at shallower depth. Extending the cells to EL -100 would only be needed for cells within 300 feet of the levee where the depth of the coarse point bar sand deepens based on existing data.

When more detailed information is available it may show that a larger diameter cell is needed due to conditions near the MRL, but that should not have a major impact on the cost of steel, since the steel required is approximately independent of the cell diameter. The only additional cost for a larger cell would be for cell fill, but this should fall within the contingency in the budget.

The closer that cells are to the MRL, the greater the amount of existing sediment that might be left inside the cells. These clayey and silty materials result in higher interlock tension than the sandy cell fill further east. Therefore, it is recommended that sheets with high interlock strength (32 k/in) be assumed for cost estimating. For conservatism this is recommended for all sheets not just the ones within 300 feet of the MRL.

Cells for EL -20 Option

For this option, cells will be closer to the MRL. It is assumed that soil conditions for Reach 3 to be representative, although no borings are in the river in this area. The elevation of the cut in this area is to EL -30, or 20 feet above the grade for the EL -40 option. Soil at this elevation in Reach 3 are clays with undrained shear strength of about 400 to 600 psf which are worse than conditions for the EL -50 cut where stiffer soils are present. Again, by inspection bearing capacity in the clays above the coarse point bars sands would not be satisfactory.

Consequently, it is recommended that these cells within 300 feet of the levee also extend to EL -100 into the dense sands for bearing capacity. Extending to the sand will also improve sliding resistance and other modes of failure. Refer to Figure 9-1 for cells that should extend to EL -100.

Construction Considerations

Dewatering of the cofferdams is vital for stability and therefore Eustis recommends that dewatering be included in the estimates. The two referenced case histories also included active dewatering inside the cells.

If soft clays are present in the river, they should be removed within the cells down to the stiffer clays and sands near EL -40. Further analysis after exploration in this area will determine the need for this. Most of these soft clays will likely be removed for constructability.

Driving of sheets this long (117.5 feet) may be difficult, although sheets of roughly this length were successfully driven for the two case histories noted. Pre-excavation, jetting, impact driving or other measures may be needed. Sheets should have a minimum thickness of ½ inch to improve drivability.

The contractor will have to evaluate stability and interlock tension during various phases of construction. These depend on his method and sequence of construction and were not evaluated in these calculations. For example the highest interlock tension noted in the Locks and Dam 26 case history occurred during filling of the cells.

An instrumentation program to monitor cell movements and possibly interlock stresses during and after construction should be developed by the contractor to provide early warning of potential problems so that they can be mitigated before a serious problem could potentially develop.

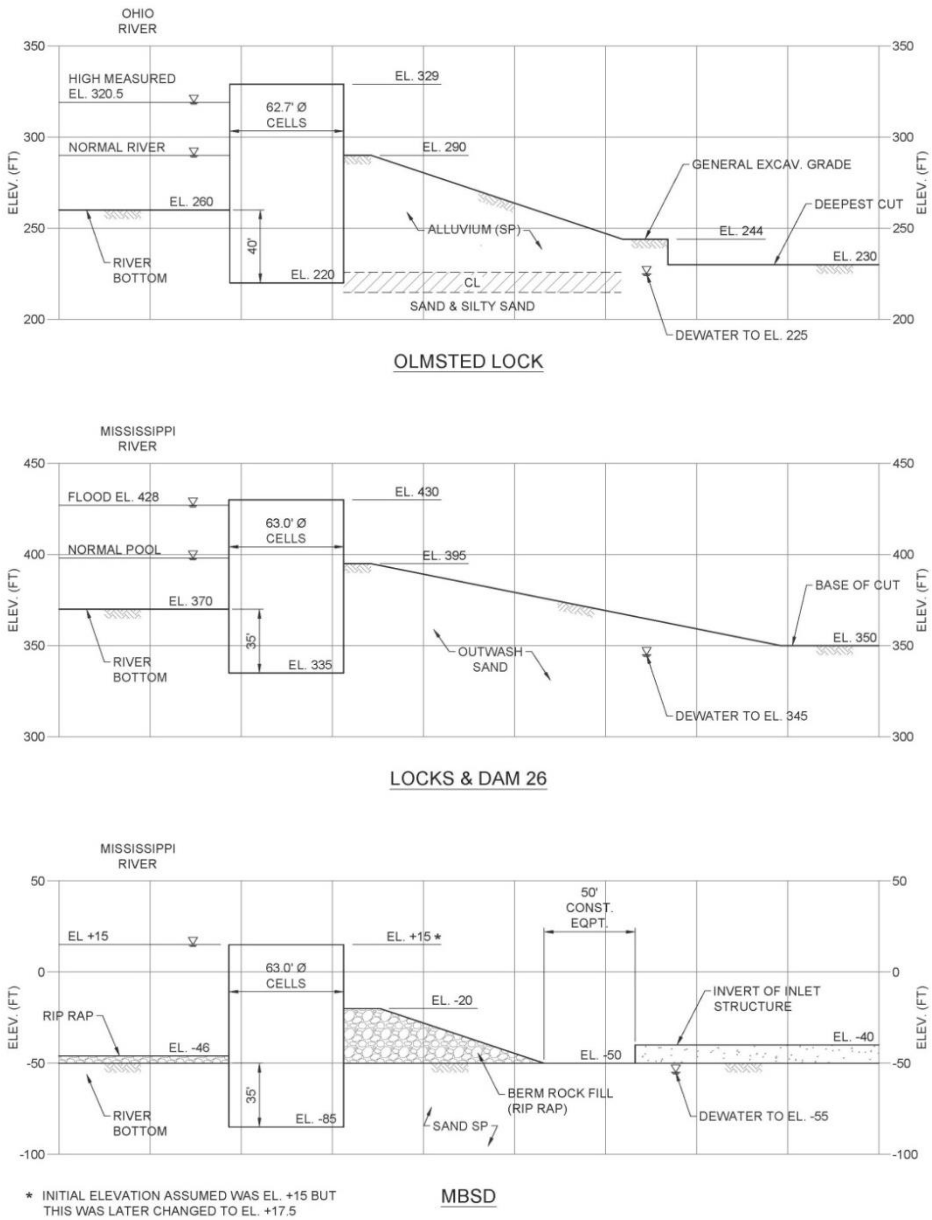


Figure 9-1: Comparison of Cofferdam Designs for Locks and Dam 26, Olmsted Lock and MBSD

9.13 Headworks Excavation Design and Dewatering (In-the-Wet)

9.13.1 Settlement of MRL Interim Levees during Construction

The DT performed settlement analyses for the MRL Interim levees using the settlement analysis program SETTLE 3D by RocScience, Inc. Vertical stresses were computed using Westergaard solutions. Soil consolidation parameters were based on soil consolidation and index tests presented in the Soil Delineation Report for Soil Reaches 4 and 5. The MRL Interim levees will serve as the Conveyance Channel levees after construction, therefore, the settlement analyses for the MRL Interim levee are applicable to the Conveyance Channel levees in Soil Reach 5. Total settlement estimates account for consolidation, immediate, and secondary settlement. It is assumed immediate settlement as approximately 30% of the total consolidation settlement. This assumption is based on DT's experience with levee construction in similar geologic conditions.

The DT used wick drains in the analyses to expedite consolidation settlement during construction. The DT considered wick drains installed through the Holocene deposits and terminating in the Point Bar deposits at approximate EL -50 in Soil Reach 4 and EL -37 in Soil Reach 5. The assumed triangular wick drain spacing for DT's analyses is 5 feet. The DT assumed the levee will be constructed in multiple 6-foot lifts with each lift occurring during a 6-month period. The DT performed iterative time-rate settlement analyses for determination of the levee overbuild required to maintain the levee design elevation for a period of 4 years after the end of levee construction. The DT provides a summary of the MRL Interim levee parameters in Table 9-10, the results of the settlement analyses in Table 9-11, and the settlement calculations in **Appendix G**.

Table 9-10: MRL Interim Levee Parameters

Soil Reach	Station Nos.	Existing Ground Surface EL (NAVD88)	Top of Levee Design EL (NAVD88)	Total Height of Fill Placement at Centerline of Levee (feet)	Number of Lifts during Construction	Construction Duration Assuming 6 Months per Lift
Reach 4	30+00 to 35+00	4	16.0	14.5	3	1.5
Reach 5	35+00 to 48+00	3	16.0	15	3	1.5

Table 9-11: Conveyance Channel Levee Settlement Summary

Soil Reach	Top of Levee Design EL (NAVD88)	Levee Overbuild EL at End of Construction (NAVD88)	Total Ground Surface Settlement at End of Construction (feet)	Total Ground Surface Settlement Occurring 4 Years after End of Construction (feet)
Reach 4	16.0	17.0	1.5	0.7
Reach 5	16.0	17.0	1.0	0.6

9.13.2 Mississippi River Interim Levee Stability

The DT performed stability analysis of the Conveyance Channel to evaluate potential modes of failure and establish critical water levels in the channel. All stability analyses use undrained shear strength (Q-case) parameters for cohesive materials and drained (S-Case) parameters for cohesionless materials following Spencer's Method of Slices. This method satisfies moment/force equilibrium and include non-circular and circular searches. Analyses were performed with GEO-SLOPE International, Ltd.'s program SLOPE/W 2016, Version 8.16, using root-method searches (i.e., non-linear algorithms). All critical circular and non-circular slip surfaces were optimized, and tension cracks filled with water were modeled to eliminate negative interslice forces (i.e., base and shear) and negative normal forces at the base of individual slices. The DT's stability analyses were performed in accordance with Section 3.5.1 of the Design Criteria Report.

The proposed bottom of the head works excavation is at EL -25 for the graving site (Soil Reach 5) and EL -50 at the gated structure and intake areas (Soil Reach 4). Design grade for the interim MRL is at EL 16.0 with 4H:1V side slopes. To determine the allowable slopes for the HW excavation, the assumed the interim MRL will be constructed while the excavation is dewatered to approximately 5 feet below the bottom of the excavation. A minimum required Factor of Safety of 1.30 was considered during construction. The allowable excavation slopes for each component of the HW excavation are shown in Table 9-12.

Table 9-12: Stability Results of Headworks Excavation Slopes

SOIL DESIGN REACH	GROUND SURFACE EL (NAVD88)	EXCAVATION BOTTOM EL (NAVD88)	EXCAVATION SLOPE	FACTOR OF SAFETY
4[1]	4	-50	6.5H:1V	1.34
5	3	-25	5.5H:1V	1.31

[1] DT considered both ML and CL soil types between el -10 and -34 for stability analyses.

The DT performed global stability analyses of the interim MRL with respect to the dewatered HW excavation considering a levee construction overbuild at EL 17. Strength gain of the foundation soils due to consolidation was considered for the interim MRL stability analyses. The DT discusses the methodology used for strength gain computations in Section 9.16.3. The results of the global stability analyses for the interim MRL and dewatered HW excavation are presented in Table 9-13.

Table 9-13: Interim MRL Global Stability Results –Excavation Dewatered

SOIL DESIGN REACH	EXCAVATION BOTTOM EL (NAVD88)	EXCAVATION SLOPE	INTERIM MRL CENTERLINE OFFSET FROM EXCAVATION TOE IN (FEET)	INTERIM MRL FLOODISDE TOE OFFSET FROM TOP OF EXCAVATION	FACTOR OF SAFETY
4[1]	-50	6.5H:1V	401	50	1.32
5	-25	5.5H:1V	252	103	1.32

[1] DT considered both ML and CL soil types between EL-10 and -34 for the analyses.

Part of the interim MRL constructed within Reach 5 will serve as the Conveyance Channel levee following the completion of HW construction. Deep soil mixing will be required to allow the interim MRL centerline to align with the future Conveyance Channel centerline while maintaining a 300-foot wide excavation bottom. The DT used deep soil mixing to EL -37 and extending 20 feet from the proposed top of HW excavation towards the interim MRL to provide a minimum Factor of Safety of 1.30 during construction. The DT assumed an improved shear strength value of 1,500 psf for soil mixing. The DT considered the global stability of the interim MRL as well as the local stability of the excavation. The results of the stability analyses of the interim MRL and dewatered HW excavation with soil mixing are presented in Table 9-14.

Table 9-14: Interim MRL Global Stability Results – Soil Mixing

SOIL DESIGN REACH	EXCAVATION BOTTOM EL (NAVD88)	EXCAVATION SLOPE	INTERIM MRL CENTERLINE OFFSET FROM EXCAVATION TOE (FEET)	INTERIM MRL FLOODISDE TOE OFFSET FROM TOP OF EXCAVATION (FEET)	FACTOR OF SAFETY	
					GLOBAL	LOCAL
5	-25	5.0H:1V	199	64	1.34	1.31

The HW excavation will be flooded after construction of the Intake Structure components and the interim MRL will need to meet a minimum stability Factor of Safety of 1.40 for flood protection. Eustis performed stability analyses for these cases considering water levels at EL 0.0(LWL) and EL 17 (top of levee). Deep soil mixing was used for the flood side analysis at Soil Reach 5. Below is a summary of these analyses on Table 9-15.

Table 9-15: Interim MRL Stability Results for Low Water Level and Flood Conditions

SOIL DESIGN REACH	SLIP SURFACE DIRECTION	EXCAVATION SLOPE	FLOOD SIDE WATER EL (NAVD88)	FACTOR OF SAFETY
4	Flood Side	6.5H:1V	0	2.08
	Protected Side	6.5H:1V	17	1.65
5	Flood Side	5.0H:1V	0	1.76
	Protected Side	5.0H:1V	17	1.52

9.13.3 Cellular Structure Buttress of Levee

The DT provided a concept for using cellular structures to serve as a buttress providing significant lateral support to the existing MRL during excavation for the gated structure. The 15% design did not further this concept from the geotechnical perspective. Cell design would include evaluations of MRL global stability, cell overturning and sliding to ensure the sheetpile tip penetrations below the bottom of excavations are adequate. Internal stability calculations such as vertical shear and hopp stress evaluations would also be required to size the sheeting and cell diameters. When site specific geotechnical data are obtained, the DT will discuss this concept with the CMAR.

9.13.4 Guide Levee Stability during Construction

The DT analyses performed for the interim MRL presented in Section 9.13.2 are applicable to the guide levees for the Conveyance Channel because the interim MRL design grade (EL 16) is approximately 0.4 feet higher than the Conveyance Channel levee design grade (EL 15.6). The DT has performed separate analyses to evaluate the Conveyance Channel levees for Soil Reach 5 which are presented in Section 9.16.

9.13.5 Seepage Analyses

Seepage analyses were performed for the interim MRL using Lane's Weighted Creep Ratio (LWCR). Soil Reach 4 was considered the critical case for seepage due to the presence of silt at approximately EL -10. The DT assumed water the interim MRL design grade (EL 16) for DT's analyses and analyzed multiple seepage paths through the foundation subsoils. Recommended minimum values for LWCR are 3 for clayey soils and 8.5 for silt[9]. Blanket theory performed in accordance with Appendix B of EM 1110-2-1913, Design and Construction of Levees and DIVR 1110-1-400, was used where the computed LWCR did not meet the recommended minimum values. Hydraulic conductivity data gathered from the previous exploration within Soil Reach 4 was used to develop parameters for blanket theory analysis. The results of DT's seepage analyses indicate that the interim MRL meets the required factors of safety for seepage and minimum recommended LWCR values. The DT provided seepage calculations in **Appendix G**.

[9] Lane, E. W., "Security from Under-seepage: Masonry Dams on Earth Foundations," Trans. Am. Soc. Civil Eng., vol. 100, p. 1257, 1935

Refined seepage analyses using blanket theory including SEEP/W (modeling) will be performed for the next phase and will include additional soil data collected during the field exploration.

9.14 Headworks (HW)

9.14.1 Piles Selection and Capacities

The DT computed allowable pile load capacities for the HW using methods outlined in Section 3.4.3 of the Project DCD. The DT analyzed 24, 36, and 48-inch open end pipe piles, 24-inch square precast concrete piles, and 14-inch H-piles using design parameters for Soil Reach 4. The top of piles and ground surface were assumed to be at EL -50. The DT provided the estimates of allowable pile load capacities and supporting calculations in **Appendix G**.

9.14.2 Global Stability

Global stability through the HW structure (i.e., pile supported gated structure) will be provided by the shear strength within the foundation soils underlying the structure. With an invert at EL -40, the likely bottom of concrete is at EL -50. The underlying soils are medium stiff to stiff clays interspersed with silts, sandy silt and silty sands. Once constructed, the HW structure will be designed to withstand the differential water across the structure that would be anticipated by a high river event. At this time, the DT's opinion is that the HW structure will satisfy the global stability requirements for Factor of Safety. This is considering the foundation soil types, the width of the structure (floodside to protected side dimension), and the supporting foundation piles. Once the additional geotechnical data is obtained and soil design parameters are verified, then a global stability analysis will be performed to verify that lateral forces do not need to be carried by the foundation piles to provide the required safety factors (often termed an "unbalanced load").

9.14.3 Underseepage Assessment/Permanent Cutoff

The DT's opinion is that the most severe seepage problems will be at the intake gate when the intake is closed and the river is at the design flood stage. The lowest completed grade will be EL -40, and the top of the coarse point bar below the gate is at about EL -90, or 50 feet below the finished concrete grade at the gate. For the same reasons stated in previous Section 9.12.3, The DT's opinion is that a seepage cutoff will probably be unnecessary for permanent seepage control. Seepage can be probably effectively controlled for the critical permanent construction case using a combination of permanent relief wells and aggregate drains. This design aspect will be carefully evaluated in the next phase of design after the results of current subsurface explorations and laboratory testing currently underway are known, together with the results of the pumping test contemplated on the coarse point bar sand stratum near the proposed gate. For this (future) evaluation, a 2D plan view numerical seepage model will be developed to evaluate seepage stability and to design seepage control measures for pressure relief. If these design analyses indicate that a seepage cutoff is necessary, a cutoff will be designed at that time. An advantage of using a pressure relief well system for permanent seepage control is that it can be designed to be pumped temporarily to provide the pressure relief needed for unwatering during gate maintenance.

9.14.4 Wing Walls at Transition Channel

The wing walls at the transition channel will consist of 14 T-Wall monoliths (T-1 through T-14) on each side of the channel. The T-Walls will start at Station 36+15 (T-1) and end at Station 42+00 (T-14) where it will tie into the Conveyance Channel levee. The protected side of the T-Walls will be backfilled to EL 2.

Design ground surface elevations on the flood side of the T-Walls vary from EL -40 at Monolith T-1 to EL 2 at Monolith T-14. Top of wall grade is EL 15.6.

The DT performed stability and seepage analyses on select T-Wall monoliths to evaluate unbalanced loads and required sheetpile tip elevations using methods outlined in Section 3.5.11 of the Project DCD using design parameters for Soil Reach 5. Due to the differential fill height between the protected side and flood side, the critical failure case occurs towards the flood side at Monolith T-1 when the water level in the channel is at EL 0.0. The DT computed an unbalanced load of 58.7 kips/ft for this case. To negate the unbalanced loads on Monolith T-1 and maintain a stability Factor of Safety of 1.40, the DT used deep soil mixing on the protected side of the T-Wall to EL -55 and extending 55 feet from the protected side edge of the T-Wall base. The DT assumed an improved shear strength value of 1,500 psf for soil mixing. Soil mixing will need to extend from Monolith T-1 through T-3 to reduce unbalanced loads to a practicable value. The DT provides a summary of the stability and seepage results performed for the T-Walls in Table 9-16 and the supporting calculations are provided in **Appendix G**.

Stability of the T-Walls should be considered for the various constructions stages to ensure the T-Walls are not subjected to excessive unbalanced loads during soil mixing operations and prior to flooding of the Conveyance Channel. This can be achieved by utilizing temporary stability berms on the flood side and/or braced excavations. Analyses will be performed to evaluate T-Wall stability throughout construction after the T-Wall construction sequence is developed with the contractor.

Table 9-16: Stability and Seepage Results for Transition T-Walls

Monolith No(s).	Flood Side Ground Surface EL (NAVD88)	Base Width (feet)	Bottom of Base Design EL [with 2-foot Working Pad] (NAVD88)	Required Sheetpile Tip EL for Seepage (NAVD88)	Stability Factor of Safety	Unbalanced Load (lbs)	Comments
T-1	-37	31	-49	-107	1.40	58700	Stability towards Flood Side
					1.44	0	Soil mix to 55 feet from T-Wall to EL -55
					1.30	0	Construction Case: 3,000 psf surcharge load required on flood side to negate unbalanced loads during soil mixing.
T-2	-30	31	-44	Not performed	1.40	23500	Stability towards Flood Side
T-3	-25	31	-39	Not performed	1.40	3000	Stability towards Flood Side
T-4	-18	31	-34	-92	1.87	0	Stability towards Flood Side
T-6	-11	24	-22	-62	Not performed	0	
T-9	-1	15	-14	-52	Not performed	0	
T-11 to T-14	2	15	-7	-52	2.14	0	Stability towards Protected Side

The DT computed allowable pile load capacities for the wing walls using methods outlined in Section 3.4.3 of the Project DCD. The DT analyzed various sizes of open end pipe piles with the top of piles at EL -3 and EL -49 using design parameters for Soil Reach 5. The DT provides estimates of allowable pile load capacities and supporting calculations in **Appendix G**.

9.15 Conveyance Channel Slope Stability

The DT performed stability analysis of the Conveyance Channel to evaluate potential modes of failure and establish critical water levels in the channel. All stability analyses use undrained shear strength (Q-case) parameters for cohesive materials and drained (S-Case) parameters for cohesionless materials following Spencer's Method of Slices. This method satisfies moment/force equilibrium and includes non-circular and circular searches. Analyses were performed with GEO-SLOPE International, Ltd.'s program SLOPE/W 2016, Version 8.16, using root-method searches (i.e., non-linear algorithms). All critical circular and non-circular slip surfaces were optimized, and tension cracks filled with water were modeled to eliminate negative interslice forces (i.e., base and shear) and negative normal forces at the base of individual slices. DT's stability analyses were performed in accordance with Section 3.5.1 of the Project DCD.

The DT performed stability analyses of the proposed 4H:1V channel side slopes using soil design parameters presented in the Soil Delineation Report for Soil Reaches 5 through 8. The bottom of channel is at EL -25. The stability analyses considered two water levels within the Conveyance Channel: water at EL 0.0 simulates in-the-wet excavation of the channel and water at EL -25 simulates in-the-dry excavation of the channel. Porewater pressures were defined using a piezometric line in the Slope/W program. Seepage forces and transient pore water pressures were not considered for these analyses. The table below summarizes the results of the stability analyses of the Conveyance Channel side slope excavations. The DT provides stability calculations in **Appendix G**.

Table 9-17: Conveyance Channel Excavation Stability Results

WATER ELEVATION IN CHANNEL (NAVD 88)	CHANNEL SIDE SLOPES	MINIMUM FACTOR OF SAFETY					
		REACH 5	REACH 6	REACH 7	REACH 7A	REACH 7B	REACH 8
0	4H:1V	2.16	2.81	1.99	2.43	2.61	1.24
-25	4H:1V	1.09	1.38	0.99	1.22	1.17	0.58

Staged excavations and stability berms are necessary to maintain a minimum Factor of Safety 1.30 during excavation of the Conveyance Channel with 4H:1V side slopes. The DT performed analyses for three excavation stages as outlined below using design parameters for Soil Reaches 5, 7, and 8. The staged excavation results for Soil Reach 7 are considered applicable to Soil Reaches 6, 7A, and 7B.

Stage 1: The Conveyance Channel is excavated in-the-dry to the depth which maintains a minimum Factor of Safety 1.30 with a 4H:1V side slope. Stage 1 excavation details and results are provided on Figure 9-2 and Table 9-18.

Stage 2 The Conveyance Channel is excavated in-the-dry to EL -25 utilizing a stability berm at the toe of the Conveyance Channel slope to maintain a minimum Factor of Safety of 1.30 for global and local stability. Stage 2 excavation details and results are provided on Figure 9-3 and Table 9-19.

Stage 3 The Conveyance Channel is flooded prior to excavating the stability berm. Stage 3 excavation details and results are provided on Figure 9-4 and Table 9-20.

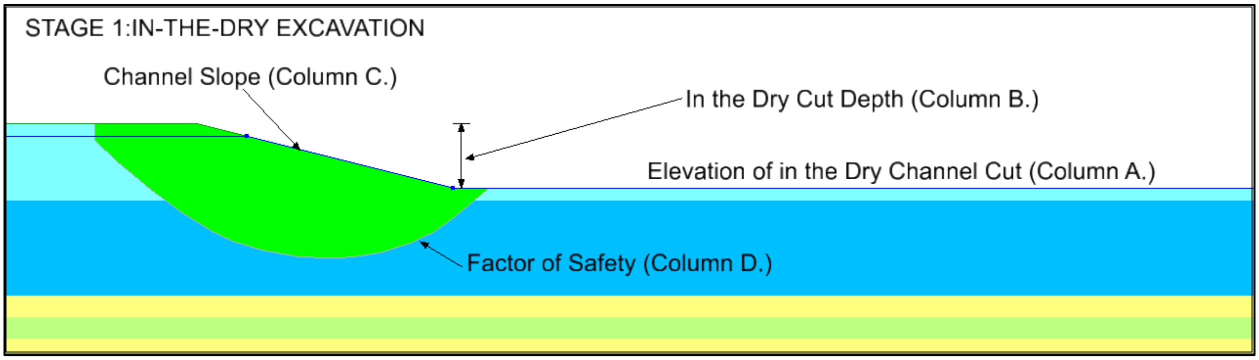


Figure 9-2: Stage 1 Conveyance Channel Excavation

Table 9-18: Stage 1 Conveyance Channel Excavation Results

SOIL DESIGN REACH	GROUND SURFACE EL (NAVD88)	A	B	C	D
		IN-THE-DRY EXCAVATION EL (NAVD88)	IN-THE DRY DEPTH OF EXCAVATION (FEET)	IN-THE-DRY CHANNEL SIDE SLOPES	FACTOR OF SAFETY
5	3	-12	15	4H:1V	1.34
7	0	-14	14	4H:1V	1.32
8	-3	-10	7	4H:1V	1.32

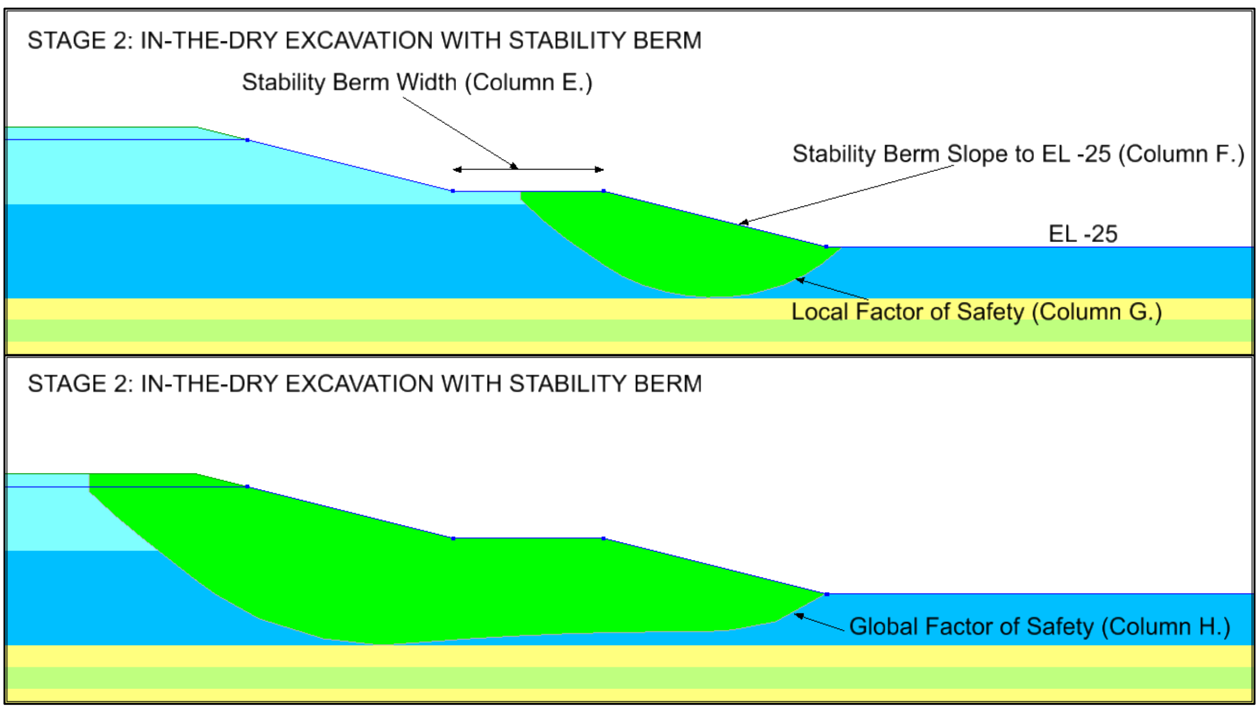


Figure 9-3: Stage 2 Conveyance Channel Excavation

Table 9-19: Stage 2 Conveyance Channel Excavation Results

SOIL DESIGN REACH	GROUND SURFACE EL (NAVD 88)	E	F	G	H
		STABILITY BERM WIDTH IN FEET	STABILITY BERM SLOPES	FACTOR OF SAFETY	
				LOCAL	GLOBAL
5	3	35	4H:1V	1.99	1.34
7	0	20	4H:1V	1.94	1.34
8	-3	65	7H:1V	1.32	1.32

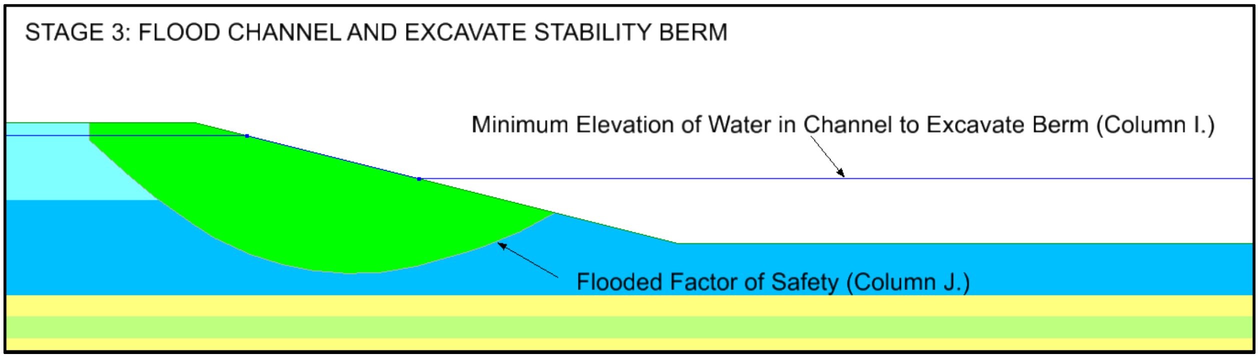


Figure 9-4: Stage 3 Conveyance Channel Excavation

Table 9-20: Stage 3 Conveyance Channel Excavation Results

SOIL DESIGN REACH	GROUND SURFACE EL (NAVD88)	I	J
		MIN. WATER EL IN CHANNEL TO EXCAVATE STABILITY BERM (NAVD88)	FACTOR OF SAFETY
5	3	-10	1.31
7	0	-12	1.31
8	-3	-7.5	1.31

9.16 Conveyance Channel Levee

The Conveyance Channel Levee (CCL) system is composed of two levees along each side of the Conveyance Channel which acts as a guide for the channel during operation and flood protection during high water or flood events. Settlement, slope stability, and seepage analyses for the CCL were performed. CCL design grades at EL 13 and EL 15.6 with side slopes of 4H:1V were analyzed. The centerline of the CCL will be offset approximately 150 feet from the edge of the Conveyance Channel. Iterative analyses to compute settlement, strength gain of the foundation soils, overbuild elevation of the levee, and evaluate stability were performed.

9.16.1 Slope Stability Analyses

The DT performed stability analysis of the CCL to evaluate potential modes of failure and establish critical water levels in the channel. All stability analyses use undrained shear strength (Q-case) parameters for cohesive materials and drained (S-Case) parameters for cohesionless materials following Spencer's Method of Slices. This method satisfies moment and force equilibrium, and include non-circular and circular searches. Analyses were performed with GEO-SLOPE International, Ltd.'s program SLOPE/W 2016, Version 8.16, using root-method searches (i.e., non-linear algorithms). All critical circular and non-circular slip surfaces were optimized and tension cracks filled with water were modeled to eliminate negative interslice forces (i.e., base and shear) and negative normal forces at the base of individual slices. DT's stability analyses were performed in accordance with Section 3.5.1 of the Design Criteria Report.

The DT performed stability analyses for the CCL at Soil Reaches 5, 7, and 8. The results for Soil Reach 7 should be considered applicable to Soil Reaches 6, 7A, and 7B. The CCL overbuild crown elevations were used in the analyses for levee design grades at EL 15.6. The DT did not consider resistance contribution from geosynthetic fabric or slope armoring. In addition, seepage forces and transient porewater pressures were not considered. The stability cases analyzed and results of the analyses are summarized in Table 9-21. The DT analyzed these cases for end-of-construction (EOC) conditions considering a minimum Factor of Safety of 1.30.

Table 9-21: Conveyance Channel Levee Stability Results

SOIL DESIGN REACH	STABILITY CASE	CCL CROWN EL (NAVD88)	WATER EL IN CHANNEL (NAVD88)	FACTOR OF SAFETY
5	Levee failure towards flood side with water at EL 0.0 (LWL)	16.6	0	1.59
	Bank failure towards flood side with water at EL 0.0 (LWL)	N/A	0	2.16
	Levee failure towards protected side with water at top of levee	16.6	16.6	1.60
7	Levee failure towards flood side with water at EL 0.0 (LWL)	17.7	0	1.51
	Bank failure towards flood side with water at EL 0.0 (LWL)	N/A	0	1.99
	Levee failure towards protected side with water at top of levee	17.7	17.7	1.85
8	Levee failure towards flood side with water at EL 0.0 (LWL)	18.9	0	1.32
	Bank failure towards flood side with water at EL 0.0 (LWL)	N/A	0	1.40
	Levee failure towards protected side with water at top of levee	18.9	18.9	1.32

The DT performed stability analyses based on the settlement and strength gain estimates to maintain a minimum Factor of Safety for stability of 1.30 during construction. When necessary, the DT extended the duration of the stage prior to placing the final lift to allow additional strength gain and meet minimum Factor of Safety requirements for stability. This iterative procedure was used to develop the stage loading times presented in Table 9-22. The DT anticipates strength gain induced by the final lift will increase stability factors of safety to the minimum value required during operations and flood events. Refined analyses will be performed during the next stage of the project using soil data obtained during the field exploration.

Note, strength gain calculations for the MRL Interim Levee at Soil Reach 5 were used for the stability analyses of the CCL at Soil Reach 5. The MRL Interim Levee design grade is at EL 16 which may be considered applicable for the CCL design grade at EL 15.6. The DT considered this reasonably equivalent for the 15% level of design.

9.16.2 Settlement Analyses

The DT performed settlement analyses for the CCL using the settlement analysis program SETTLE 3D by RocScience, Inc. Vertical stresses were computed using Westergaard solutions. Soil consolidation parameters were based on soil consolidation and index tests presented in the Soil Delineation Report for Reaches 7 and 8. The DT has assumed the settlement analyses for Reach 7 are applicable for the Conveyance Channel Reaches 6, 7A, and 7B. Total settlement estimates account for consolidation, immediate, and secondary settlement. The DT assumed immediate settlement due to lateral spread as approximately 30% of the total consolidation settlement. The DT based this assumption on the experience with levees being constructed on soft marsh deposits in Louisiana. The DT modeled immediate settlement in SETTLE 3D using typical elastic modulus (Es) values for each soil type and consistency in the model.

The DT used wick drains in the DT's analyses to expedite consolidation settlement during construction. The DT considered wick drains installed through the Holocene deposits to approximate EL -115 using a triangular wick drain spacing of 5 feet. The DT assumed the levee will be constructed in multiple 6-foot lifts with each lift occurring during a 6-month period. The DT performed iterative time-rate settlement analyses for determination of the levee overbuild required to maintain the levee design elevation for a period of 10 years after the end of levee construction. The DT provides a summary of the CCL parameters in Table 9-22 and the results of the settlement analyses Table 9-23.

Table 9-22: Conveyance Channel Levee (CCL) Parameters

Soil Reach	Station Nos.	Existing Ground Surface EL (NAVD88)	Top of Levee Design EL (NAVD88)	Total Height of Fill Placement at Centerline of Levee (feet)	Number of Lifts during Construction	Construction Duration (Years) Assuming 6 Months per Lift
Reach 7	48+00 to 85+00	0	13.0	19	4	2
			15.6	22	5	2.5
Reach 8	85+00 to 140+00	-3	13.0	30	5	2.5
			15.6	34	6	4 (1)

(1) Time between the final two lifts was extended to 1.5 years to satisfy slope stability requirements.

Table 9-23: Conveyance Channel Levee Settlement Summary

Soil Reach	Top of Levee Design EL (NAVD88)	Levee Overbuild EL at End of Construction (NAVD88)	Total Ground Surface Settlement at End of Construction (feet)(1)	Total Ground Surface Settlement Occurring 10 Years after End of Construction (feet)(2)
Reach 7	13.0	15.8	3.2	2.2
	15.6	17.7	4.3	1.9
Reach 8	13.0	18.5	8.5	5.2
	15.6	18.9	12.1	3.0

(1) These values represent the total settlement experienced over the construction period from the fill placed above the existing ground surface to achieve the constructed top-of-levee grade.
(2) These values represent the settlement predicted at the levee crown that will be experienced 10 years after the end of construction. These values do not include any settlement experienced during construction.

9.16.3 SHANSEP/Stage Construction

The consolidation-induced gain in strength of foundation soils due to the placement of the CCL following the Stress History and Normalized Soil Engineering Properties (SHANSEP) method outlined by Ladd and Foott, 1974 was estimated. The relationship between the undrained shear strength of a soil, the effective vertical stress, and the over-consolidation ratio of the soil is defined as,

$$\frac{S_u}{\sigma'_v} = S(OCR)^m \qquad (9.17.3\text{-}1)$$

where

S_u = undrained shear strength
σ'_v = effective vertical stress
S = undrained strength ratio
OCR = over consolidation ratio
m = empirical exponent

The over consolidation ratio is defined as the ratio of the maximum vertical stress a soil has experienced to the current vertical stress,

$$\frac{\sigma'_p}{\sigma'_v} = OCR \qquad (9.17.3\text{-}2)$$

where

σ'_p = past maximum vertical effective stress

The undrained strength ratio for the soils encountered at the MSBD site is estimated as 0.22, as discussed in the Delineation of Soil Parameters report. The empirical exponent is 0.8 for the DT's analyses. The SHANSEP equation may be rearranged to solve for OCR. Using the rearranged SHANSEP equation and the parameters discussed above, the DT computed the initial OCRs for each soil strata using the shear strengths presented in the Delineation of Soil Parameter report and the in-situ vertical effective stress.

The DT used the RocScience Inc. program, SETTLE 3D to compute changes in effective vertical stress due to consolidation at the center of each foundation soil strata. Vertical stress distributions were computed using the Westergaard solution within the SETTLE 3D program. The improved undrained shear strength estimated for each foundation soil sublayer was computed by applying the increase in vertical effective stress beneath the CCL and change in OCR due to newly induced loads.

As discussed in Section 9.17.2 of this report, the DT assumed staged construction of the CCL in 6-foot soil lifts. The allowable thickness of each lift will be estimated in the next phase of the project. Six-foot lifts were assumed to simplify the settlement analyses. The DT anticipates the actual lift thickness will vary for each Soil Design Reach based on the bearing capacity of the foundation soils.

The critical stability case for the staged construction process is immediately after the placement of the final lift. In this instant, the levee crown is at its highest elevation prior to foundation soils experiencing consolidation-induced strength gain from the final lift. The DT estimates strength gain based on consolidation of the foundation soils during the second-to-last construction lift with the CCL crown at its respective overbuild elevation for each soil reach. The DT evaluated strength gain at various locations within the CCL cross-section which include the edge of the stability berms, the center of the stability berms, the center of the CCL slopes, and the center of the CCL crown. In-situ soil strengths were assumed at the edge of the stability berm. Strength gain calculations are provided in **Appendix G**.

9.16.4 Wick Drain Assessment

Settlement analyses considers the use of wick drains to accelerate consolidation to induce strength gains of the Holocene-Era deposits beneath the CCL. Wick drains may experience folding or kinking due to the anticipated vertical and lateral settlement of the CCL within Reaches 7 and 8. An instrumentation program should be implemented to monitor pore pressures and settlement during CCL construction. If excess pore pressures are unable to dissipate as estimated, it may become necessary to install wick drains for the CCL a second time to allow remaining excess pore pressures to dissipate. Instrumentation observations will determine if this secondary wicking of the foundation soils will be necessary.

9.16.5 Borrow Pit Excavations

The DT has performed slope stability analyses to optimize proposed borrow pit geometries with respect to the CCL at Soil Reaches 7 and 8. The CCL at Soil Reaches 7 and 8 requires the most fill, therefore, the DT has only performed the borrow pit analyses for these soil reaches. The results for Soil Reach 7 may be conservatively applied to Soil Reach 5 and 6.

The excavations of on-site borrow pits are expected to occur during the construction of the CCL. Local stability of the borrow pit excavations were assessed to provide recommended excavation slopes and bottom elevations for the borrow pit. The DT provides multiple safe excavation slopes that correspond with different bottom elevations. Depending on right-of-way requirements, there may be a borrow pit geometry that is more desirable in terms of total volume of fill available. Note, the side slopes and excavation bottom elevation that the DT presents are not dependent on the CCL, and therefore may be applied to any excavation performed within the limits of Soil Reaches 7 and 8 that meet the minimum offset requirements from the CCL as discussed herein. The DT considered a minimum required Factor of Safety of 1.30 for the local stability analyses of the borrow assuming this is a temporary condition during construction. The results of the analyses are presented in Table 9-24.

Table 9-24: Local Stability Results for Borrow Pit Excavation

SOIL REACH	EXCAVATION SLOPE	EXISTING GROUND SURFACE EL (NAVD88)	BOTTOM OF EXCAVATION EL (NAVD88)	DEPTH OF EXCAVATION (FEET)	FACTOR OF SAFETY
7	4H:1V	0	-14	14	1.3
	6H:1V	0	-30	30	1.34
8	4H:1V	-3	-10	7	1.31
	7H:1V	-3	-12	9	1.31
	10H:1V	-3	-30	27	1.35

During construction of the CCL, the DT has assumed the borrow pit will remain fully dewatered and the Conveyance Channel will not be subject to flood loading until after construction is complete. The critical global stability case for the CCL with respect to the borrow pit occurs at the end of construction when the CCL crown is at the final overbuild elevation. The DT provides minimum offset distances for the borrow pit from the toe of the protected side CCL stability berm which is governed by the critical global stability case at the end of construction. The DT considered a minimum required Factor of Safety of 1.30

for global stability of the CCL and borrow pit because this is a temporary condition during construction. The results of the analyses are presented in Table 9-25.

Table 9-25: Global Stability Results for Borrow Pit Excavation at End of Construction

SOIL REACH	CCL CROWN EL AT END OF CONSTRUCTION (NAVD 88)	WATER EL IN CHANNEL (NAVD 88)	BORROW PIT OFFSET DISTANCE FROM BERM TOE (FEET)	FACTOR OF SAFETY
7	17.7	0	30	1.32
	17.7	0	30	1.34
8	18.9	0	70	1.3
	18.9	0	80	1.32
	18.9	0	130	1.36

The DT assumed borrow pit excavations will be flooded after construction of the CCL. During the operational life of the channel, the critical global stability analysis for the CCL with respect to the borrow pit occurs when the Conveyance Channel water level is at the top of levee crown. The DT considered a minimum Factor of Safety of 1.40 for global stability of the CCL failing towards the borrow pit during highwater conditions. The results of the analyses are presented in Table 9-26.

Table 9-26: Global Stability Results for Borrow Pit Excavation during Highwater Conditions

SOIL REACH	WATER EL IN CHANNEL (NAVD 88)	FACTOR OF SAFETY
7	15.6	1.82
	15.6	1.90
8	15.6	1.72
	15.6	1.73
	15.6	1.83

9.16.6 Seepage Analyses

Seepage analyses were performed for the CCL using Lane's Weighted Creep Ratio (LWCR). Soil Design Reaches 7 and 8 were considered due to the presence of silt at approximately EL -15 for Reach 7 and EL -27 for Reach 8. The DT assumed water at the top of the project grade of the levee, EL 15.6, for the DT's analyses and analyzed multiple seepage paths through the foundation subsoils. Recommended minimum values for LWCR are 3 for clayey soils and 8.5 for silt[10]. Blanket theory performed in accordance with **Appendix** B of EM 1110-2-1913, Design and Construction of Levees and DIVR 1110-1-400, was used where the computed LWCR did not meet the recommended minimum values. Hydraulic conductivity data gathered from the previous exploration for ML soils was used to develop parameters for blanket theory analysis. The results of the seepage analyses indicate that the CCL meets the required factors of safety for seepage and minimum recommended LWCR values. Seepage calculations are included in **Appendix G**. Refined seepage analyses using blanket theory will be performed for the next phase and will include additional soil data collected during the field exploration.

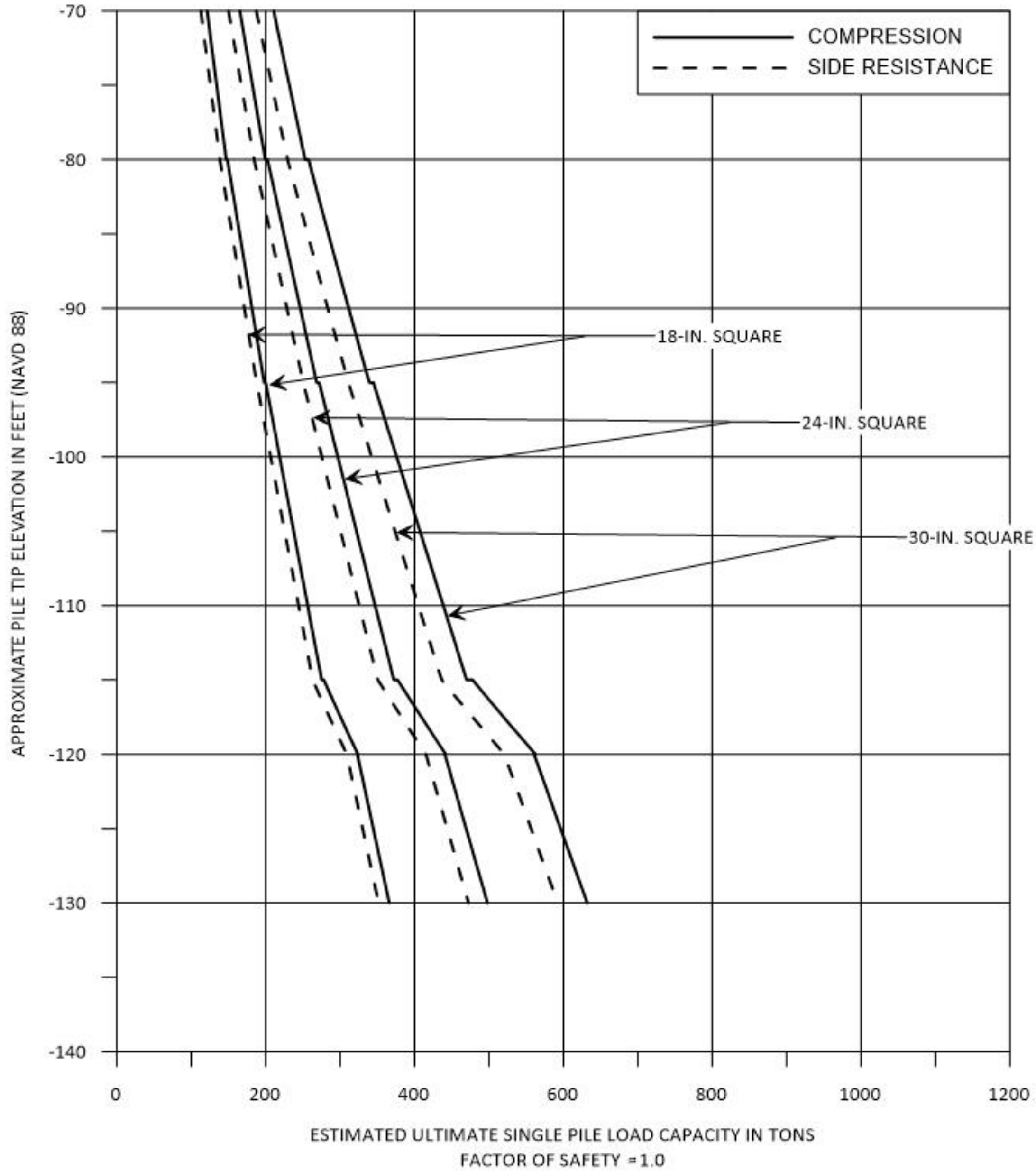
[10] Lane, E. W., "Security from Under-seepage: Masonry Dams on Earth Foundations," Trans. Am. Soc. Civil Eng., vol. 100, p. 1257, 1935

9.17 Hwy 23 Bridge

The Hwy 23 Bridge will be located at approximate Station 65+00. The bridge will span the guide levees and Conveyance Channel. Currently 16 bents spaced on 128-foot centers are envisioned for support of the bridge. We anticipate abutment settlement will require pile support transition slabs to limit settlement. Design and construction of the bridge will conform to standard requirements of the Louisiana Department of Transportation and Development. The bridge lies entirely in generalized Soil Reach 7 and parameters developed for this reach as described in the Delineation of Soil Parameters Report were used for analyses.

9.17.1 Piles Capacities

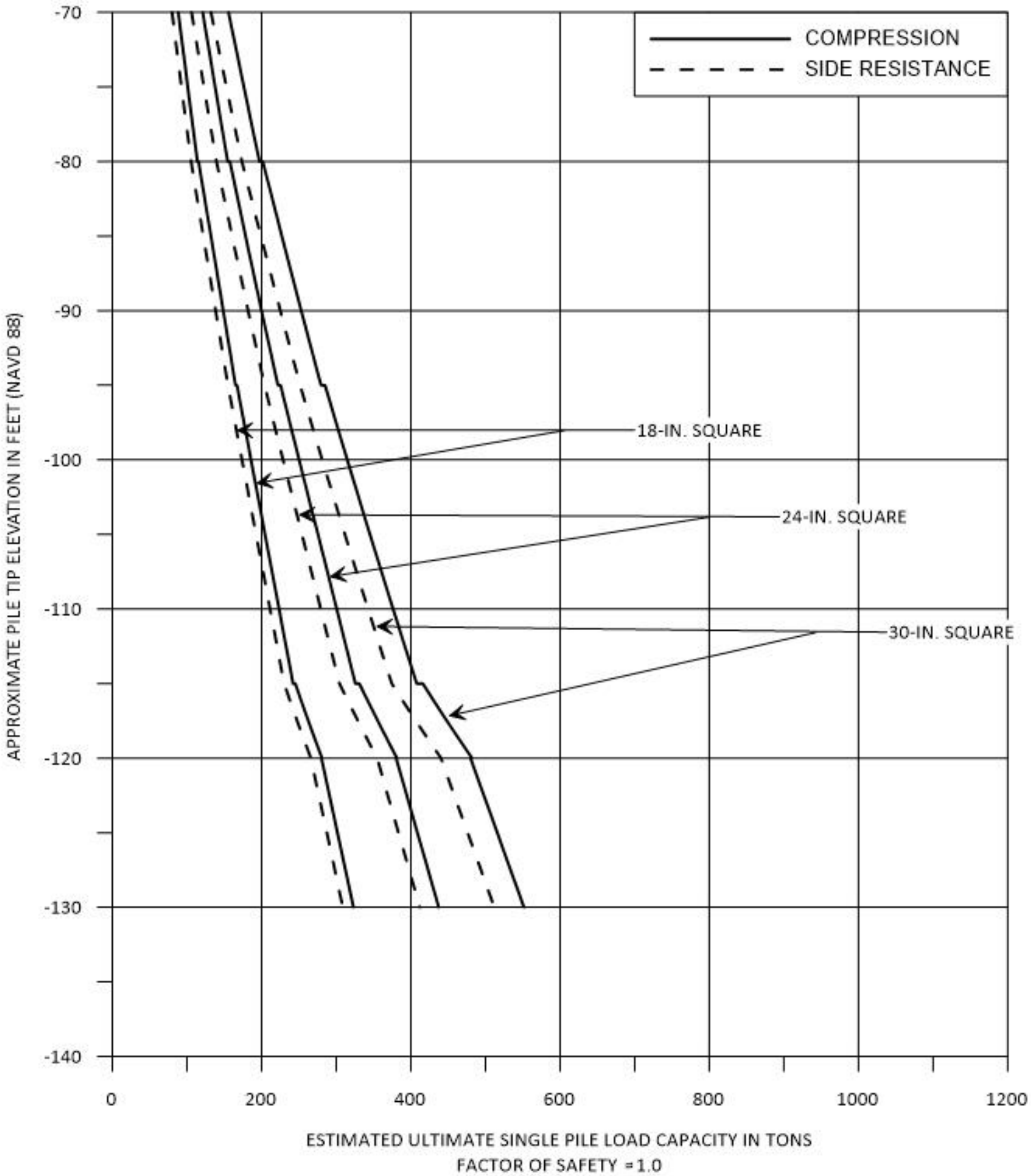
We computed ultimate pile load capacities for the bridge using methods outlined in Section 3.4.3 of the Project Design Criteria using LRFD procedures. Specifically, we used the computer program DrivenPiles 1.3.6. Factors of safety will be established considering the laboratory test data, static pile test program, and dynamic tests performed during construction as indicated by the LRFD requirements. Unfactored capacities were computed for 18, 24, and 30-inch square precast concrete (SPC) piles for support of the bridge structure and treated ASTM D25 timber piles for the transition approach slabs. Pile capacities for SPC piles are shown on Figure 9-5 for piles located at existing grade (el 0) and on Figure 9-6 for piles located in the Conveyance Channel at EL -25. Table 9-28 tabulates timber pile capacities for the abutments at EL 0.0. The calculations are presented in **Appendix G**.



NOTES:

1. ULTIMATE PILE LOAD CAPACITIES PRESENTED ON THIS FIGURE DO NOT INCLUDE THE WEIGHT OF THE PILES.
2. PILES ASSUMED TO BE INSTALLED BY IMPACT DRIVING EQUIPMENT WITHOUT ASSISTANCE FROM VIBRATORY EQUIPMENT.
3. ULTIMATE PILE LOAD CAPACITIES COMPUTED USING DRIVENPILES 1.3.6 SOFTWARE.
4. APPROPRIATE LRFD RESISTANCE FACTORS SHOULD BE APPLIED TO THE ULTIMATE PILE CAPACITIES.
5. ULTIMATE PILE LOAD CAPACITIES DO NOT ACCOUNT FOR SCOUR.

Figure 9-5: Hwy 23 Bridge Ultimate Pile Load Capacities for SPC Piles with Ground Surface at EL 0.0



NOTES:

1. ULTIMATE PILE LOAD CAPACITIES PRESENTED ON THIS FIGURE DO NOT INCLUDE THE WEIGHT OF THE PILES.
2. PILES ASSUMED TO BE INSTALLED BY IMPACT DRIVING EQUIPMENT WITHOUT ASSISTANCE FROM VIBRATORY EQUIPMENT.
3. ULTIMATE PILE LOAD CAPACITIES COMPUTED USING DRIVENPILES 1.3.6 SOFTWARE.
4. APPROPRIATE LRFD RESISTANCE FACTORS SHOULD BE APPLIED TO THE ULTIMATE PILE CAPACITIES.
5. ULTIMATE PILE LOAD CAPACITIES ON THIS FIGURE DO NOT ACCOUNT FOR SCOUR.

Figure 9-6: Hwy 23 Bridge Ultimate Pile Load Capacities for SPC Piles with Ground Surface at EL -25

Table 9-27: Hwy 23 Ultimate Pile Load Capacities for Treated Timber Piles with Ground Surface at EL 0

TAPERED PILE DIAMETERS	PILE TIP EMBEDMENT BELOW GROUND SURFACE IN FEET (1) (2)	PILE TIP EL (NAVD 88)	ESTIMATED ULTIMATE SINGLE PILE LOAD CAPACITIES IN TONS (3) (4) (5) (6) (7)	
			COMPRESSION	SIDE RESISTANCE
8-Inch Tip 12-Inch Butt Timber	30	-30	16 ½	16
7-Inch Tip 12-Inch Butt Timber	40 50	-40 -50	22 ½ 29	22 29 ½
7-Inch Tip 13-Inch Butt Timber	60 70	-60 -70	39 48 ½	38 47 ½

Notes:
1. Selection of pile tip embedment should also consider settlement potential.
2. Ground surface assumed to be at EL 0.0.
3. These estimated capacities do not include limitations on structural capacity as imposed by some building codes.
4. Piles assumed to be installed by impact driving equipment without assistance from vibratory equipment.
5. Ultimate pile capacities computed using DrivenPiles 1.3.6 software.
6. Appropriate LRFD resistance factors should be applied to the ultimate pile capacities.
7. Ultimate pile load capacities do not account for scour.

9.17.2 Scour requirements

Scour protection will be provided throughout the Conveyance Channel, between the top of the channel and the levee toe, and up the levee slope. Therefore, scour was not considered for the piles located within the confines of this scour protection.

9.17.3 Abutment Settlement

Preliminary calculations estimate settlement at the Conveyance Channel edge of the transition ramps to be 12 to 16 inches. The results of these settlement calculations are included in **Appendix G**. Therefore, we will consider utilizing a pile supported transition slab, a preload surcharge, or a combination of these options. A surcharge will likely be a viable, economical option because wick drains will be used for the guide levees in this area.

9.17.4 Pavement Recommendations

The pavement section for Hwy 23 is anticipated to be 2 inches of Superpave asphaltic concrete wearing course on 2 inches of Superpave binder course, with 9 inches of asphaltic concrete base course on 12 inches of Class II base course. Shoulders are anticipated to be 4 inches of Superpave asphaltic concrete. Pavement components for the north and south haul roads and levee access roads will be 2 inches of Superpave asphaltic concrete wearing course on 2 inches of Superpave asphaltic concrete binder course. Embankments for Hwy 23, the bridge ramps, the levee access roads, and the haul roads will meet the material and construction standards describe in Section 203 of the Louisiana Standard Specifications for Roads and Bridges (LSSRB), 2016 Edition.

9.17.5 T-Wall Design

The T-Walls at the Hwy 23 Bridge will consist of five monoliths (T-1 through T-5) on each side of the Conveyance Channel at Station 65+00. The ground surface on the protected is at EL 0.0 and the ground surface on the flood side is at EL 3. Top of wall grade is EL 15.6. Braced excavations will be used to construct the T-Walls and these stability analyses will be performed after the T-Wall construction sequence is developed with the contractor.

The DT performed stability and seepage analyses for the T-Wall monoliths with the flood side water level at EL 15.6 to evaluate unbalanced loads and required sheetpile tip elevations using methods outlined in Section 3.5.11 of the Project DCD using design parameters for Soil Reach 7. A summary of the stability and seepage results performed for the T-Walls in Table 9-28 and the supporting calculations are provided in **Appendix G**.

Table 9-28: Stability and Seepage Results for Hwy 23 T-Walls

Monolith No(s).	Protected / Flood Side Ground Surface EL (NAVD 88)	Base Width (feet)	Bottom of Base Design EL [with 2-foot Working Pad] (NAVD 88)	Required Sheetpile Tip EL for Seepage (NAVD 88)	Stability Factor of Safety	Unbalanced Load (lbs)
T-1 to T-5	0 / 3	15	-10	-37	1.66	0

The DT computed allowable pile load capacities for the Hwy 23 T-Walls using methods outlined in Section 3.4.3 of the Project DCD. The DT analyzed various sizes of open end pipe piles with the top of piles at EL 10 using design parameters for Soil Reach 7. Estimates of allowable pile load capacities and supporting calculations in **Appendix G**.

9.18 Conveyance Channel Guide Levee Closures of Canals

The final configuration of the CCL will require closures of Timber Canal at approximate Station 113+50 and the NOV Back-levee Canal at approximate Station 140+00. The NOV Back-levee Canal has an invert elevation at approximate EL -10 which is deeper than the Timber Canal invert at approximate EL -7. The DT performed stability analyses for the critical case at the NOV Back-levee Canal.

9.18.1 Settlement Considerations

The CCL at the canal closures will have similar cross-section dimensions as the Soil Reach 8 CCL. Therefore, the settlement analyses provided for the CCL at Soil Reach 8 are considered applicable for the canal closures. Detailed settlement analyses considering the filling of the canals will be performed for the next phase and will include additional soil data collected during the field exploration.

9.18.2 Stability

The DT performed stability analysis of the Conveyance Channel to evaluate potential modes of failure and establish critical water levels in the channel. All stability analyses use undrained shear strength (Q-case) parameters for cohesive materials and drained (S-Case) parameters for cohesionless materials following Spencer's Method of Slices. This method satisfies moment/force equilibrium and include non-circular and circular searches. Analyses were performed with GEO-SLOPE International, Ltd.'s program SLOPE/W 2016, Version 8.16, using root-method searches (i.e., non-linear algorithms). All critical circular and non-circular slip surfaces were optimized, and tension cracks filled with water were modeled to eliminate negative interslice forces (i.e., base and shear) and negative normal forces at the base of individual slices. Stability analyses were performed in accordance with Section 3.5.1 of the Design Criteria Report.

The DT evaluated stability of the levee into the canal considering the canal invert at EL -10. The canal closure requires the placement of 300 feet of geosynthetic reinforcement placed beneath a sand working pad. The DT recommended a woven geosynthetic with a minimum tensile strength of 5,000 lbs/ft at 5% strain. The DT also recommended 200-ft wide sand working pad be placed at the levee centerline with the top of sand at EL -3. The DT assumed uncompacted clay fill will be placed beyond the sand fill in the canal to EL -3. Uncompacted clay fill placed to EL -3 is required to extend an additional 100 feet beyond the protected side stability berm to meet a minimum Factor of Safety of 1.30 during construction. Strength gain parameters computed for the Soil Reach 8 CCL and the deformed shape of the levee based on settlement results for the Soil Reach 8 CCL were modeled in the analyses. Results of the stability analyses in Table 9-29 and calculations are provided in **Appendix G**.

Table 9-29: Stability Results of Canal Closure Levee Section during Construction

Description of Analyses	Water Level in Conveyance Channel (NAVD88)	Minimum Factor of Safety Computed
Levee failure towards flood side at LWL	0	1.31
Bank failure towards flood side at LWL	0	1.34
Levee failure towards protected side with water at top of levee	18.9	1.34
Levee failure towards protected side with water at levee design grade	15.6	1.41

The DT anticipates strength gain induced by the final levee lift will increase stability factors of safety to the minimum value required during operations and flood events. Refined analyses will be performed during the next stage of the project using soil data obtained during the field exploration.

9.18.3 Seepage Considerations

The canal closure levee cross-section will have a sand core at the levee bottom for the canal closure case. The DT performed seepage analyses for the CCL at Soil Reach 8 which are presented in Section 9-16. Based on the Soil Reach 8 CCL seepage results, the DT does not anticipate an underseepage issue due to the addition of the sand core in the levee section. Detailed seepage analyses using blanket theory will be performed for the next phase and will include additional soil data collected during the field exploration.

9.19 Siphon

The inverted Siphon at Timber Canal will be located at Station 113+50. Construction of the inverted Siphon will precede construction of the Conveyance Channel levee to maintain water flow of Timber Canal during construction of the Conveyance Channel levee.

9.19.1 TRS Requirements for Installation

The DT performed analyses to evaluate temporary braced excavations for the pipes at approximate Station 113+50 using design parameters for Soil Reach 8. The DT assumed the Conveyance Channel excavation will be completed prior to performing excavations for the Siphon pipes. The stability berms at the toe of the Conveyance Channel excavation should remain in place during the installation of the sheet piling for the retaining system. The DT's analyses were performed in accordance with Section 3.5.8 of the DCD using the software CWALSHT from the US Army Corps of Engineers Waterways Experiment Station Information Technology Laboratory version date 2003/05/02. To limit sheet pile lengths to 90 feet, the DT used anchor supports and degrading near the Siphon excavation. Eustis presents the results of the analyses in Table 9-31 and the calculations are in **Appendix G**.

Table 9-30: Results of Temporary Retaining Structure for Siphon Excavation

Anchored Condition	Top of Wall EL (NAVD 88)	Ground Surface EL (NAVD 88)	Excavation EL (NAVD 88)	Required Sheetpile Tip EL (NAVD88)	Anchor EL (NAVD 88)	Anchor Force (Lbs/ft)	Maximum Moment (Lbs-ft/ft)
Anchored	-15	-15	-33	-94	-17	14,853	172,050
Anchored	-25	-25	-42	-81	-25	7,766	65,715
Cantilever	-25	-25	-42	-112	N/A	N/A	418,810

The anchored case with the ground surface at EL -15 is applicable from the edge of the Conveyance Channel to the intake and outlet structures of the Siphon and requires a 12-foot cut to EL -15 to reduce the height of retained soil. The cut to EL -15 should extend 50 feet from the sheetpile wall then slope to the existing ground surface at a 1V:7H slope. The anchored and cantilever cases the ground surface at EL -25 are applicable within the Conveyance Channel excavated to EL -25. The DT does not anticipate seepage being an issue for the TRS because the required sheetpile tip elevations are deeper than interbedded silt layer at Soil Reach 8. A detailed seepage assessment of the excavation and TRS will be performed for the next phase of the project and will include additional soil data collected during the field exploration. The DT recommends hot-rolled sheet piles be specified for seepage control through the interlocks.

The structural engineer should review the estimated anchor force and maximum applied moment when selecting a sheet pile section. The DT considered one anchor location for the TRS analyses for the BOD Phase of the project. The DT will refine the analyses for the next phase to include multiple anchor points which may reduce the required tip elevation, anchor forces, and applied moment for the TRS sheet piles.

9.19.2 Settlement at Guide Levees

The DT evaluated settlement of the Siphon Intake Structure and pipe located beneath the Conveyance Channel levee assuming the Intake Structure is supported by 70-ft long timber piles. The Conveyance Channel settlement analyses for Reach 8 was used for evaluation of the Siphon structures. The DT estimated pile downdrag settlement at the channel side of the pile-supported Intake Structure to be more than 4 feet and differential settlement across the Intake Structure to be more than 3 feet. The DT estimated settlement of the pipe beneath the Conveyance Channel levee to be approximately 12 feet due to the subsoils consolidating from the load induced by the levee. The DT will provide settlement calculations for the Siphon structures in **Appendix G**.

The DT recommends implementing a T-Wall system near the Siphon structure due to the large settlement estimates of the Siphon structures induced by construction of the levee. In addition, void spaces may develop beneath the Intake Structure due to near surface soils consolidating beneath a pile-supported structure. A T-Wall system will reduce settlement of the Siphon structures to a tolerable level.

9.19.3 Pile Capacities

The DT computed allowable pile load capacities for the Siphon using methods outlined in Section 3.4.3 of the Project DCD. The DT analyzed various sizes of Class B timber piles with the top of pile at EL -11. Estimates have been provided of allowable pile load capacities and supporting calculations in **Appendix G**.

9.19.4 Seepage Assessment

The DT performed seepage analyses for the proposed T-Wall sheetpile cutoff using LWCR to provide a minimum sheet pile tip elevation for seepage cutoff. The DT assumed flood water at the top of the T-Wall at EL 15.6 and tail water at EL -10 within the Siphon Intake and outlet structures and considered multiple seepage paths through the foundation subsoils. The DT recommends a minimum sheetpile tip at EL -40 to provide a minimum LWCR of 3 and adequate seepage cutoff of the potential interbedded silt between EL -27 and EL -33 encountered in CPT NL-1C. The DT will provide seepage calculations in **Appendix G**. The DT will perform detailed blanket theory analyses for the next phase of the project and will include additional soil data collected during the field exploration.

9.20 Outfall Transition Feature

9.20.1 General

The Outfall Transition Feature or Outfall Channel is considered the area on the basin side of the existing NOV Levee that transitions the Conveyance Channel to the natural ground within the basin. The design of the Outfall Channel considers two primary functions. The first and primary feature is the slope transition between the Conveyance Channel and the natural ground within the basin to reduce the head loss. The analysis is performed with hydraulic models and includes an iterative process to optimize the transition. The second feature provides scour protection near the NOV Levees and the transition channel.

9.20.2 Stability of Excavated Slopes

The DT performed stability analyses of the Outfall Channel to evaluate the potential failure of the channel excavation. All stability analyses use undrained shear strength (Q-case) conditions for cohesive materials and drained (S-Case) parameters for cohesionless materials following Spencer’s Method of Slices, which satisfies moment and force equilibriums. The DT’s analyses include non-circular and circular searches. These analyses were performed with GEO-SLOPE International, Ltd.’s program SLOPE/W 2016, Version 8.16, using root-method searches (i.e., non-linear algorithms). All critical slip surfaces were optimized, and tension crack lines filled with water were modeled to eliminate negative interslice forces (i.e., base and shear) and negative normal forces at the base of individual slices. Porewater pressures were defined using a piezometric line in the Slope/W program. Seepage forces and transient porewater pressures were not considered for these analyses. The DT’s stability analyses were performed in accordance with Section 3.5.1 of the Design Criteria Report.

The DT evaluated the stability of the Outfall Channel slope into the Conveyance Channel with invert at EL -25. The DT analyses considered water levels within the excavation and Conveyance Channel at EL -25 to simulate the in-the-dry excavation of the channel and water at EL -3 (existing grade in the Outfall Area) to simulate the in-the-wet condition of the channel. The DT developed an allowable slope of 1V:10H for the Outfall Channel. The results of the analyses are presented in Table 9-31.

Table 9-31: Outfall Channel Stability Results

Outfall Channel Slopes	Water Level in Conveyance Channel (NAVD88)	Minimum Computed Factor of Safety	Required Factor of Safety
1V:10H	-25	1.40	1.30 (During Construction)
	-3	4.00	1.40 (During Operation)

The DT will refine the analyses to model the proposed rip-rap base of the channel for the next phase of the project and will include additional soil data collected during the field exploration program. The DT anticipates that future analyses will yield adequate factors of safety based on the BOD Phase results. Calculations for the Outfall Channel stability are presented in **Appendix G**.

The DT performed stability analyses of the Outfall Channel to evaluate the potential failure of the channel excavation. All stability analyses use undrained shear strength (Q-case) conditions for cohesive materials and drained (S-Case) parameters for cohesionless materials following Spencer's Method of Slices, which satisfies moment and force equilibriums. The DT's analyses include non-circular and circular searches. These analyses were performed with GEO-SLOPE International, Ltd.'s program SLOPE/W 2016, Version 8.16, using root-method searches (i.e., non-linear algorithms). All critical slip surfaces were optimized, and tension crack lines filled with water were modeled to eliminate negative interslice forces (i.e., base and shear) and negative normal forces at the base of individual slices. Porewater pressures were defined using a piezometric line in the Slope/W program. Seepage forces and transient porewater pressures were not considered for these analyses. The DT's stability analyses were performed in accordance with Section 3.5.1 of the Design Criteria Report.

The DT evaluated the stability of the Outfall Channel slope into the Conveyance Channel with invert at EL -25. The DT's analyses considered water levels within the excavation and Conveyance Channel at EL -25 to simulate the in-the-dry excavation of the channel and water at EL -3 (existing grade in the Outfall Area) to simulate the in-the-wet condition of the channel. The DT developed an allowable slope of 1V:10H for the Outfall Channel. The results of the analyses are presented in Table 9-32.

Table 9-32: Outfall Channel Stability Results

Outfall Channel Slopes	Water Level in Conveyance Channel	Minimum Computed Factor of Safety	Required Factor of Safety
1V:10H	-25	1.40	1.30 (During Construction)
	-3	4.00	1.40 (During Operation)

The analyses to model the proposed rip-rap base of the channel for the next phase of the project and will include additional soil data collected during the field exploration program will be refined. It is anticipate that future analyses will yield adequate factors of safety based on the BOD Phase results. Calculations for the outfall channel stability are presented in **Appendix G**.

Stability analyses of the Outfall Channel to evaluate the potential failure of the channel excavation was performed. All stability analyses use undrained shear strength (Q-case) conditions for cohesive materials and drained (S-Case) parameters for cohesionless materials following Spencer's Method of Slices, which satisfies moment and force equilibriums. The analyses include non-circular and circular searches. These analyses were performed with GEO-SLOPE International, Ltd.'s program SLOPE/W 2016, Version 8.16, using root-method searches (i.e., non-linear algorithms). All critical slip surfaces were optimized, and tension crack lines filled with water were modeled to eliminate negative interslice forces (i.e., base and shear) and negative normal forces at the base of individual slices. Porewater pressures were defined using a piezometric line in the Slope/W program. Seepage forces and transient porewater pressures were not considered for these analyses. Stability analyses were performed in accordance with Section 3.5.1 of the Design Criteria Report.

The stability of the Outfall Channel slope into the Conveyance Channel with invert at EL -25. Analyses considered water levels within the excavation and Conveyance Channel at EL -25 to simulate the in-the-dry excavation of the channel and water at EL -3 (existing grade in the Outfall Area) to simulate the in-the-wet condition of the channel will be evaluated. An allowable slope of 1V:10H for the Outfall Channel was developed. The results of analyses are presented in Table 9-33.

Table 9-33: Outfall Channel Stability Results

Outfall Channel Slopes	Water Level in Conveyance Channel	Minimum Computed Factor of Safety	Required Factor of Safety
1V:10H	-25	1.40	1.30 (During Construction)
	-3	4.00	1.40 (During Operation)

Analyses to model the proposed riprap base of the channel for the next phase of the project will be refined and will include additional soil data collected during the field exploration program. Future analyses will yield adequate factors of safety based on the BOD Phase results will be anticipated. Calculations for the outfall channel stability are presented in **Appendix G**.

9.21 Development of Erodibility Flume Testing Program

During the BOD, the DT identified a few SMEs who have expertise in the field of soil erodibility due to water flows in coastal areas. We engaged Prof. Kehui Xu, PhD of LSU because of his local expertise in this research area. The DT has begun discussions with Professor Xu to develop a flume test program that is versatile and mobile. We are considering topics such as 1) reviewing the adequacy of existing borings planned in the basin (Borings OF-1 to OF-6) for use in the testing; 2) considering soil erodibility of existing, in-situ basin sediments versus sediments that will be deposited once the MBSD project is operational; and 3) developing a SedFlume testing apparatus that covers the appropriate range of flows and corresponding shear stresses. This flume testing program will be used for MBSD and could potentially be a resource for other diversion projects.

9.22 Risk of Faulting

The DT reviewed a document published by members of the New Orleans Geological Society that discusses the presence of faulting in the vicinity of the MBSD project area, notably the Ironton Fault. According to this document, "Episodic or slow fault creep may occur without the induction by or the creation of seismicity". Due to the limited evidence based on historical mapping, this document advocates for 3D seismic surveys or high resolution 2D imaging to refine our understanding of faults. According to the researchers, additional seismic mapping will enhance our ability to quantify the risk associated with faulting on the planned infrastructure for the MBSD project, in addition to a better understanding of the subsidence impacts in the outfall basin. The DT is currently in communication with several potential SMEs and will engage one SME to serve as the principal investigator for this task in the 30% design. Another goal of the testing program is to establish a correlation between the flume test results and standard geotechnical testing (moisture content, Atterberg limits, sieve/hydrometer tests, undrained shear strength testing) such that these standard test results can be used as a proxy for basin erodibility.

10. STRUCTURAL ENGINEERING OF HYDRAULIC STRUCTURES

10.1 General

The DT performed a preliminary design of many structural components identified in the 2014 Basis of Design provided by CPRA for the BOD Phase. The individual Design Team members, their design tasks, and status of those tasks are provided in Table 10-1 below. Alternatives beyond the 2014 BOD were developed in an attempt to further improve sediment delivery, address possible cost savings (construction and life-cycle), and adjust to concurrent hydraulic modeling. Throughout the BOD Phase, designs were evaluated jointly by the DT and CPRA to focus attention on specific alternatives and put others on hold.

Table 10-1: Structural DT, Tasks and Status

Structure	Design Firm	Status
Intake Structure In-the-dry	WSP	Selected and progressing
Intake Structures In the-wet	WSP	On hold per Workshop No. 2
Intake Training Walls	AECOM	Selected and progressing
Gated Diversion Structure	AECOM	Tainter gated selected per Diversion Gate Study, structure progressing
MRL Tie-in Walls	TBS	EL 16.4 primary, EL 20.1 alternative
Transition Walls	TBS	EL 15.6 progressing, EL 12.1 alternative
Floodwalls at Hwy 23	TBS	EL 15.6 progressing, EL 12.1 alternative
Siphon	Principal	Selected and progressing
Back Structure	GISE	Eliminated at Workshop No. 1
Pump Station at Bayou Chenier		Eliminated by Siphon Alternative based on Cost.

10.2 References and Publications

All references used are listed in Section 5.1 of the Project DCD (**Appendix U**).

10.3 Design Approach

Hydraulic structures are designed in accordance with USACE Engineering Manuals and HSDRRS design guidance. The Headworks, all River tie-in options, floodwalls and the Siphon are all considered to be hydraulic structures. LRFD methods are applied to concrete structures in accordance with ACI 318-14 and load factors and detailing are per EM 1110-2-2104. The use of the EM criteria, as stated in Paragraph 3.6 of the EM 2104, precludes the need to check crack control. However, to assure durability, in the next design phase tension stresses shall be calculated to assure cracking is minimal. LRFD steel design is in accordance with AISC Manual of Steel Construction, 14th Ed., and load factors are per ETL 1110-2-584. All hydraulic structures are pile founded. At this time pile designs use the ASD method; however, future designs may use a LRFD process. The DT has chosen a small number of load cases to examine for each structure's preliminary design based on engineering judgement of typical governing conditions.

It is anticipated that the structure geometry may be revised to meet future requirements and changes to design water elevations but the structure type and design approach likely will not change.

Concept designs for Interim Structures are provided by the DT but final designs shall be the responsibility of the CMAR. All CMAR designs shall be reviewed by the DT.

10.4 River Intake Designs

10.4.1 Intake U-Frame Design Alternatives

The intake structures are designed to guide sediment flows into the diversion. Of the four alternative designs investigated, the open channel exhibited the best hydraulic properties. The Open Channel option consists of two primary structures. The primary structure is a reinforced concrete U-Frame with invert at EL -40 and a top-of-wall EL 16.4. This U-shaped structure extends from the Gated Intake into the river approximately 550 feet. The second feature is a set of flared training walls that continue towards the river centerline. These walls are inverted pile-founded T-Walls that step up in elevation gradually to follow the contour of the MRL. An alternative with Top Wall elevations increased to EL 20.1 was included for just the Open Channel Intake. This change only affected structures that form the line of protection along the River.

The selection of this structure was driven primarily by the hydraulic characteristics of the intake geometry and bolstered by lower anticipated costs, adaptability of the system, and the robustness of the structure. Because the selected intake does not extend significantly into the Mississippi River, it is likely that the site can be dewatered within a cofferdam (See Section 9) and therefore, conventional in-the-dry construction methods can be used.

10.4.2 Codes and Standards

See **Appendix U** – DCD, for Codes and standards used on the MBSD Project.

10.4.3 Options Investigated

Several options were evaluated from a conceptual standpoint. Prior to this BOD phase the dimensions and elevation of the intake were hydraulically unproven, the type of construction was unknown, and the viability of constructing a cofferdam that could extend a significant distance into the Mississippi River was in question. As such, conceptual options were evaluated for a variety of construction methodologies, sizes, configurations and elevations. The four primary concepts investigated included the following:

- Open Channel at EL -40: This is the chosen option described above.
- U-Frame at EL -40 With Interior Walls: In this option the U-Frame is constructed to the existing EL -40 contour in the riverbed, resulting in a significantly longer primary structure. The 1,150 foot long intake channel was divided into three bays of equal width and stepped down the wall height towards the river end of the structure.
- U-Frame at EL -40 Without Interior Walls: This option matches the previous U-Frame geometry but excludes the center walls (only one center bay).
- Submerged Culvert at EL -40: This option is a 1,150 foot long closed culvert extending from the river opening to the gate structure. The culvert geometry varies in height and width to maintain a constant opening area; the height at the river end was limited by navigation clearance concerns.

For the primary options summarized above, in-the-wet construction methods were evaluated for the U-Frame and the Submerged Culvert. The driver for evaluating the in-the-wet methods was the viability of constructing and dewatering a cofferdam extending far into the Mississippi River. For the Open Channel Option in-the-wet was not considered because the required cofferdam did not protrude significantly out into the River. It has since been determined that constructing and dewatering a cofferdam sufficient for the in-the-dry construction of the Open Approach is viable, the training walls that extend riverward will be constructed within a braced excavation or use the lift-in method of construction.

Variations of the above were modeled and structural plans developed. Other intake options evaluated included more rudimentary, pro-rated designs for the following:

- Open Channel at EL -50
- U-Frame at EL -20 without interior walls
- Submerged Culvert at EL -50
- Open Channel at EL-20
- Open Approach at EL -40 with top of wall at EL 20.1

10.4.4 In-the-dry Methodology

When a cofferdam can be properly constructed and dewatered without excessive difficulty, permitting issues, negative impact on navigation, or possible increases in flood levels, it is believed that in-the-dry construction methods will provide the most cost-effective and robust intake structure. The design and construction are conventional and there is a very knowledgeable labor force able to perform the work. Beyond the cofferdam construction the work will primarily consist of pile driving and reinforced concrete construction. Protective structures will also be required to prevent vessel impact to the cofferdam.

10.4.4.1 Critical Loadings

There are three primary loading cases that will govern the design of the in-the-dry structures, summarized in the table below.

Table 10-2: In-the-Dry Methodology Critical Loading Stages Summary

Construction Stage/Load Case	Design Considerations
Construction	• Mass concrete applications and thermal crack control • Maximum pile loads due to the absence of uplift effects
Service	• Hydrostatic forces from riverine and hurricane flood events • Ship / Barge / Debris impact • Abrasion of flowing water • Backfill soil loading • Scour of foundation soils
Maintenance Dewatering	• Unbalanced hydrostatic and backfill forces • Uplift due to buoyancy

In sections that are to be dewatered it should be noted that the structure will essentially transform from a net downward loading with relatively balanced water pressure to a net upward loading with high unbalanced water pressure that cause tensile forces on piles and upward moments on structural members. As such, the final design will carefully evaluate the necessity of dewatering the structure and which parts of the structure require dewatering. For the preliminary designs it was assumed that for the Open Channel and U-Frame the sections inboard of the MRL would need to be dewatered while those outboard would not. For the submerged culvert, it was assumed that the entire structure would need to be dewatered.

10.4.4.2 Cofferdam

A large cellular cofferdam would be required for U-Frame or Submerged Culvert construction extending out into the river. Discussion of this retaining system is found in Section 9.12. Structural items that require design beyond the cofferdam itself are dolphins and protection cells to keep vessels away from the structure and a combiwall tie-in to the MRL.

The Open Channel option also requires a cellular cofferdam but it will enclose a significantly smaller area and protrude less into the river. The training walls can be constructed within a braced excavation (described in **Section 10.4.4.4.2**) or built using lift-in construction.

10.4.4.3 Toe Sheeting

The possible requirement of additional seepage cutoff protection within the cofferdam system is described in **Section 9.12**.

10.4.4.4 Open Channel Alternative

The Open Channel in-the-dry alternative uses a constant invert elevation at EL -40 and a consistent top of wall elevation at EL 16.4 for the U-Frame reach and stepped elevations for the Training T-Walls. The Training walls are not part of the flood protection system. The river end monoliths will be submerged.

The wall and slab thicknesses are governed by shear and flexural requirements in accordance with EM 2104 ; the pile design is governed by the construction case (axial compression) and the dewatered state (axial tension). In the dewatered state, the pile connections are required to resist uplift, which is achieved using pile embedment with tension hooks rebar configurations. A minimum pile embedment of one-foot is recommended so that there is sufficient tolerance in the top of pile elevation. While bending stress in the piles is not expected to govern the pile design, the pile stresses will be checked during final design assuming a fixed and pinned head condition. The potential lateral movement of the structure under any lateral loading will be checked assuming a pinned pile connection.

High capacity 48-inch diameter pipe piles, which derive their capacity from a combination of end bearing and skin friction, are used as the current foundation scheme for the Open Channel alternative. For the 15% level design, downdrag is not assumed to act on the piles but shall be included once the final grades are established. Additional pile types shall be investigated once the CMAR is under contract and the results of the recent soil borings are available.

Because the walls are cantilevered and resist relatively high loading, 3 layers of reinforcement are required in the current design. The U-Frame structures are currently designed to resist the dewatered condition, this load case governs wall design. The pile foundation was laid out to control the level of reinforcement in the base.
The primary benefits of this option are the use of conventional construction methods, length of piling and volume of concrete is significantly lower than other alternatives, and the option for maintenance

dewatering provides an increase in overall structure robustness and the possibility of increased longevity.

10.4.4.4.1 Training Wall Design

Inverted T-shaped retaining walls are designed for the Open Channel alternative using in-the-dry construction methods and channel EL -40. These walls are not floodwalls, rather, their purpose is to guide water towards the intake structure and restrict riverbank soils from filling in the channel. Two cross-sections are analyzed: one near the intake structure and one near the river end of the alignment. These two cross-sections are a representative sample of the highest and lowest backfill levels. Wall sections in between are interpolated between these two extremes. The primary load case for this level of design is an extreme high soil condition where siltation is assumed to have occurred behind the wall (on top of what is already the high soil side). The level of silting is set equal to the Normal River Stage of EL 5 as it seems possible for silt to build up to this level under normal operation conditions.

Thirty-six (36) inch diameter x ½ inch wall steel pipe piles are analyzed using CPGA with no allowable overstress. Both the pinned and fixed connection conditions are examined to ensure geotechnical pile capacity, structural pile capacity, and overall monolith deflection are within acceptable limits. Pile batters are limited to 6V:1H or steeper for large diameter piles to ensure piles do not interfere with the surrounding cofferdam system.

Concrete walls and slabs are sized for shear and moment forces. Reinforcement is not fully designed in this level of design but member size is checked to ensure required flexural reinforcement does not exceed the USACE limit of $0.25\rho_{bal}$ set in EM 1110-2-2104. The load case is considered Usual as per EM 1110-2-2104 resulting in an applied uniform load factor of 2.2. As per the Design Criteria, K_0 for all horizontal soil loads including the accumulated silt is 0.95. To reduce the amount of concrete used the wall stems are tapered, the walls are spot-checked at multiple elevations to ensure the taper does not result in a localized overstress.

10.4.4.4.2 Training Wall Cofferdam Design

Beyond the limits of the U-Frame structure the walls are constructed in isolated, braced excavations. The width of the braced excavation shall be sufficient to permit the driving of battered piles. It is assumed that the piles shall be driven in the wet with sufficient water pressure to eliminate heave. Prior to dewatering the braced excavation a seal slab will be placed to counter heave and minimize seepage. The seal slab shall also serve as a work platform. A cofferdam system will be built around the proposed open channel tie-in walls to dewater the area during construction. Two rectangular cells will be built with one around each wall alignment in order to limit the area being dewatered. The assumed construction process of both cofferdams is as follows:

1) AZ-46 sheets will be driven to approximately EL -64.
2) Soil areas within the cells will be excavated with water to remain inside the cells.
3) Piles are driven using the braced excavation as a template
4) A slurry seal will be installed at the bottom of the excavation to cut off seepage into the cell.
5) Water will be pumped out in stages. As the water is removed, W27x161 wales and 24-inch diameter x ½-in wall pipe struts will be installed. In total, there will be three vertical layers of waters and struts in each cofferdam.

The system has been designed using the soil information from Reach 3 and for an external top of soil elevation of EL -20. The water level outside of the cell is set at EL 8. It is assumed that the cell is dewatered to just below each strut level before the waler and strut is installed. The end monoliths could also use precast, lift-in units and avoid the braced excavation. The T-Wall base footprint would be excavated and piles driven in the low water season. A short sheet pile wall maybe required to minimize siltation of the prepared excavation.

10.4.4.5 U-Frame Alternative

The U-Frame in-the-dry alternative uses step-down walls ranging in top elevation from EL -20 at the outboard end to EL 16.4 at the Gated Structure. The top-of-wall elevations are determined by hydraulics analysis and consider the potential for vessel impact. Top-of-wall elevations can be adjusted during final design without significant additional structural analysis or study. The table below summarizes the sections that are assumed to be dewatered for maintenance. The design and purpose of the walls do not change except that the outboard sections are not designed for the dewatering load condition.

Table 10-3: Maintenance Dewatering Assumptions

Station From	Station To	Top of Wall EL	Design Assumption
22+10	24+20	EL -20	Not dewatered
24+20	26+30	EL -6	Not dewatered
26+30	28+40	EL 8	Not dewatered
28+40	33+50	EL 16.4	Dewatered

The design of the walls and invert of the outboard sections is governed by shear and flexural capacity by the soil backfill and structure self-weight. For the inboard sections that will be dewatered, their design is nearly identical to that of the Open Channel except for sections that encroach significantly beyond the MRL may need to be analyzed for scour in their final condition if not armored. A scour protection study will need to be performed during future design stages if this option is decided upon. The pile design is governed by the construction case where the structure is in-the-dry and not yet subjected to submerged buoyancy forces. The scour analysis may impact the length of the embedded piles but is not anticipated to change the loading on the base.

The piles are 48 inch diameter steel piles that derive their capacity from a combination of end bearing and skin friction are shown as the current foundation scheme for the U-Frame alternative. For the 15% level design, downdrag is not assumed to act on the piles. Alternative piles shall be investigated when new soil boring results are available and the CMAR is under contract.

The primary benefits of this option are the use of conventional construction methods and the ability to dewater the majority of the intake structure.

10.4.4.6 Submerged Culvert Alternative

The Submerged Culvert Alternative has a consistent EL -40 invert and constantly tapering roof and walls. Prior to performing the hydraulic modeling for this structure it was presumed that it would yield superior sediment-to-water ratios than the open approach methods and was therefore considered even though the roof would add weight and some construction complication. However, as outlined in Section 3, the Submerged Culvert did not present the expected sediment transport results and has a risk of becoming clogged. For these reasons it is excluded from further study. That being said, the concept was advanced to a level where a layout was created and approximate quantities could be estimated.

The outboard end width of the U-Frame is approximately 300 feet, which results in roof and floor spans of approximately 100 feet. This span length is infeasible when considering a dewatered condition that causes large hogging moments and shear forces on the spans. In order to make the spans work, it would need to be assumed that either no maintenance dewatering would occur or that intermediate walls would be acceptable from a hydraulics standpoint. It was determined that neither of these options are acceptable because there is a high risk of clogging, dewatering should be accounted for and the intermediate walls add an unacceptable amount of head loss to the system. Interior walls were included in the BODR to account for additional cost increases.

The following table summarizes the stations where additional intermediate walls would be required. These assumed wall layouts are used in the quantity calculations for this alternative.

Table 10-4: Submerged Culvert Layout Summary

Station From	Station To	No. Interior Walls	Overall Width (ft)	Interior Height (ft)
22+10	24+90	5	314 to 270	20 to 27
24+90	27+80	5	270 to 227	27 to 34
27+80	30+65	2	227 to 184	34 to 41
30+65	33+50	2	184 to 140	41 to 48

Beyond the negative aspects described previously, the wall and slab layout in the previous table show that significantly more concrete will be needed for this option. More concrete results in more weight, and therefore increases the foundation demand. Similar to the other options, a pile foundation consisting of 48 inch diameter steel piles will be used. For the 15% level design, downdrag is not assumed to act on the piles.

One difference in loading that the Submerged Culvert will experience is that of the soil backfill over the tunnel required for the MRL and the addition of a rail loading on top of the culvert. The train loading is not analyzed in this design phase for the Submerged Culvert but from preliminary analyses it should be assumed that minor structural modifications could accommodate this loading. If this alternative is revived in later design stages, the train loading should be assessed and accounted for.

10.4.5 In-the-Wet Methodology

In-the-wet construction methods provide an alternative means of construction. The deep riverward cofferdam can be avoided by constructing the concrete intake structure in a graving site and then floating the monoliths into place and submerging them on pre-driven piles. For the most outward elements that cannot be floated due to their limited wall height, they can be cast off-site, towed into place on a barge, and picked up and placed with a barge-mounted crane. Details and considerations for these methods and alternatives are explained below. ACI 350 and ACI 357 shall be used to design the float in sections. As such, crack control will most likely govern the base design.

10.4.5.1 Critical Loadings

The in-the-wet method requires that the monoliths be buoyant during transport, which will require the interior of each element be dry (i.e., to have a “bathtub” configuration). During this load case there will be unbalanced hydrostatic pressure on the outside of the element, causing significant hogging moment and shear forces on the invert, roof and exterior walls. Similarly, because there are such drastic differences in loading conditions during fabrication and transport compared to the final in-service condition, each construction stage needs to be carefully coordinated with the CMAR to ensure that each stage has a load case developed for which the elements can be designed accordingly. The following table presents several of the expected governing load cases.

Table 10-5: In-the-Wet Methodology Critical Loading Stages Summary

Construction Stage/Load Case	Design Considerations
Construction	• Mass concrete applications and thermal crack control • Stripping strength and creep of concrete after stripping
Transport	• Dynamic loading from waves and transports • Design of appurtenances for towing, lifting and temporary works • Buoyancy and draft • Water-tightness of bulkhead and temporary walls
Immersion	• Effect of bulkhead connections on structure • Maximum unbalanced hydrostatic forces on structure and longitudinal transference • Negative buoyancy and ballasting • Precision of placement and tolerances • Water-tightness of bulkhead and temporary walls
Joining	• End frame planar tolerances • Unbalanced hydrostatic force transferred longitudinally • Water-tightness of bulkhead and temporary walls • Water-tightness of gina-type seal
Service	• Hydrostatic forces from riverine and hurricane flood events • Ship / Barge / Debris impact • Abrasion of flowing water • Backfill soil loading • Scour of foundation soils • Maximum axial pile compression
Maintenance Dewatering	• Unbalanced hydrostatic and backfill forces • Uplift due to buoyancy

10.4.5.2 Flotation, Transport and Ballasting

After casting and installation of the temporary walls and bulkheads, the floating monoliths be buoyed with a draft sufficient to safely clear the shallowest water along the transport route and in the graving site. In addition, ballast (typically in the form of water tanks) will be required to immerse the elements by making them slightly negatively buoyant. With a slight negative buoyancy, the elements can be lowered and maneuvered into a precise location in a controlled manner. The Culvert and U-Frames can be made into a buoyant "bathtub" using end bulkheads that seal the water out during float-in and immersion. Their design is explained in subsequent sections.

For the U-Frame methods that have step-down walls, the use of temporary walls on lower wall sections (i.e., with final top of wall elevations below the construction WSE) is an economical way to place the majority of the U-Frame sections using the Floating Monolith concept. The Floating Monolith concept utilizes large pre-cast sections and only minimal in-water work, which should provide a robust means of delivering a quality product in challenging conditions. Where the wall sections are so low that the temporary walls become burdensome and costly (in this design, below EL -6), drop-in modular sections barged into place and assembled in-place will be used.

As noted previously, the condition where elements are immersed to their final location yet still dewatered inside is likely to govern many of the structural designs. In this condition, there is significant unbalanced hydrostatic force on the outside of the structure and virtually no interior pressure to counteract the force. For the purposes of flotation, ballasting, and buoyancy, the unit weights considered should be conservative enough such that a slight variation in concrete unit weight or in-situ water unit weight will not affect the floating, transport, and immersion process. Therefore, for example, the water unit weights for the ballast calculation required for immersion should consider mud-laden water with a higher unit weight, while the calculation of draft should consider relatively fresh water with a low unit weight. Field investigations should be undertaken during final design to confirm both concrete and water unit weights as shown in the following table:

Table 10-6: Unit Weights for Buoyancy

Material	Minimum Unit Weight (pcf)	Maximum Unit Weight (pcf)
Concrete	142	154
River Water	62.4	64.5

A careful accounting of weight balance including all structural steel and concrete as well as any temporary construction appurtenances (i.e. push-pull knees, bollards, etc.) shall be kept during final design and construction so that transport draft and ballasting needs can be accurately calculated. A multi-beam sonar survey of the final location and transport route should be performed prior to construction to confirm that a minimum clear depth of at least 2 to 3 feet can be maintained and that no debris accumulation will impede the transport, immersion and placement of the elements.

Although the transport distance will be relatively short from the graving site to the final location, towing and transport forces will be accounted for in the design and sufficient freeboard will be provided so that any waves, wakes or turbulence will not pose undue risk to the structures. The minimum recommended draft and freeboard requirements are tabulated below.

Table 10-7: Transportation Requirements for Floating Structures

Variable	Minimum Draft/Freeboard (ft)
Controlled Waters Draft Clearance	2.0
Uncontrolled Waters Draft Clearance	4.0
Calm Water Freeboard (U-Frame)	4.0
Calm Water Freeboard (Culvert)	2.0
Intermittent Wave Height	2.0
Unbalanced Water Height	4.0

In its final in-service condition the structures will be immersed in water with interior and exterior water levels essentially even. Designing for buoyancy in the final condition will only be necessary where the structure is expected to be dewatered. In this case, the pile-to-structure interface should be designed in accordance with EM 1110-2-2102 where the connection provides adequate resistance against the tensile forces induced by buoyancy. Conversely, for parts of the structure not designed to be dewatered, negative buoyancy during construction can be provided by ballast or through the pile-to-structure connection. During the construction condition, the Factor of Safety against buoyancy shall be as follows:

Table 10-8: Buoyancy Safety Factors

Condition	Minimum Factor of Safety
Ballast and Gravity Loads Only	1.05
Ballast plus Structural Connections	1.10

Based on the selected configuration of the graving site, transport channel, and structure there is a potential that some amount of secondary pour concrete will be required. In this case, the structural elements and buoyancy will need to be checked at each stage of concrete placement to ensure sufficient buoyancy, structural integrity and draft.

The floating structures will be moved into placed with either a custom-built catamaran barge or using flotation tanks, barges, and anchored lines. The design of these features shall be performed by the selected contractor and coordinated with the DT. The final structural design will need to accommodate the contractor's means and methods during final float-in.

10.4.5.3 Temporary Walls

As previously noted, some shorter structures will require temporary walls to create the "bathtub" buoyancy effect required for flotation. These walls need to be essentially watertight, with performance characteristics similar to that of a sheet pile cofferdam.

In the current U-Frame configuration, the float-in construction accounts for approximately 80 percent of the intake structure length. Approximately 210 feet of that will require temporary walls. The following table presents a summary of the floating sections and their temporary walls.

Table 10-9: Temporary Wall Requirements

Section	Station From	Station To	Temp Wall Height (ft)
F-1	33+50	30+95	n/a
F-2	30+95	28+40	n/a
F-3	28+40	26+30	n/a
F-4	26+30	24+20	12

The temporary walls consist of steel plates bolted and welded to vertical W-sections which are in turn connected to the concrete monoliths using cast-in-place studs. Studs are designed for shear and tension/compression from the overturning moment. Pullout resistance of the studs dictate a thicker top of wall than would otherwise be required. The current 15% level concrete monolith design includes loads induced by the temporary walls.

The walls will be built concurrent with the concrete monoliths and will be removed after final placement. The removal and demolition of these walls can either use divers or mechanized equipment to cut or otherwise detach (i.e. through a bolted connection) the wall just above the permanent structure and lift out each wall section. Temporary walls are currently designed to EL 6, which should be confirmed during final design based on the time of year and water levels at the anticipated floating, transport and immersion time.

10.4.5.4 End Bulkheads

The end bulkheads, while a temporary structure, are a critical item of the float-in system because they close in the "bathtub" and are a relatively major work item. Bulkhead walls have historically been constructed with both concrete and steel designs. For the depth and height of these hydraulic structures, a steel wall will likely provide a more economical solution that is also easier to demolish and remove.

Due to the large horizontal and vertical spans, significant bracing and stiffening of the bulkheads is required. The current concept uses steel plates connected to vertical stiffeners and horizontal walers that transfer the hydrostatic loads to rows of vertical and horizontal kickers connected to the concrete monolith. The bulkheads are provided with access doors to allow passage into the annular spaces between bulkheads to check the Gina compression prior to final concrete placement.

It is standard practice that at least two bulkheads are in place at all times between the river and any construction activity being done within the buoyant structure. With less than two bulkheads in place in front of workers, limited operations should take place. Because the last bulkhead will be directly against the river in the final condition, it is envisioned that this bulkhead could be demolished by divers when the structure is flooded or a floating-type gate similar to those used in dry-dock operations could be used. This detail has not been designed at this time.

10.4.5.5 Connections

At this time, it is envisioned that the elements will be connected using a Gina-type seal between elements. Using this method, the Gina-type seal on one element is mated against a plain steel end frame of an adjacent element. An initial seal is made, at which point the space between elements, bounded by the Gina-type seal, can be dewatered causing an unbalanced water pressure that pushes the elements together. From this point, the structural connection between elements can be made in-the-dry with rebar couplers and a second concrete pour. This will allow the connections between elements to be as smooth as a finished concrete surface with limited imperfections or grade differences that could cause head loss or sediment build-up. If it is determined from a hydraulic perspective that the connections between elements do not require this level of precision, the elements could simply be connected using tremie concrete. This will be determined at a later date by the DT after hydraulic modeling is complete and with input from the CMAR.

10.4.5.6 U-Frame Alternative

The U-Frame Alternative in-the-wet has similar dimensions to that of the in-the-dry alternative except that temporary walls are required and the entire floating structure is designed to resist hogging moments and shears caused by the unbalanced external water pressure. In addition, only steel pipe piles are considered since they will be driven through the water column with a follower or underwater hammer instead of constructed in-the-dry.

The most outboard sections of the structure will need to be constructed using modular lift-in methods since the wall elevation is too low to practically design and build temporary walls for float-in and immersion. The following table presents the limits of the float-in construction vs. the lift-in construction.

Table 10-10: Proposed In-the-Wet Construction Methodology

Section	Station From	Station To	Construction Methodology
F-1	33+50	30+95	Float-in
F-2	30+95	28+40	Float-in
F-3	28+40	26+30	Float-in
F-4	26+30	24+20	Float-in
L-1	24+20	23+50	Lift-in
L-2	23+50	22+80	Lift-in
L-3	22+80	22+10	Lift-in

One potential lift-in sequence involves casting the wall sections off-site in the lengths shown above, barging them into place, and setting them on pre-driven piles. The lengths of the walls are defined herein assuming a maximum pick weight of 2,000 tons. In between the lift-in walls the slab could be either lift-in as well or could be constructed using tremie methods with the reinforcement cage placed underwater onto a screeded gravel bed. If this method is revived during later design stages, the CMAR should provide input on their desired methods of slab construction.

10.4.5.7 Submerged Culvert Alternative

The Submerged Culvert alternative is not feasible in that some elements cannot be designed for buoyant transport and immersion without significant allowances and accommodations. When the culvert concept was broached, the outboard dimensions were not known and it was considered feasible. Since that time it has been determined that for outboard elements to float, they would need to use lightweight concrete and additional flotation devices such as barges attached structurally to the elements. The inboard sections could potentially be floated into place but the outboard sections are where the in-the-wet methodology has the most tangible benefits. Therefore, without significant dimensional modifications, this alternative is not recommended for further study.

10.4.6 Intake Armoring

10.4.6.1 General

Armoring analysis for the intake channel commenced after Workshop No. 2 selection of the Open Cut Intake configuration, constructed in the wet, to EL -40. For armoring analysis, this single intake alternative was considered. To proportion the armoring, EM 1110-2-1601 was selected from the various approaches in the Design Criteria for relative conservatism of predicted results, and for familiarity of USACE New Orleans District (District) reviewers with the EM method within their waterways.

Armoring is designed to stabilize a channel or embankment by resisting:

- Tractive force-induced movement of revetment material
- Piping erosion of underlying fines
- Undermining by scour at the toe
- General revetment slump (underlying bank slope failure)

“Classic” design of channel armoring can be simplified for discussion as follows:

1) Project cross sections, geometry, and limits are established
2) Hydraulic analysis provides water velocities or tractive forces
3) Riprap stone or ACB depth is sized

4) Riprap gradation or ACB dimension is established
5) Layer thickness is established (riprap)
6) Filter layer gradations/thicknesses are selected
7) Transitions and special features detailed
8) Iterate/adjust design as necessary

10.4.6.2 Pre-Analysis Alternative Screening

In order to eliminate unnecessary effort, armoring alternatives were qualitatively screened in the context of MBSD project conditions. Feasible armoring alternatives for screening were judged to be stone riprap and articulated concrete blocks or mattresses (ACBs or ACMs). Feasible filter layer alternatives for screening were judged to be geotextile fabric (fixed to underside of ACB), fines contained within compartmented flexible mattresses, and coarser-graded loose filter material. Geotextile filter or loose filter material underlying riprap, constructed in-the-wet, was not considered constructible. Given the in-the-wet construction method selected for the intake channel, practical armoring placement considerations were rapidly found to dominate. These considerations, which alter the approach from classic armoring design, are as follows:

- Reliable placement of light riprap in flowing water, at the MBSD project depths (up to 45-50 feet), has not been demonstrated as possible with surface dump methods. USACE District experience in the Mississippi River reflects loss of fine (<4 lb. particle) stone material within riprap to drift during in-the-wet surface dump placement, often subsequently found hundreds of feet downstream.
- Placement of fine material at MBSD project depths could potentially be achieved with a clamshell lowered to river bottom prior to opening, or with slurry pumping through a tremie pipe and diffuser. If technically feasible, these methods may prove tedious when wide coverage is required, and favorable economics must be established prior to implementation.
- Predicted Mississippi River current velocity during construction will strongly influence the choice of armoring scheme and details of design. Currents may alter the un-armored banks between dredging and armoring, and may disperse any insufficiently heavy intermediate filter or stone material prior to final armoring layer placement.
- While the USACE District successfully places ACMs as revetment on the Mississippi River bank, and even places irregular “pocket” revetment ACMs successfully, this placement uses specially constructed barges for such a purpose. To date, no similar case history demonstrating successful placement of commercially available ACB matting, with interlocked segments comparable to the District ACMs, placed in comparable water depth, has been discovered. The HDR Report suggests that for an ACB alternative to be successful, use of divers would be required to guarantee coverage and to interlock the commercial ACB segments while underwater; and that such a method would be difficult and expensive.

The USACE District approach to Mississippi River bank revetment in this region, exhibited in the Myrtle Grove revetment surrounding the intake channel, is to place anchored and interlocked ACMs without a filter layer directly on the underlying bank, and tolerate subsequent local movement resulting from scour between individual ACM block units. A similar approach is applied to rock dikes and riprap, where heavy stone is placed directly on river banks. Increased stone layer thickness is reported as successful in reducing water turbulence at the interface with underlying banks, such that erosion of fines is not widespread. Monitored and maintained, revetments constructed by these techniques have held the river bank location static for decades.

Riprap armoring alone was chosen to advance for analysis and proportioning in this 15% BOD stage. Until conclusion of the next design stage, the ACB constructability and case history investigation is recommended to remain open, as satisfactory methods may demonstrate ACBs a viable alternative to riprap.

Filter layers, rigorously proportioned by particle diameters according to EM 1110-2-2300, were eliminated from further analysis during 15% BOD due to uncertain constructability, and due to the feasible alternative approach employed by the USACE District as described above. An underlying stone layer of 4-inch diameter screening would be a minimum filter or foundation material size for use with in-the-wet placement from the surface. Similarly to ACBs, investigation of construction methodology facilitating cost effective and satisfactory filter placement is recommended to remain open through the next design stage. Rigorously proportioned filter layers, if feasible, may permit reduced stone layer thicknesses and improve durability of the intake channel armoring, reducing construction and O&M cost, respectively.
Following selection of riprap and assuming elimination of filter, the armoring design process, simplified for discussion, generally becomes:

1) Project cross sections, geometry, and limits are established
2) Hydraulic analysis provides water velocities or tractive forces
3) Riprap stone is sized for tractive forces
4) Riprap stone size validated/adjusted against practical in-the-wet minimum
5) Riprap gradation is established
6) Layer thickness is established from EM method
7) Layer thickness is adjusted based on EM and local judgement for O&M serviceability
8) Transitions and special features detailed
9) Iterate/adjust design as necessary

Should ACBs and filter stone layers prove to be constructible alternatives at competitive cost prior to final selection of an armoring design, the process will be modified.

10.4.6.3 Armor Stone Sizing

A color-coded depth-average velocity figure was provided from hydraulic model output for a 75,000 cfs diversion channel flow during Mississippi River discharge at 1,000,000 cfs. This figure visually displays the velocities at various locations along the intake channel and within the river cross-section in the area where the diversion currents approach the intake channel. This model represents only the case used for intake screening, and not the entire design envelope; additional model outputs across the full envelope of flows will be provided as completed. The controlling case for armoring is anticipated to be the Corps of Engineers design discharge, referred to as the Mississippi River and Tributaries Project Flood discharge, for the Mississippi River at the proposed location of the intake channel, a value of 1,250,000 cfs.

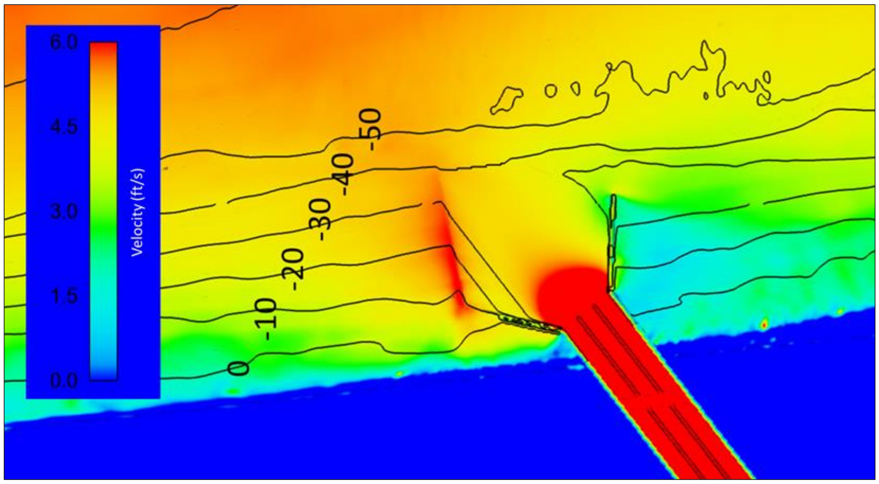


Figure 10-1: Depth-Average Velocity Distribution, 75k cfs MBSD / 1.0M cfs MR, from Intake Alternative Screening Model

The hydraulic model output revealed highest velocities where the currents veer towards the southwest to enter the intake channel from the river, and where the cross sectional area constricts into the intake structure. For highest design confidence in the armoring solution at late design stages, depth-average velocity figures should be calculated and shown to the maximum level of detail possible so that high localized velocities, particularly where the currents veer towards the southwest to enter the intake channel from the river, in excess of the average flow velocity, can be detected.

For this analysis, the maximum modeled value of velocity, exhibited at the northern edge of intake channel cut slope, and in the proximity of the U-frame entrance, will be used to select a single size of armoring stone. The value read is 6.0 ft/s (red coloration in the figure).

According to EM 1110-2-1601, from selected armoring design velocity, the minimum W_{50} of a gradation required to resist the tractive force was determined using the graph on Plate B-29. See clipped and annotated Plate in the figure following.

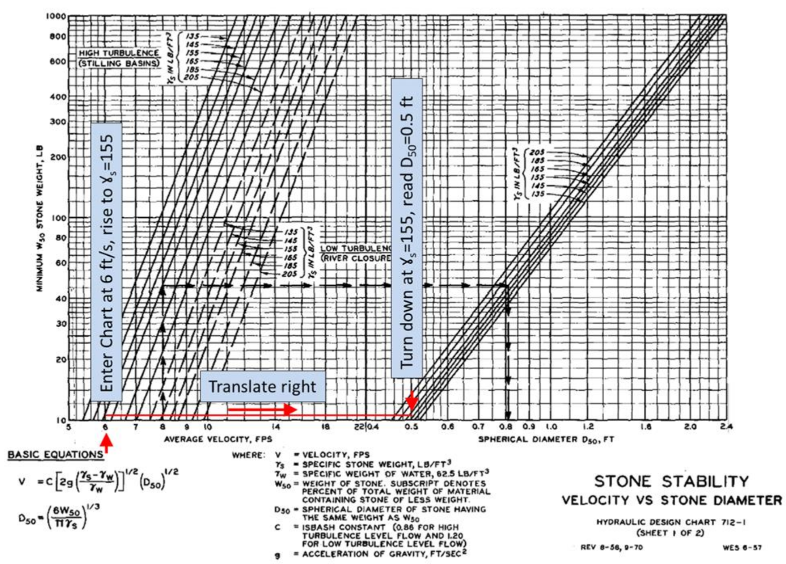


Figure 10-2: Stone D_{50} Selection by Depth-Average Velocity

The 6.0 ft/s modeled velocity, at a selected stone unit weight of 155 lb/ft^3, yields D_{50}=0.5ft (W_{50}=10.2 lb). From the USACE Lower Mississippi Valley Division (LMVD) Report on Standard riprap gradations appended to EM 1110-2-1601 as page F-18, the lightest commonly produced gradation with W_{50} no less than a calculated 10.2 lb minimum likely yields a W_{100} range of 40 – 90 lb. For cross-reference to an independently defined gradation, this roughly corresponds to the LADOTD definition of 30-lb Class Riprap. See the annotated LMVD report chart following.

LMVD   12 November 81

STANDARD RIPRAP GRADATIONS
(Design Sepcific Weight 155 pounds per cubic feet)

	GRADATION NORMALLY PRODUCED MECHANICALLY								GRADATIONS NORMALLY REQUIRNG SPECIAL HANDLING				
Layer Thickness in Inches High Turbulent Flow	12	15	18	21	24	30	36	42	48	54	63	72	81
Layer Thickness in Inches Low Turbulent Flow			12	14	16	20	24	28	32	36	42	48	54
Percent Lighter by Weight													
100	25 10	50 20	90 40	140 60	200 80	400 160	650 260	1000 400	1500 600	2200 900	3500 1400	5000 2000	7400 3000
50	10 5	20 10	40 20	60 30	80 40	160 80	280 130	430 200	650 300	930 440	1500 700	2200 1000	3100 1500
15	5 2	10 5	20 5	30 10	40 10	60 30	130 40	210 60	330 100	460 130	700 200	1100 300	1500 500

Minimum W_{50} Exceeding 10.2 lb.

Figure 10-3: Standard Riprap Gradation with W_{50} > 10.2 lb.

The gradation above was identified on the basis of the modeled 6.0 ft/s velocity generated in an early alternative screening model, and is likely to be adjusted as modeling advances.

On the Mississippi River, the USACE District uses a heavier riprap for revetment repair where the existing ACMs are disrupted, or where revetment by ACM is not feasible. The gradation is annotated in the following figure, taken from the 2015 USACE stone placement contract, and titled "Grade Stone B without Fines".

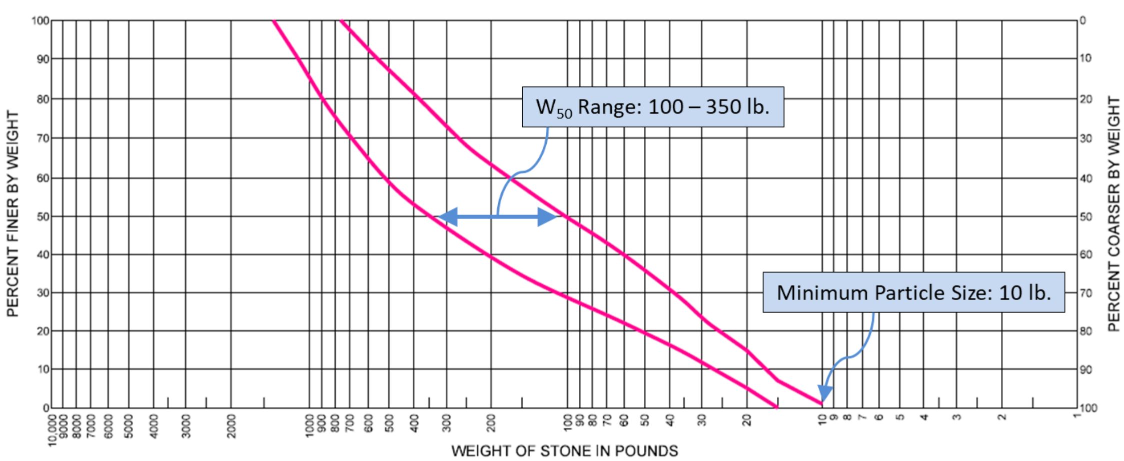


Figure 10-4: Mississippi River Revetment Riprap Gradation Specified by USACE District

The two riprap gradations resulting from a calculated W_{50}, and from USACE District specifications, are significantly different as shown in the following table.

Table 10-11: Riprap Gradation Comparison

% Lighter by Weight	Calculated by EM	Grade Stone B
W_{100}	40 – 90 lb	750 – 1200 lb
W_{50}	20 – 40 lb	100 – 350 lb
W_{15}	5 – 20 lb	20 – 35 lb

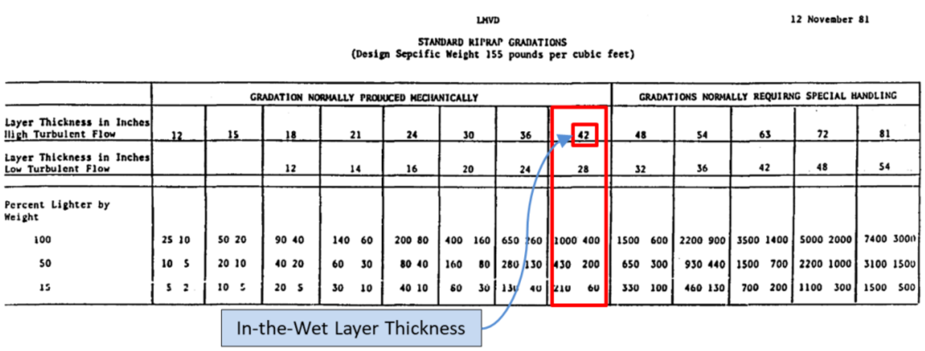
At this stage, the heavier riprap gradation, Grade Stone B (B-Stone), was selected for advancement. Lighter or differently distributed gradation(s) may be ultimately selected following more detailed hydraulic and construction method analysis. Use of B-Stone is not explicitly required by published document; however, it represents the following advantages over the calculated gradation:

- Greater placement reliability from the surface in river currents.
- Conservatism in stone gradation to account for uncertainty in localized velocities at structures, or unforeseen turbulence.
- Larger riprap gradations exhibit better stability on steep slopes, lending better revetment resistance to stone layer slump resulting from toe scour or migration of underlying fines.

10.4.6.4 Layer Thickness

By EM, the selected gradation upper limit D_{100} is 2.45 feet, from a W_{100} of 1,200 lb. 1.5 times the upper limit D_{50} is 2.45 ft (1.5 x 1.63 feet), from a W_{50} of 350 lb., which established the minimum layer thickness. For in-the-wet construction, the thickness was increased by 50% to 1.5 x 2.45 = 3.68 feet. Transverse bank slopes are modest in this vicinity, generally 1v:10h or flatter, suggesting that further adjustment of stone layer thickness for sideslope stability is not warranted; though local intake channel slopes may require, as geometry is developed, upward thickness adjustment.

Alternately, from the LMVD Standard Riprap Gradations chart in the EM, a gradation most near B-Stone was selected, with a recommended "Layer Thickness in Inches – Low Turbulent Flow" value of 28 inches, appropriate for in-the-dry placement. The "Layer Thickness in Inches – High Turbulent Flow" value of 42 inches is commonly used for in-the-wet placement in low turbulence applications such as anticipated at the MBSD. The 42 inch value (3.5 feet) is essentially equal to the 3.68 feet value calculated above.


LMVD 12 November 81

STANDARD RIPRAP GRADATIONS
(Design Sepcific Weight 155 pounds per cubic feet)

	GRADATION NORMALLY PRODUCED MECHANICALLY								GRADATIONS NORMALLY REQUIRNG SPECIAL HANDLING				
Layer Thickness in Inches High Turbulent Flow	12	15	18	21	24	30	36	42	48	54	63	72	81
Layer Thickness in Inches Low Turbulent Flow			12	14	16	20	24	28	32	36	42	48	54
Percent Lighter by Weight													
100	25 10	50 20	90 40	140 60	200 80	400 160	650 260	1000 400	1500 600	2200 900	3500 1400	5000 2000	7400 3000
50	10 5	20 10	40 20	60 30	80 40	160 80	280 130	430 200	650 300	930 440	1500 700	2200 1000	3100 1500
15	5 2	10 5	20 5	30 10	40 10	60 30	130 40	210 60	330 100	460 130	700 200	1100 300	1500 500

Figure 10-5: Riprap Layer Thickness from LMVD Standard Gradation Chart

Construction tolerances for underwater stone layer thickness are commonly written at 6 inches over/under; however, the 12 inch vertical range may be shifted to all "over" or all "under" as required. Difficult placement conditions at grade breaks, transitions, or boundaries may warrant relaxed tolerances and/or a thicker layer; such conditions being identified as channel geometry and diversion structures are refined.

The intake channel will be constructed into the predominant fine point bar deposits. At the time of the 2013 geotechnical investigation, the bank constituent soils at the uppermost elevations of borings (project Station 20+00 to Station 25+00) are generally sands with silt, and silts, SP and ML, respectively. A single boring at Station 21+50 reflects a very soft clay deposit of 18" at the surface, overlaying the same SP layer. Surface deposits of soft clay may be dispersed or displaced by stone placement, resulting in depressed revetment surface.

The uniform layer thickness required, as of 15% BOD, was established at the minimum rounded value of 4.0 feet. For conservatism, pending further analysis, the riprap revetment has been drawn at 5.0 feet. Depending on the final construction specifications for under/over thickness tolerances, level of concern for isolated soft bank deposits, and particular geometric or hydraulic constraints, the layer thickness may be adjusted to meet scour protection or other non-armoring criteria.

Upon more detailed hydraulic analysis, review of USACE District O&M experience at the Myrtle Grove revetment, and establishment of CPRA preferred O&M approach; detailing of the following armoring features may be accomplished:

- Toe scour protection, likely as a heavily thickened launchable stone layer toward the river-most extent of the revetment. The launchable layer is located above the expected zone of attack and anticipated to fill scour voids over time, creating a trenched-in thickened toe.
- End scour protection, likely as thickened stone layer placed on top of existing ACM revetment. The required ACM/riprap lap distance required by the USACE District may be upwards of 80 ft., based on experience. Transitions between measures in erosive zones merit particular attention.
- Rock dikes of significantly greater depth than the greater 5.0 ft layer thickness, adjacent to structures, may be provided to either provide stability and toe protection or to increase bathymetric elevation following excavation for structure placement.

10.4.6.5 Further Considerations

Design will advance according the basis established above, and may incorporate the following tasks:

- Use predicted and/or measured normal Mississippi River current velocities at the location of revetment construction, at varying river stages, for the purpose of establishing threshold(s) for suspension of construction activity, by phase and/or task.
- Analyze predicted water velocities at progressive phases of construction, informed by feasible construction methods, to establish the lower limit of filter or stone particle size practical.
- Coordinate construction specification tolerances, gradation, and finished grade requirements across technical disciplines to ensure no negative impact on sediment transport or hydraulic performance is caused by intake armoring.

10.5 Gated Diversion Structure

10.5.1 Design Approach

The concrete gated structure houses steel gates which allow river water to pass through the MRL into the Conveyance Channel. Tainter gates are used based on the recommendation of the Diversion Gate Study found in **Appendix O**. The initial design layout has set the intake entrance at Station 33+50; however, several locations have also been investigated. Based on decisions made in Workshop No. 2 (see **Appendix R**), the primary design effort uses a sill elevation of EL -40 with three 45 foot wide gates.

Prorated designs for invert levels EL -20 and EL -50 have also been developed to determine approximate size and cost differences between these levels and EL -40.

Concrete monolith and steel gate designs are described below. The intake structure construction is assumed to use a conventional in-the-dry method. All intake structures will be pile founded and all concrete is traditional reinforced concrete with the exception of the tainter gate trunnion connection, which is post-tensioned.

The Diversion Gated Structure is loaded from both sides. The river side ties into the MRL and is controlled by riverine flood conditions. The design top of wall elevation based on riverine flood is currently EL 16.4. The design flood condition for the basin side is based on a 50-Year hurricane event with water EL 15.6. These are the river and basin flood elevations used in the primary intake structure design.

Although not authorized in this reach of the MRL, CPRA is considering incorporating the hurricane criterion that is used for flood protection on MR levees. For this submittal, a 50-Year hurricane event with flood EL 20.1 is used as a secondary design case. The pile foundation for the gate monolith is designed equally for EL 16.4 and 20.1. All concrete components are prorated to determine EL 20.1 quantities.

The following table is a summary of all intake options examined for this submittal:

Table 10-12: Intake Options Summary

Alternative	Sill Invert	River Side TOW	Basin Side TOW	Design Level
1	-40	16.4	15.6	Designed
2	-40	20.1	15.6	Prorated
3	-50	16.4	15.6	Prorated
4	-50	20.1	15.6	Prorated
5	-20	16.4	15.6	Prorated
6	-20	20.1	15.6	Prorated

Two alternative gate locations were investigated, one moving the structure closer to the MRL to Station 32+00, a 150 foot shift towards the river, and a second location that shifted the gate 2,100 feet towards the Basin to Station 50+00. The Station 50+00 was investigated when it was unknown if the sands at the riverward locations could be dewatered for construction. Geotechnical analysis has since proven that the sand strata can be dewatered using conventional means. The added cost and increased head loss on Conveyance eliminated the 2,100 setback from consideration. The slight move towards the river has no apparent negative impacts with respect to MRL stability construction or conveyance. The shift will be made in future designs once hydraulic conditions with partial gate openings are modeled and found to not to be detrimental. The shift will be limited to 100 feet, leaving an approximate 200-foot space between the Railroad Bridge and gated structure to allow maintenance floating enough room to operate.

10.5.2 Concrete Monolith Design Loadings

All load cases are defined in the Project Design Criteria found in **Appendix U**. The 15% designs included in this submission use only the load cases that the DT judges to be worst-case scenarios. A full analysis of all load combinations will be calculated in later design phases.

The critical load cases considered for concrete and pile designs are as follows:

- Construction: River Side water EL 0.0, Basin Side water EL 0.0
- Dewatering: River Side water EL 5, Basin Side water EL 1
- (MR flow line or flow at design SWL: River Side water EL 12.4, Basin Side water EL 1
- MR design grade (TOW): River Side water EL 16.4, Basin Side water EL 1
- Reverse MR design grade (TOW): River Side water EL 1, Basin Side water EL 15.6

Concrete design load combinations are based on EM 1110-2-2104 and are as follows:

Table 10-13: Concrete Design Load Combinations

No.	Load Case Name	Description	Factored Load Combinations	Load Category
1	Construction plus Wind	Dead, Lateral, Surcharge, Gate Equipment, Wind	1.6(D+EH+Ls+Q+W)	Unusual
2	Maintenance Dewatering, (Pervious)	Dead, Lateral, Surcharge, Gate Equipment, Pervious Cut-off	1.6(D+EH+ES+Q+Hs+Hu)	Unusual
3	Water at Design SWL or Flowline (Pervious)	Dead, Lateral, Surcharge, Gate Equipment, Pervious Cut-off	2.2(D+EH+ES+Q+Hs+Hu)	Usual
4	Water to Top of Wall (Pervious)	Dead, Lateral, Surcharge, Gate Equipment, Pervious Cut-off	1.6(D+EH+ES+Q+Hs+Hu)	Unusual
5	Reverse Water to Top of Wall (Pervious)	Dead, Lateral, Surcharge, Gate Equipment, Pervious Cut-off	1.6(D+EH+ES+Q+Hs+Hu)	Unusual

The Construction Load Case assumes vertical loads including dead load, uniformly distributed construction surcharge load over the foundation, gate weight and operation equipment load on walls. Lateral loads include wind load on walls and earth force due to an assumed 5-foot differential in bank grades.

The Maintenance Dewatering Load Case assumes vertical loads including dead load, uniformly distributed construction surcharge load over the foundation, gate weight and operation equipment load on walls in the gravity direction and uplift pressure on the slab in the opposite direction. Lateral loads include saturated earth pressure on both left and right banks, construction surcharge transmitted through the soil and hydrostatic load on the stoplogs.

The Water at Design SWL or Flowline, Water to Top of Wall and reverse Water to Top of Wall Load Cases assume vertical loads in the downward direction including dead load, water pressure on the channel slabs, gate weight (in closed position) and operation equipment load on walls. Uplift pressure is applied to the slab and is assumed to vary linearly between head pressures beneath the monolith. Lateral loads include saturated earth pressure on both left and right banks, soil surcharge and hydrostatic load on walls.

10.5.3 Pile Foundation

The pile foundation is analyzed in accordance with USACE EM 1110-2-2906. The software used is CPGA which uses the stiffness method and assumes the pile cap is rigid. More advanced software which utilizes P-Y and T-Z springs and a flexible base will be used in subsequent designs. Given the large footprint of the structure an all-vertical pile geometry is used. Downdrag effects are not considered and unbalanced loads are not present. Two pile types are considered: a 24-inch diameter pipe pile and a 36-inch diameter pipe pile. Construction cost and driving preference of the CMAR will ultimately influence the final design pile type. Because a static pile load test program will be conducted in advance of structure construction, a Factor of Safety of 2.0 is used in the design. For this submission, piles are structurally designed using the allowable stress design (ASD) method, though future structural analyses may use the load resistance factor design (LRFD) method. The pile size, pile tip elevation and pile capacities can be found in the drawings and calculations, **Appendix D** and **Appendix J**, respectively. The pile capacities are calculated using the Eustis Engineering Capacity Curves described in Section 9.

10.5.4 Finite Element Model

The Gated Structure is modeled in SAP2000 structural analysis program as a 190-foot long monolith with top of wall elevations of EL 16.4 and EL 15.6 at river and basin sides (RS & BS) respectively. The monolith includes three, 45-foot bays that are divided by 8-foot thick walls. Elevations used in this report are not final and may be subject to change. Also, construction, maintenance, equipment, gate and wind loads are estimated and may be subject to change. The wall and slab thicknesses are defined based on the shear and moment capacity of the sufficiently reinforced sections and checked with the model's results to make sure that the structure can effectively carry the lateral and vertical loads.

To model the piles in SAP2000, the pile stiffness matrix for round pinned piles derived by the CPGA program is applied in the SAP2000 model as joint springs. Though both 24-inch and 36-inch diameter piles are possible foundation options, the SAP2000 design model used assumes 36-inch piles. Compression, tension and displacement values of the piles are then evaluated and checked against the pile capacity including allowable overstresses. Piles diameter, depth and number are defined based on the pile capacity report that provides the compression and tension capacity for given pile sizes and tip elevations. In choosing the pile tip elevations, the design aims to keep the tip a sufficient distance above the weak layer that occurs around EL -130 in this reach.

10.5.5 Gate Structure Prorated

For the gate monolith, vertical and lateral forces related to TOW EL 16.4 and invert EL -40 are analyzed in spreadsheet format using forces similar to those described for the SAP2000 finite element model. The loads generated from this case are analyzed in CPGA using 36-inch diameter x ½-in wall pipe pile in a 11.75 foot spacing pile grid. The CPGA output data shows that the greatest pile forces are generated by the construction case (Load Case No. 1 in the above table) therefore, this case is used as the basis for all prorated foundation designs.

The total vertical force from the construction case is divided by the number of piles in the grid to develop an average force per pile. Next, the vertical loads of the sill EL -50 and EL -20 cases are calculated using the same spreadsheet. The total vertical force for each option is divided by the EL -40 average pile force to prorate the number of piles required to support the structure. This process is also used to determine the number of piles required when the TOW is extended to EL 20.1.

The walls of the concrete monolith are prorated using a lateral soil load from top of grade EL 4 with no water inside the channel which is the worst case condition for the cantilever walls. Thicknesses are determined by verifying the wall has adequate shear capacity and enough thickness to conform to the USACE maximum reinforcement limit of $0.25\rho_{bal}$ set in EM 1110-2-2104.

10.5.6 Gate Type and Design

Per the recommendation of the Diversion Gate Study, steel tainter gates are chosen for preliminary design and uses a top of wall EL 16.4 and sill EL -40. The analysis follows the LRFD design procedure described in ETL 1110-2-584, Design of Hydraulic Steel Structures, Appendix D Spillway Tainter Gates. Two load cases are applied for the 15% level design:

1) High River Condition:
    a. Water to Top of Gate EL 16.4 on river side (top of wall for river side)
    b. Water to EL 1.0 on basin side (lowest design elevation)
2) High Basin Condition:
    a. Water to EL 1.0 river side (lowest design elevation)
    b. Water to EL 15.6 on basin side (top of wall for Conveyance Channel)

Although these load cases are relatively simplistic, they will accurately determine the required member sizes because they represent the most extreme head differentials in each direction. Other cases that would include temporary loads such as wave, impact, or the more extreme gate friction forces would use lower water levels or would be considered an extreme limit state.

Included in the LRFD procedure is the USACE performance factor α, which further reduces the design nominal resistance beyond the traditional resistance factor ϕ. For this project α is set to 0.85 because maintenance and repair may be difficult and disruptive and because brackish water will likely back up to the gate on the Conveyance Channel side. Load factors applied to dead and water loads conform to ETL 1110-2-584 Appendix D, Table D-1 ($1.2D + 1.4H_s$).

A 2D analytical procedure is followed for the skin plate and rib sizing. The skin plate is conservatively assumed to act as a simple beam spanning between two ribs (ETL 584 allows use of fixed-end moments) and the ETL's recommendation of a 3/8 inch minimum thickness is followed. The ribs are analyzed as simple beams spanning between horizontal girders assuming the skin and rolled ST-shape rib section act compositely.

Horizontal girders, vertical and diagonal girder bracing, end frames, and end frame bracing is all sized using a SAP2000 3D model. The skin plate assembly is included as a shell element with modifiers applied to represent the added stiffness and weight provided by ribs. All frames are assigned rolled shapes. Water loads are applied to the front and back faces of the skin plate. Pinned restraints are applied at the trunnion pin and the bottom edge of the gate is supported by rollers that closely mimic how the gate will rest on the bottom seal plate (per guidance from EM 1110-2-2702, no longer in production, which provided additional details on how boundary conditions should be modeled in tainter gate design). The load cases above are input in SAP2000 with applicable load factors and the program's steel design process checked all members using the ϕ*α*nominal resistance limit.

Multiple preliminary gate designs are developed for the various alternatives described in Section 10.5.1. Because the majority of steel weight is based on primary member sizing it was decided that fully running the preliminary gate design for each option would more accurately reflect cost differences than assuming prorated steel shape sizing. Some portions of the gate such as the skin and rib sizing are the same regardless of the sill elevation because they are primarily dependent on maximum head differential and not overall water height. In total four gate options are modeled:

1) TOW & River EL 16.4, Sill EL -40
2) TOW & River EL 20.1, Sill EL -40
3) TOW & River EL 17.5, Sill EL -50 (17.5 is an earlier iteration of the max. river elevation)
4) TOW & River EL 17.5, Sill EL -20

10.5.7 Maintenance Bulkheads

Truss type bulkheads are included for both emergency and maintenance conditions. Bulkheads shall be designed in accordance with ETL 1110-2-584 with a load factor of 1.6. Two types of bulkheads shall be included. One set shall be designed with casters to allow installation in flowing waters in an emergency closure. The bulkhead dam for this emergency and maintenance condition shall be 50-foot tall. The second set shall be designed without rollers and will be installed in a steady state condition. Fracture critical members shall be designed using redundant connections where possible. Welding shall be done in accordance with AWS D1.5.

10.6 Mississippi River Levee Tie-Ins

10.6.1 Interim Line of Protection

The interim flood protection system is discussed in Geotechnical Section 9.

10.6.2 Permanent Line of Protection

10.6.2.1 In-the-Wet Tie-Ins

The U-Frame Intake Structure is enclosed on both the north and south sides with inverted T-Wall monoliths that form the MRL tie-in. Since the T-Walls are within the open excavation for the U-Frame and Gated Diversion Structure, the nearest MRL T-Walls will match their bottom elevations and step upward as they embed further into the levee.

There are three alternate U-Frame alignments based on the proposed sill options: EL -40, EL -50, and EL -20; EL -40 is the primary design and the remaining two are prorated designs. The top of wall for the primary design is set at EL 16.4 to match the current MRL Riverine Design Grade. The MRL tie-in walls are also analyzed with the top of wall at EL 20.1 to investigate the costs associated with adopting the USACE NOV Hurricane Protection 50-Year Event Design Grade. All calculated and prorated designs and their associated drawings are found in **Appendix J** and **Appendix D**, respectively.

10.6.2.1.1 Geometry

As stated previously, all alternatives start with a TOS elevation to match the adjacent U-Frame Structure and step upwards to TOS EL 0.0 before embedding in the MRL. T-Walls are backfilled with sand to EL 2 on both sides of the stem wall regardless of slab depth. All monoliths contain a PZ-22 sheet pile cutoff wall, are built on pile foundations, and terminate in a sheet pile transition which connects the T-Walls to the levee embankment.

The primary design with sill EL -40 and TOW EL 16.4 extends 290 feet from the U-Frame into the levee and is comprised of six T-Wall monoliths. Slab depths step up in 10 foot increments from T-1 at TOS EL -40 to T-5 at TOS EL 0; the T-6 slab matches that of T-5. All monoliths are 50 feet long with the exception of T-6, which is 40 feet long. The walls for monoliths T-1 through T-4 are 3 feet thick at the top and thicken at a 1:12 slope on the land side. Walls for monoliths T-5 and T-6 are a constant 3 foot thickness. Slabs vary from 32 feet wide and 7 feet thick at the lowest TOS elevation to 15 feet wide and 5 feet thick at the highest.

The EL -50 alternative extends the tie-in alignment to 350 feet and contains seven 50-foot long monoliths. Slabs again step up in 10-foot increments with the most exterior monolith, T-7, maintaining TOS EL 0.0. Walls for monoliths T-1 through T-4 are 3 feet thick at the top and thicken at a 1:12 slope on the land side and T-5 through T-7 walls are a consistent 3 feet thick. Slabs vary in size from 40 feet wide and 7 feet thick at EL -50 to 15 feet wide and 5 feet thick at EL 0.0.

The alternative for sill EL -20 is the most simplistic design. A 200-foot length of T-Wall is broken into four 50 foot monoliths with two stepped transitions. Only T-1 has a sloping wall similar to those described above and the slab measures 24 feet wide by 5 feet thick. The remaining three monoliths have consistent 3 feet thick walls and 15 feet wide by 5 feet thick slabs.

The last alternative examined matches the primary design but extends the wall height to EL 20.1. The general T-Wall layout remains the same in terms of step height and monolith length. T-1 through T-3 again have 1:12 sloped walls with 3 feet top thickness; however, these will be thicker at their bases because of the increased wall height. T-4 through T-6 walls are unchanged. The primary difference between this and the TOW EL 16.4 design is an increase in slab width and thickness because an extra row of piles is required. The largest slab is 40 feet wide and 8 feet thick but again transitions to a 15 feet by 5 feet slab.

10.6.2.1.2 Design Approach

The Sill EL -40 and TOW EL 16.4 option base slabs, foundations, and stem walls are analyzed as the primary design. From the EL -40 design, EL -50 and EL -20 alternates are prorated to determine number of piles, pile sizes, pile tips, length, wall thickness, and base slab dimensions. The T-Wall top of slab elevations start at EL -40 (or -50/-20 depending on alternative) at the U-Frame and end at EL 0.0 at the levee tie-in.

Calculations following the Ultimate Strength Design method described in ACI 318-14 and EM 1110-2-2104 are performed to determine allowable shear and flexure acting on the stem and slab of the inverted T-Wall monoliths. Serviceability requirements are not checked at this time for concrete structures; however, in using EM 1110-2-2104 criteria, serviceability requirements are met. A more comprehensive check will be performed during the next phase of the design.

Piles are designed using soil parameters found within **Appendix J**. According to the geotech information provided by Eustis, there are no unbalanced loads or significant down drag at the fill areas near levee tie-ins. A detailed analysis of downdrag and settlement will be investigated by the geotechnical team in the future phases and those results will be included in tie-in pile designs.

Analysis of the 3-dimensional structure is performed using a combination of hand calculations and Excel spread sheets. The hand calculations consider the self-weight of the T-Wall monolith, water weight and pressure, soil weight and pressure, and uplift forces. Totaling up a combination of these forces and moments, the result allows us to find the total forces and moments acting on the pile foundation. Hand calculations are also done to check the design of the stem wall and the base slab of the inverted T-Wall monolith, according to the MBSD Design Criteria factored loads for allowable shear calculations to find if the thickness of slab and stem are adequate.

10.6.2.1.3 In-the-Wet Tie-in Design Loadings

The load cases as described in the MBSD Design Criteria Table 5-5 (**Appendix U**) are the basis for the load cases evaluated in the analysis. Engineering judgment is used in selecting a limited number of preliminary design load cases by comparing the magnitude of the applied loads and the applicable Load Factor. Design resiliency checks will be evaluated in a later phase of the project. The analysis evaluated both the pervious and impervious cut-off wall uplift conditions. The following table shows the selected preliminary load cases.

Table 10-14: MRL T-Wall Concrete Design Load Combinations

Load Case	Description	River Side Water EL	Land Side Water EL	Factored Load Combinations
1	Construction without soil, with surcharge	N/A	N/A	1.6(D+EH+EV+Ls)
4 & 5	Water at Design SWL	12.8	1.0	2.2(D+EH+EV+Hs+Hu)
17 & 18	Water to Top of Wall	16.4	1.0	1.6(D+EH+EV+Hs+Hu+HW+W)
17 & 18 Alt.	Water to Top of Wall	20.1	1.0	1.6(D+EH+EV+Hs+Hu+HW+W)
19	Maintenance Dewatering	5.0	3.0	1.6(D+EH+EV+Hs+Hu)

Notes: 1) Unbalanced loads not considered in this phase
2) 4, 17 & 19 impervious uplift, 5, 18 & 19 pervious uplift
3) DL= Dead Load, EH= Lateral Earth, EV= Vertical Earth, Ls= Construction Surcharge, Hs= Peak Hydrostatic, Hu= Uplift, HW= Wave, and W= Wind

10.6.2.1.4 Pile Foundations

For the 15% phase the piles are designed for lateral and vertical loads only; the moment from vertical and lateral loads is not considered for analysis. During the next phase, all loads and moments will be included in the analysis for deflection and combined stress for piles. Assuming a static pile load test will be performed the allowable Factor of Safety for pile loads is 2.0. Pile tips are set to mitigate differential settlement between monoliths. Group analysis on piles is not done for this phase. Pile tips are set to mitigate differential settlement among monoliths. Group analysis on piles is not done for this phase.

All vertical and horizontal forces acting on the structure are summed for each load case. Vertical loads are assumed to be carried by all piles and lateral loads are assumed to be carried by only the piles battered against the direction of loading. This in itself is conservative as the lateral capacity provided by the opposing batters is ignored. Lateral loads are converted to axial pile forces by multiplying them by the pile batter. Once loads are distributed two maximum pile forces are calculated, one due to the lateral force and one due to the vertical. The required pile tip elevation is then found using the higher of these two values (compression, tension, or both) from the analysis results and plotting the points along the pile capacity curve for 24 inch and 30 inch diameter open-end steel pipe piles.

10.6.2.1.5 Cutoff Sheet Pile Wall

A PZ-22 sheet pile cutoff wall is included beneath all monoliths to limit seepage; the embedment criteria is specified in Section 9. Cutoff sheet pile will extend via a sheet pile transition wall into the levee embankment. The transition wall will be 30 feet long and the top of the sheet is matched with the levee crown.

10.6.2.1.6 Braced Excavations

A cofferdam (TRS) is designed for the EL -40 T-Wall monolith including the excavations for bottom and tremie seal slabs below. The sheet pile for the MRL cofferdam has a tip elevation of EL -64. The proposed width of the cofferdam is 47 feet to avoid the battered piles for the T-Wall foundations and the length is about 315 feet to provide adequate clearance around both ends of the wall alignment. The depth of the retaining systems will be reduced as the T-Wall base slab elevations go up towards the levee tie-ins. The wales and struts to support the sheet piles are sized using the ASD method found in the Steel Construction Manual (14^{th} Ed.). There is a 10-foot thick slurry seal below the 2 foot tremie seal slab to resist hydrostatic uplift and ensure a relatively dry work environment inside the cofferdam.

Cofferdams for the EL -50 and EL -20 alternatives are prorated based on the EL -40 design; a cofferdam for EL -40 with top of wall at EL 20.1 is also investigated using a similar methodology.

10.6.2.1.7 Future Analysis and Design Considerations

The following will be addressed in future submissions:

- Coordinate with the adjacent structures to identify and rectify any pile conflicts
- Coordinate and rectify interference with U-Frame and Gated Diversion Structure for selected alignments
- Evaluate all applicable load cases, including the design resiliency checks
- Verify the assumed construction sequence to determine its appropriateness
- Investigate pile foundation deformations and mitigation measures
- Determine the piles that require tension connections and design these items.
- Pile analysis using the Group pile program by Ensoft Corporation.
- Perform a more detailed design check for all of the structural members including rebar for shear and flexure
- Future Design grade (TOW EL 20.1) for hurricane is considered for this design phase as a prorated design based on TOW EL at 16.4 calculations. Actual calculations will be provided if this alternative is chosen.

10.6.2.2 In-the-Dry Tie-Ins

The U-Frame Intake Structure is enclosed on both the north and south sides with inverted T-Wall monoliths that form the MRL tie-in. The joint between the U-Frame and T-Wall monoliths will be sealed with water stops which can provide lateral movement between these two structures. The waterstop will be embedded into the U-Frame the full height of required seepage cutoff depth. For this construction method it is proposed that MRL T-Walls be built after backfilling the U-Frame and Gated Diversion Structure excavations. Unlike the MRL In-the-Wet Tie-Ins, the dry construction tie-in walls consider only one consistent TOS at EL 2. Overall two alternatives are considered, one for TOW at EL 16.4 and one for TOW at EL 20.1.

10.6.2.2.1 Geometry

Both alternatives set a TOS EL 2 and contain two identical 50-foot monoliths on either side of the U-Frame. The increase in wall height due to the changing TOW elevation does not affect any member sizing. All monoliths have a 3-foot thick uniform stem wall and a base slab that measures 15 feet wide and 5 feet thick. As with the In-the-Wet design, a PZ-22 sheet pile cutoff is located below the slab and all monoliths are pile-founded.

10.6.2.2.2 Design Approach

Calculations following the Ultimate Strength Design method described in ACI 318-14 and EM 1110-2-2104 are preformed to determine allowable shear and flexure acting on the stem and slab of the inverted T-Wall monoliths. Serviceability requirements are not checked at this time for concrete structures; however, in using EM 1110-2-2104 criteria, serviceability requirements are met. A more comprehensive check will be performed during the next phase of the design.

Piles are designed using soil parameters found within **Appendix J**. According to the geotech information provided by Eustis, there are no unbalanced loads or significant down drag at the fill areas near levee tie-ins. A detailed analysis of downdrag and settlement will be investigated by the geotechnical team in the future phases and those results will be included in tie-in pile designs.

Analysis of the 3-dimensional structure is performed using a combination of hand calculations and excel spread sheets. The hand calculations consider the self-weight of the T-Wall monolith, water weight and pressure, soil weight and pressure, and uplift forces. Totaling up a combination of these forces and moments, the result allows us to find the total forces and moments acting on the pile foundation. Hand calculations are also done to check the design of the stem wall and the base slab of the inverted T-Wall monolith, according to the MBSD Design Criteria factored loads for allowable shear calculations to find if the thickness of slab and stem are adequate.

10.6.2.2.3 In-the-Dry Tie-In Design Loadings

The load cases used for these monoliths are the same as those used for the In-the-Wet Tie-In design. See Table 10-14 for a discussion about the chosen design cases and a summary of the load combinations and applicable safety factors.

10.6.2.2.4 Pile Foundations

For the 15% phase the piles are designed for lateral and vertical loads only; the moment from vertical and lateral loads is not considered for analysis. During the next phase all loads and moments will be included in the analysis for deflection and combined stress for piles. Assuming a static pile load test will be performed the allowable Factor of Safety for pile loads is 2.0. Pile tips are set to mitigate differential settlement among monoliths. Group analysis on piles is not done for this phase.

All vertical and horizontal forces acting on the structure are summed for each load case. Vertical loads are assumed to be carried by all piles and lateral loads are assumed to be carried by only the piles battered against the direction of loading. Lateral loads are converted to axial pile forces by multiplying them by the pile batter. Once loads are distributed two maximum pile forces are calculated, one due to the lateral force and one due to the vertical. The required pile tip elevation is then found using the higher of these two values (compression, tension, or both) from the analysis results and plotting the points along the pile capacity curve for 24-inch and 30-inch diameter open-end steel pipe piles.

10.6.2.2.5 Cutoff Sheet Pile Wall

A PZ-22 sheet pile cutoff wall is included beneath all monoliths to limit seepage; the embedment criteria are specified in Section 9. Cutoff sheet pile will extend via a sheet pile transition wall into the levee embankment. The transition wall will be 30 feet long and the top of the sheet is matched with the levee crown.

10.6.2.2.6 Future Considerations

In the event this option is chosen as the alternative to be constructed, the same future considerations will be made for this design as are described for the In-the-Wet options in Section 10.6.2.1.7.

10.7 Transition Structures

10.7.1 Geometry

10.7.1.1 Transition Wing Wall In-the-Dry

The Transition T-Wall monoliths are located on both sides of the Conveyance Channel starting from the Gated Diversion Structure and span to the west. With In-the-Dry construction, there are three alternative sill elevations (based on the U-Frame channel elevations): EL -40, EL -50 and EL -20. The T-Walls on both sides of the Conveyance Channel are identical in all aspects and span from the U-Frame to the guide levee tie-ins. For all examined alternatives, the original top of wall elevation is EL 13. Top of wall elevations were increased to increase to EL 15.65 according to the 50-Year Future Hurricane Grade; however, effects of this change is not examined during the preliminary design phase. Additionally, walls were also designed using a lower level of flood protection at EL 12.1. There is no cofferdam proposed to construct the transition T-Walls; the walls will be constructed within the HW earthen cofferdam.

All alternatives contain a continuous PZ-22 sheet pile cutoff wall is beneath the monolith and are pile supported. Base slab elevations are set to match finished grade so that the base slab generally has 2 to 4 feet of cover on the channel side and land side of the T-Walls is backfilled with sand to EL 2. An 8-foot clear roadway is also proposed regardless of alternative on top of the T-Wall to provide small vehicle access across from the U-Frame and Gated Diversion Structure to T-Wall and guide levee tie-ins in accordance with the MBSD DCD. Side mounted LADOTD guard rails are also proposed on both sides of the roadway.

10.7.1.2 Alternative EL -40

For this alternate, the lowest base slab is at EL -40 which matches the U-Frame channel elevation and the highest base slab elevation is at EL 0.0. There are fourteen T-Wall monoliths starting from base slab EL -40 (T-1) to base slab of EL 0.0 (T-14). The Conveyance Channel bottom grade slopes upward (in the west direction) from EL -40 to EL -25 over 150-feet and continues sloping up to EL 2; monoliths step up to mimic this slope. The total T-Wall length is approximately 720 feet.

The walls for monoliths T-1 through T-7 are 2 feet 6 inches thick at the top and thicken at a 1:12 slope on the land side. Monoliths T-8 through T-14 have uniform walls with a thickness of 2 feet 6 inches. The width of the base slab varies from 31 feet at the EL -40 level to 15 feet at the guide levee tie-in. Typical monolith length is 50 feet long. The T-Wall base slab thickness and width also vary according to the bottom slab elevations.

10.7.1.3 Alternative EL -50

For this alternate, the lowest base slab is at EL -50 which matches the U-Frame channel elevation and the highest base slab elevation is at EL 0.0. There are fourteen T-Wall monoliths starting from base slab of EL -50 (T-1) to base slab of EL 0.0 (T-14). The Conveyance Channel bottom grade slopes upward (in the west direction) from EL -50 to EL -25 over 250-feet and continues sloping up to EL 2; monoliths step up to mimic this slope. Total T-Wall length is approximately 700 feet.

The walls for monoliths T-1 through T-8 are 2 feet 6 inches thick at the top and thicken at a 1:12 slope on the land side. Monoliths T-9 through T-14 have uniform walls with a thickness of 2 feet 6 inches. The width of the base slab varies from 40 feet at the EL -50 level to 15 feet at EL 0. Typical monolith length is 50 feet long. The T-Wall base slab thickness and width also vary according to the bottom slab elevations.

10.7.1.4 Alternative EL -20

For this alternate, the lowest base slab is at EL -20 which matches the U-Frame channel elevation and the highest base slab elevation is at EL 0.0. There are thirteen T-Wall monoliths starting from base slab of EL -20 (T-1) to base slab of EL 0.0 (T-13). The Conveyance Channel bottom grade remains constant at EL -20 until T-6, then slopes upward to EL 2 at T-13. The total T-Wall monolith length is approximately 644 feet each side of the Conveyance Channel.

The walls for monoliths T-1 through T-7 are 2 feet 6 inches thick at the top and thicken at a 1:12 slope on the land side. Monoliths T-8 through T-13 have uniform walls with a thickness of 2 feet 6 inches. The width of the base slab varies from 24 feet at the EL -20 level to 15 feet at the EL 0.0 level. Typical monolith length is 50-feet long. The T-Wall base slab thickness and width also vary according to the bottom slab elevations.

10.7.2 Design Approach

For the 15% design phase there are three proposed alternatives for the transition T-Walls based on the U-Frame Channel EL -40, EL -50 and EL -20. The EL -40 alternate is the only alternative calculated and designed. From the EL -40 design, EL -50 and EL -20 alternates are prorated for quantities of the T-Wall including number of piles, pile sizes, pile tips, length and base slab dimensions.

For the transition T-Walls, hand calculations based on the Ultimate Strength Design using ACI 318-14 and EM 1110-2-2104 are preformed to determine allowable shear and flexure acting on the stem and slab of the inverted T-Wall monolith. Serviceability requirements are not checked at this level of design; however, in using EM1110-2-2104 criteria, serviceability requirements are met. A more comprehensive check will be performed during the next phase of the design.

The multiple sized T-Wall monoliths and pile foundations are designed based on hand calculations and Excel spreadsheets for the design of pipe piles, stem and base slab. The soil parameters provided by Eustis Engineering are used to calculate the soil pressures and pile capacities. All calculated and prorated designs and their associated drawings are found in **Appendix J** and **Appendix D**, respectively.

10.7.3 Pile Foundation

The piles are designed for lateral and vertical loads only for the 15% design phase. The moment from vertical and lateral loads is not considered for analysis. During the next phase, all the loads and moments will be included in the analysis for deflection and combined stress for piles. Assuming that a static pile load test will be performed, the allowable Factor of Safety for pile loads is 2. Group analysis on piles is not performed for the 15% design phase.

Vertical and horizontal forces acting on the structure are summed for each load case. Vertical loads are assumed to be carried by all piles and lateral loads are assumed to be carried by only the piles battered against the direction of loading. Lateral loads are converted to axial pile forces by multiplying them by the pile batter. Once loads are distributed two maximum pile forces are calculated, one due to the lateral force and one due to the vertical. The required pile tip elevation is then found using the higher of these two values (compression, tension, or both) from the analysis results and plotting the points along the pile capacity curve for 24-inch and 30-inch diameter open-end steel pipe piles.

10.7.4 T-Wall Design

Analysis of the 3-dimensional structure is performed using a combination of hand calculations and Excel spreadsheets. The hand calculations consider the self-weight of the T-Wall monolith, water weight and pressure, soil weight and pressure, and uplift forces. There are unbalanced loads shown in the geotechnical stability analysis at EL -40 to EL -25. The DT is proposing to eliminate the unbalanced loads by soil remediation with soil cement stabilization. Therefore, the unbalanced load for the 15% level design phase is not considered.

By summation of the applied forces and moments acting on the wall, the pile force and moments below the T-Wall are determined. Hand calculations are also performed to check the design of the stem wall and the base slab of the inverted T-Wall monolith in accordance with the MBSD Design Criteria. Factored concrete design loads are used to confirm the adequacy of the stem wall and slab thickness.

To streamline the design process across each of the Alignments the T-Walls are designed identical. Design and analysis is performed for only the EL -40 base slab elevation and geometry for EL -50 and EL -20 alternates are prorated from the EL -40 alternate. All monoliths are pile supported with pile tips set to mitigate differential settlement among monoliths. Settlement calculations are not performed in the 15% level design but will be performed in the future phases.

10.7.4.1 Load Cases

The load cases as described in the MBSD Design Criteria Table 5-5 (**Appendix U**) are the basis for the load cases evaluated in the analysis. Engineering judgment is used in selecting a limited number of preliminary design load cases by comparing the magnitude of the applied loads and the applicable Load Factor. Design resiliency checks will be evaluated in a later phase of the project. The hydraulic grade and design grades are from the MBSD Design Criteria Table 2 and 3 of Section 2, Rev. 2, submittal draft no. 3 dated 4/27/2018. The basic load cases selected for the analysis are as stated in the table below.

The analysis evaluates both the pervious and impervious cut-off wall uplift conditions. The following table shows the selected load cases.

Table 10-15: Transition T-Wall Design Load Case Summary

Load Case	Description	River Side Water EL	Land Side Water EL	Factored Load Combinations
1	Construction without soil, with surcharge	N/A	N/A	1.6(D+EH+EV+Ls)
4 & 5	Water at Design SWL	9.1	1.0	2.2(D+EH+EV+Hs+Hu)
14 & 15	Channel Low Water Reverse Head	1.0	1.0	2.2(D+EH+EV+Hs+Hu)
17 & 18	Water to Top of Wall	15.6	1.0	1.6(D+EH+EV+Hs+Hu+HW+W)
17 & 18 Alt.	Water to Top of Wall	12.1	1.0	1.6(D+EH+EV+Hs+Hu+HW+W)

Notes: 1) Unbalanced loads not considered in this phase
2) 4, 14 & 17 impervious uplift, 5, 15 & 18 pervious uplift
3) DL= Dead Load, EH= Lateral Earth, EV= Vertical Earth, Ls= Construction Surcharge, Hs= Peak Hydrostatic, Hu= Uplift, HW= Wave, and W= Wind

10.7.5 Future Analysis & Design Considerations

The following will be addressed in future submissions:

- Coordinate with the adjacent structures to identify and rectify any pile conflicts.
- Coordinate and rectify interference from U Frame/Gate structures and the T-Wall for selected Alignments.
- Evaluate all applicable load cases, including the design resiliency checks.
- Verify the assumed construction sequence to determine its appropriateness. Investigate pile foundation deformations and mitigation measures.
- Perform detailed design checks for all structural members including sizing and detailing of rebar for shear and flexure.
- Determine piles that require tension connections.
- Perform pile analysis using advanced software such as Group by Ensoft Corporation. Use spring constants and structural software that account for the flexible base of the larger structures. Use pile curves based on the recent, extensive boring program. Maintain pile tips within the boring depths. ADT continues to recommend Pile Load Test on all major structure foundations to verify theoretical values.
- Perform alternative pile comparison to assure capacity and economy. Prestressed concrete piles will be considered where unbalanced loads and the effects of downdrag on battered piles are not factors.
- Future Design grade and hydraulic grade for hurricane is not considered for this design phase but will be considered in the future design phases.
- Determine piles that require moment connections.

10.7.6 Concrete Channel Base

Armoring options for the Channel are addressed in Section 11.

10.7.7 Riprap Channel Base

Armoring options for the Channel are addressed in **Section 11**.

10.8 Siphon

10.8.1 Design Approach

10.8.1.1 Structural Description and Design Criteria

The Inverted Siphon consists of three elements: the Intake Structure, the Inverted Siphon piping, and the Outlet Structure. The reinforced concrete Intake and Outlet Structures are essentially subdivided rectangular U-frame channels with partition walls subdividing the structures at each Inverted Siphon pipe. Additionally, the Intake Structure will have finger weirs for each Inverted Siphon pipe.

The Intake Structure will feature a 20 foot wide access deck across the width of the structure and steel bar screen. In a similar fashion, the Outlet Structure will have a 15 foot access deck. Both structures feature wing walls and sluice gates for each Inverted Siphon pipe. Both the Intake and Outlet Structures will be pile supported.

The Intake and Outlet Structures as rectangular U-Frame channels will be designed in accordance with EM 1110-2-2007, *Structural Design of Concrete Lined Channels,* and ACI 318-14, *Building Code Requirements for Structural Concrete.*

The Inverted Siphon piping will consist of two - 48” and four - 60” diameter reinforced concrete pipes and will be designed in accordance with EM 1110-2-2902, *Conduits, Culverts, and Pipes.* This Inverted Siphon piping configuration varies from that discussed in section 8.11.5 Conceptual Inverted Siphon Sizing by eliminating the single 48” and single 60” pipes that were added for redundancy. The redundant pipes are not shown in the drawings and were eliminated to reduce project costs by removing two lines of piping and narrowing the required excavation limits. This can be changed if the Owner decides to have redundant piping included in the project.

The pile foundations for the Intake and Outlet Structures will be designed in accordance with EM 1110-2-2906, *Design of Pile Foundations,* based on the allowable pile capacities specified by Eustis Engineering for the Inverted Siphon Headworks Structure. Tension connectors will need to be utilized on all piling for the Intake and Outlet Structures to counteract buoyance in the channel-dry maintenance condition.

10.8.1.2 Functional Characteristics

The Intake and Outlet Structures were designed to include features and proportioned such that the following functional criteria are met:

1. Influent stormwater flow is regulated by weirs to direct successive utilization of pipes. As water surface elevation increases in the Intake Structure, additional pipes are recruited, in order that desired minimum velocity is exceeded during the widest range of influent flow magnitudes. See Hydraulic Level Control below.

2. Each pipe shall be capable of individual isolation and unwatering for maintenance.

3. Each pipe shall be capable of sealing at the culvert inlet (HSDRRS requirement).

4. Debris is screened, collected, and removed upstream of pipes.

5. Personnel and vehicular access is provided for operations and maintenance.

6. Operator safety and facility security are maintained.

10.8.1.3 Hydraulic Level Control

Stormwater influent flow magnitude, interior drainage basin headwater stages, intake stages, pipe number/diameter, and weir elevation increments will be iterated during the interior drainage modeling process in order to optimize pipe flow velocities, while meeting the broader interior drainage design criteria.

Intake stage increments between flow magnitudes, and individual pipe design flow in that stage increment will be used iteratively with the model to establish weir length. The sharp-crested weir equation will be used for this purpose.

Sharp-crested weir equation: $Q = \frac{2}{3} c_d \sqrt{2g} b H^{3/2}$

10.8.2 Excavation

Two alternate methods of excavation are presented for construction of the Inverted Siphon: Fully Sloped and Sloped-TRS. The Fully Sloped method utilizes a simple sloped excavation with 8H:1V side slopes. The existing grade elevation at the Inverted Siphon location is approximately EL -4. The cut would need to be excavated to minimum EL -39 at the Diversion Channel bottom. The required bottom width of the excavation is approximately 60 feet, with the current number and diameter of Inverted Siphon pipes.

The Sloped-TRS excavation method is a combination of a simple sloped excavation for the upper portion and a vertical sided excavation for the lower portion utilizing a temporary retaining structure (TRS) to minimize the overall amount of excavation. 4H:1V side slopes would be utilized from natural grade at -4 to -15. TRS would be utilized from -15 to -39. The width of the excavation is 53.2 feet and the excavation would be dewatered. The design of the TRS is the responsibility of the Contractor.

The Sloped-TRS excavation method greatly reduces the amount of excavation required but with the length of the excavation and large width of the excavation to accommodate the six Inverted Siphon pipes the cost of TRS may be prohibitive making the Fully Sloped method the more economical alternate. Excavation costs will be determined, evaluated, and reviewed at the next plan stage.

10.8.3 Pipe Selection (Concrete and Steel)

With number and diameter of pipes provided by the completed interior drainage model, the Inverted Siphon piping shall be designed according to EM 1110-2-2902, as pipe through levees. Considerations include the following:

1. The alignment shall maintain minimum clear cover between diversion channel bottom and top of pipe. Five (5) foot clearance is the assumed lower limit.

2. Each individual pipe shall resist buoyant force when dewatered, during design flow of the diversion channel, by combination of pipe weight and buoyant weight of soil wedge above.

3. The pipe shall adequately resist soil pressures, hydrostatic pressures (positive and negative), and remain serviceable should differential settlement be induced after construction by surface features.

Steel and concrete pipe alternates were investigated. During preliminary cost research, the estimated cost of the steel pipe alternate was found to be significantly higher than the cost for the concrete pipe alternative. Therefore, concrete pipe (AWWA C300) was selected for the Inverted Siphon piping.

10.8.4 Inverted Siphon Geometry

The Inverted Siphon profile is dictated by the Diversion Channel and levee as the Intake Structure is located at the protected side toe of the north levee and the Outlet Structure is located at the protected side toe of the south levee. The invert of the Inverted Siphon at the Intake Structure is -10. The Inverted Siphon pipe then descends at a 10H:1V slope crossing below bottom of the Diversion Channel with an invert EL -35. Once the Inverted Siphon pipe crosses the Diversion Channel it ascends at a 10H:1V slope reaching the Outlet Structure with an invert EL-10.

There are pile supported T-Walls with sheet pile cutoff providing the flood protection at the Intake and Outlet Structure locations. The steel sheet pile seepage cutoff will need to be driven prior to installation of the Inverted Siphon pipe and penetrations will be required for the Inverted Siphon piping.

In addition the location of T-Wall foundation piling, steel H-piles, will need to be coordinated with the Inverted Siphon piping to avoid damage to the Inverted Siphon piping during pile driving. Pre-drilling of the steel H-piles is recommended.

10.8.5 Headworks Design

The Intake Structure will be designed as a U-Frame channel with 20 degree wing walls at the structure’s entrance and a headwall at the end of the structure where the influent transfers to the Inverted Siphon piping. The length of the Intake Structure is 109’-6” not including wing walls. The width of the structure is 91’-10”. The height of the Intake Structure is 10 feet with top of U-Channel wall EL 0.0 and an invert EL -10.

The Intake Structure feeds four 60-inch and two 48-inch Inverted Siphon pipes. The channel is subdivided between each Inverted Siphon pipe location. All four 60” pipe subdivisions and the interior 48-inch pipe subdivision are flow controlled by finger weirs with EL -5.

Sluice gates are provided for each Inverted Siphon pipe at the headwall and are provided adjacent to the access deck at the front of the structure. The gates adjacent to the access deck are for maintenance dewatering purposes, and could be replaced with a manually-inserted stoplog or bulkhead system to reduce the O&M burden of mechanically operated gates. There is a 20-foot access deck at the front of the Intake structure. This deck will be designed for HS-20 loading. Additionally there is a steel bar screen at the entrance to the structure to capture debris.

The Intake Structure will be pile supported on timber piling and the design will look at the maintenance condition with the structure dewatered at maximum buoyancy. The piles will require tension connectors.

Sedimentation entering the Inverted Siphon piping is a major concern. While the width of the Intake Structure will slow velocities and cause some sediment to fall out prior to entering the Inverted Siphon piping, we believe that a proper Sedimentation Basin located immediately upstream designed to slow the canal velocity further than what is possible with the Intake Basin would be a beneficial addition to this project decreasing maintenance of the Inverted Siphon piping system and Inverted Siphon system performance between maintenance intervals.

The Outlet Structure will also be designed as a U-Frame channel. There are 30 degree wing walls at the structure's outlet and a headwall at the beginning of the structure where the influent transfers from the Inverted Siphon piping to the Outlet Structure. The length of the Outlet Structure is 30'-0" not including wing walls. The width of the structure is 47'-10". The height of the Outlet Structure is 10 feet with top of U-Channel wall elevation of 0.0 and an invert EL -10. The channel is subdivided between each Inverted Siphon pipe location.

Sluice gates are provided for each Inverted Siphon pipe and at the end of the structure. The same substitution of stoplog or bulkhead system in place of dewatering gates may be made at the outlet structure. There is a 15-foot access deck at the end of the Outlet Structure which will be designed for HS-20 loading.

The Outlet Structure will be pile supported on timber piling and the design will look at the maintenance condition with the structure dewatered at maximum buoyancy. The piles for the Outlet Structure will require tension connectors.

10.8.6 Gates and Trash Racks

The Intake Structure will have six (6) 10-foot sluice gates at the entrance as well as four (4) 5-foot and two (2) 4-foot sluice gates for each Inverted Siphon pipe at the rear headwall. All cast iron sluice gates will be rising stem, cast iron and meet AWWA C560. The sluice gates will be have flush bottom closures to eliminate the recess required for a standard gate closure which could prevent the gate from being fully closed should debris collect in the recess.

The Inlet Structure will also feature a steel bar screens with mechanical bar screen cleaners at the entrance to the structure preventing debris and trash in the canal from entering the structure and Inverted Siphon piping.

For the Outlet Structure, there will be four (4) 5-foot and two (2) 4-foot sluice gates for each Inverted Siphon pipe at the influent headwall. There will be six (6)-6 foot sluice gates at the exit of the structure. The cast iron sluice gates will be rising stem, cast iron and meet AWWA C560 specification. The sluice gates will be have flush bottom closures to eliminate the recess required for a standard gate closure which could prevent the gate from being fully closed should debris collect in the recess.

10.9 Marine Structures

TBD

10.10 Hwy 23 Bridge T-Walls

The Hwy 23 Bridge is located approximately at Station 65+00 of the Conveyance Channel alignment and is approximately 2,250 feet west of the guide levee tie-in for the Transition T-Wall. To protect from hurricane surge, T-Walls are proposed below the bridge instead of earthen levee on both sides of the

Conveyance Channel. The T-Walls are located on both the north and south sides of the channel and are identical. The proposed T-Wall will connect to the guide levee tie-ins. The Conveyance Channel T-Walls are located at a potential in-the dry construction zone. There is no need for braced construction to construct these T-Walls. The top of the base slab for the all Conveyance Channel T-Walls is at EL 3.

10.10.1 Design Approach

For the 15% design phase, hand calculations based on the Ultimate Strength Design using ACI 318-14 and EM 1110-2-2104 as listed in the Design Criteria, Rev. 2 dated 4/27/2018 are performed to determine allowable shear and flexure acting on the stem and slab of the inverted T-Wall monoliths. Serviceability requirements are not checked at the 15% level design but will be checked in future phases.

For the 15% preliminary design phase, the quantities and size of T-Wall including number of piles, pile sizes, pile tips, length and base slab dimensions are calculated and can be found in **Appendix J**. The Conveyance Channel T-Walls under Hwy 23 Bridge start at EL 3 at the eastern guide levee tie-in and end at EL 3 at the western guide levee tie-in. The T-Wall monoliths and pile foundations are calculated based on hand calculations and excel spreadsheets for the design of components. Soil parameters provided by Eustis Engineering are used to calculate the soil pressures and pile capacities. All structural calculations and geotechnical information are included in **Appendix J**.

10.10.2 Pile Foundation

All monoliths are pile supported with pile tips set to mitigate differential settlement among monoliths. The piles are designed for lateral and vertical loads only for the 15% design phase. The moment from vertical and lateral loads are not considered for analysis. During the next phase, all the loads and moments will be included in the analysis for deflection and combined stress for piles. Pile axial capacity is calculated by multiplying the lateral load times the pile slope. Assuming that a static pile load test would be performed, the allowable Factor of Safety for pile loads is 2.0 in accordance with the MBSD Design Criteria. The required pile tip elevation is then found using the maximum tension and compression loads from the analysis results and plotting the points along the pile capacity curve for 24-inch diameter open-end steel pipe pile. Group analysis on piles is not performed for the 15% design phase. The pile size, pile tip elevation and pile capacities can be found in the drawings and calculations, **Appendix D** and **Appendix J**, respectively. The pile capacities are calculated by using the Eustis Engineering Design Soil Parameters and Pile Capacity data in Section 9.12.

10.10.3 Geometry

10.10.3.1 Base Slab and Stem

The base slab for the Conveyance Channel T-Walls is at EL 3 and the T-Wall monoliths extends 250 feet (50-foot per Monolith) from the east guide levee tie-in to the west guide levee tie-in on the north and south side of the Conveyance Channel. There are five identical T-Walls on both the north side and south sides of the Conveyance Channel. The T-Wall monoliths are identical on both sides. For this phase the top of slab for all Conveyance Channel T-Walls is at EL 3 and top of wall is EL 15.6. The T-Walls are back-filled with sand to EL 5 on both sides of the stem wall. Top of wall elevation is EL 15.6 for the 15% design phase. Wall stem height is 12-foot 6-inches and is the same for all monoliths. Base slab width and thickness is 15 feet and 5 feet, respectively. A continuous cut-off sheet pile curtain wall is installed beneath the monolith base slabs. All monoliths are pile supported with pile tips set to mitigate differential settlement among monoliths. Settlement calculations are not performed in the 15% level design but will be performed in the future phases. See **Appendix D** for pile layout, tip elevations, sizes and other pile features.

10.10.3.2 Cut-off Wall Sheet Pile

The cut-off wall of sheet piling is provided to limit seepage, and the embedment criteria are specified in the Geotechnical Report Section 9. Cutoff sheet pile will extend via a sheet pile transition wall into the levee embankment. The transition wall will be 30 feet long and the top of the sheet is matched with the levee crown. Cut-off sheet pile will be extended 30 feet beyond the T-Wall at the guide levee tie-in for the T-Wall monoliths. The top of the sheet pile at these locations is set to match with the guide levee tie-in crown elevation.

10.10.4 T-Wall Analysis

Analysis of the 3-dimensional structure was performed using a combination of hand calculations and Excel spreadsheets. The hand calculations, provided in the **Appendix J**, consider the self-weight of the T-Wall monolith, the water weight and pressure, the soil weight and pressure, and uplift forces. There are no unbalanced loads shown in the geotechnical stability analysis at EL 3. The DT is proposing to eliminate the unbalanced loads by soil remediation with soil cement stabilization. Therefore, the unbalanced load for the 15% level design phase is not considered.

By summation of the applied forces and moments acting on the wall, the pile force and moments below the T-Wall were determined. Hand calculations were also performed to check the design of the stem wall and the base slab of the inverted T-Wall monolith in accordance with the MBSD Design Criteria. Factored concrete design loads are used to confirm the adequacy of the stem wall and slab thickness.

To streamline the design process across each of the Alignments, the T-Walls are designed identical. Design and analysis are performed for only the EL 3 base slab elevation. A continuous cut-off sheet pile curtain wall is installed beneath the monolith base slabs. All monoliths are pile supported with pile tips set to mitigate differential settlement among monoliths. Settlement calculations are not performed in the 15% level design but will be performed in the future phases. See **Appendix D** for pile layout, tip elevations, sizes and other pile features. Settlement calculations are not performed in the 15% level design but will be performed in the future phases. See **Appendix D** for pile layout, tip elevations, sizes and other pile features.

10.10.4.1 Load Cases

The load cases as described in the MBSD Design Criteria Table 5-5 (**Appendix U**) are used as a guide for creating the load cases evaluated in the analysis, which were considered most likely to control the design. Engineering judgment is used in selecting the load cases by comparing the magnitude of the applied loads and the allowable overstress. Only the basic load cases are evaluated. The design resiliency checks will be evaluated in a later phase of the project. The basic load cases selected for the analysis are as stated in the table below.

The analysis evaluated the pervious and impervious cut-off wall uplift conditions. The following table shows the selected load cases. The hydraulic grade and design grades are from the MBSD Design Criteria Table 2 & 3 of Section 2, Rev. 2, submittal draft No. 3 dated 4/27/2018.

Table 10-16: Hwy 23 T-Wall Design Load Case Summary

Load Case	Description	River Side Water EL	Land Side Water EL	Factored Load Combinations
1	Construction without soil, with surcharge	N/A	N/A	1.6(D+EH+EV+Ls)
4 & 5	Water at Design SWL	9.1	1.0	2.2(D+EH+EV+Hs+Hu)
14 & 15	Channel Low Water Reverse Head	1.0	1.0	2.2(D+EH+EV+Hs+Hu)
17 & 18	Water to Top of Wall	15.6	1.0	1.6(D+EH+EV+Hs+Hu+HW+W)
17 & 18 Alt.	Water to Top of Wall	12.1	1.0	1.6(D+EH+EV+Hs+Hu+HW+W)

Notes: 1) Unbalanced loads not considered in this phase
2) 4, 14 & 17 impervious uplift, 5, 15 & 18 pervious uplift
3) DL= Dead Load, EH= Lateral Earth, EV= Vertical Earth, Ls= Construction Surcharge, Hs= Peak Hydrostatic, Hu= Uplift, HW= Wave, and W= Wind

10.10.5 Future Analysis and Design Considerations

The following will be addressed in future submissions:

- Coordinate with the adjacent structures to identify and rectify any pile conflicts.
- Combine the floodwall and siphon headwall as an alternative design.
- Evaluate all applicable load cases, including the design resiliency checks.
- Verify the assumed construction sequence to determine its appropriateness.
- Investigate pile foundation deformations and mitigation measures.
- Perform a more detailed design check for all of the structural members including rebar for shear and flexure.
- Determine the piles that requires tension connections.
- Piles analysis using group pile program by Ensoft Corporation.
- Future Design grade and hydraulic grade for hurricane is not considered for this design phase, but will be considered for the future design phase per DT.
- Determine piles that require moment connections.

11. CONVEYANCE CHANNEL AND LEVEES

11.1 General

The Conveyance Channel was designed to convey the sediment-laden river water from the Intake Structure to the Basin without overtopping the guide levees with enough velocity to prevent buildup of siltation in the channel and with protection against scour. At Workshop No. 2, a parallel Hurricane/Guide Levee alternative was compared to a Back Gate alternative, and the parallel Hurricane/Guide Levee alternative was selected. This is discussed in **Section 7**. The Guide Levees from the Diversion Gate Discharge Transition Segment to the new federal NOV-5a Levee Reach, which is located near the Timber Canal, will serve as hurricane flood protection. From the NOV-5a Levee Reach to the Diversion Outfall, the guide levees will serve only to convey the discharge flows.

With the decision at Workshop No. 2 to eliminate the Back Gate Structure, the channel guide levees must not only confine the diversion's discharge, but also serve as hurricane flood protection levees against hurricane storm surges.

11.2 Design Approach

The approach for the hydraulic design of the Conveyance Channel is discussed in **Section 8.6**; the geotechnical design approach for the levees is discussed in **Section 9.16**.

11.3 Conveyance Channel Geometry

The results of the numerical modeling of the Conveyance Channel are discussed in **Section 8.6**. The cross section of the channel includes a bottom width of 300 feet, with invert EL -25. Side slopes extend at 4H:1V until EL -2, where a berm extends 97 feet to EL 4. The total width of the Conveyance Channel is 734 feet.

11.4 Levee Design

Without a Back Gate Structure, the levees must provide hurricane coastal protection against storm surges. The DT investigated two design grades, one at EL 12.1 and the second at EL 15.6. The EL 12.1 grade provides a higher level of storm damage risk reduction than does the proposed USACE New Orleans to Venice (NOV) 5a levee project. The USACE project Design Grade is EL 9.6, which correlates to a 25-yearr event without overbuild for future Sea Level Rise (SLR). The EL 12.1 equates to a 25-year Storm with overbuild to account for 25 years of SLR and regional subsidence based on rates established by the USACE. The EL 15.6 grade is the USACE Design Grade for the Reach NOV-NF-W-05c, projected 50 years into the future (i.e., 2063), also accounting for SLR and regional subsidence. The DT recommends a Design Grade of EL 15.6 as further explained in **Section 11.5.9**.

The levee will be constructed with an overbuild of earthen materials, which will vary along the reaches of the channel as dictated by geotechnical analysis. A 10-foot wide levee crown will be topped with a 6-inch thick gravel access road. Side slopes will be constructed at 4H:1V with turf reinforcement and/or armoring; the levee slopes will extend to EL 4, then will slope to intersect existing ground on the protected side, and slope to form a berm to the top of the Conveyance Channel on the flood side. The wick drains will accelerate most of the predicted settlement to occur within the planned construction duration. One, 12-inch lift will be required at 20 years after construction to maintain EL 15.6. The DT estimates that sufficient quantities of suitable material required to construct the levee, including overbuild for settlement, is available from conveyance channel and Headworks excavation. The quantity calculations used the soil boring data obtained during BOD Phase, the latest topographical surveys, and a conservative 1.5 loss factor. Note that the unsuitable material will be used as Beneficial Use Material as described in **Section 24**.

Installation of a wick drain system will accelerate expected levee settlement. A grid layout of wick drains will be overlain by a granular drainage layer, and the levees will be constructed in stages so that the underlying soils incrementally gain strength as the levee is raised. A through-seepage cut-off will need to be installed through the drainage layer. The 15% drawings show a clay plug; however the final design will be decided in coordination with the CMAR. The DT briefly considered Deep Mixing Method (DMM) columns or panel to support the levee embankment, but did not develop a conceptual design because there is sufficient real estate to construct through wick-drain-aided staged construction, and by inspection this will be more economical than DMM columns/panels, provided there is sufficient on-site fill material available to complete embankment construction. The selection of the wick drains will be confirmed in coordination with the CMAR during the 30% Phase.

Other Conveyance Channel features of note include T-wall segments beneath the new Hwy-23 Bridge and at the new Inverted Siphon inlet and outlet. The Inverted Siphon will be located near the Timber Canal. Canal closures at the Timber Canal and Back Levee Canal will also be features of the Channel and Guide Levee System. T-walls are discussed in **Section 10**. Canal Closures are discussed in **Section 9**.

11.5 Armoring Design

11.5.1 General

The DT conducted an analysis of viable methods to protect the Conveyance Channel from erosion damage. The methodology and details of that analysis are presented in the Conveyance Channel Revetment Study included in **Appendix N**. The work involved the review of numerous guidance documents which are enumerated in the study and in the DCD in **Appendix U**.

The DT established four criteria to evaluate the protective armoring: 1) Maintain a stable bank configuration, 2) Protect against erosive forces, 3) Provide minimal frictional resistance, and 4) Be cost-effective. The team reviewed the plan and profile along with the cross-section of the Conveyance Channel in detail, dividing the channel into five sections: 1) Channel bottom, 2) Channel slope, 3) Stability berm, 4) Bottom half of levee slope, and 5) Top half of levee slope. The DT evaluated the conditions at each section and developed recommended armoring solutions. The team determined that three types of armoring were viable alternatives and reviewed each of them in detail: 1) Riprap revetment, 2) Articulated concrete blocks (ACBs), and 3) Turf reinforcement mats.

11.5.2 Geotechnical Considerations

The DT reviewed the main geotechnical considerations that would affect the performance of the various revetment alternatives. Based on the limited geotechnical data gathered to date, a major portion of the native material is comprised of highly dispersive clays that are readily subject to erosion without some form of protection. Geotechnical analyses of the available data indicate that substantial settlement will occur in the areas where the new levee and stability berm will be constructed **(Appendix G)**. The DT geotechnical analyses predict major settlement both during construction, as well as over 3-feet of additional long term settlement after completion of construction. The size and required layer thickness of the riprap will result in greater settlement than an ACB system due to the significant difference in weight. The heterogeneous nature of soils suggests that the settlement will not be uniform across all areas, thus the DT anticipates that there will be significant differential settlement. The differential settlement is problematic for the ACB system.

The small size of the clay soil particles, along with the seepage potential due to changing water levels inside and outside of the channel, will require a filter base to prevent the loss of fines. The DT recommends the use of a graded filter, along with a geotextile separator fabric, where feasible, to address this issue. Due to the lack of complete geotechnical information, the final filter design cannot be performed at this time. Based on the available data, the DT assumed that the riprap would have a filter base of 2-feet of sand plus 6 inches of No. 57 stone. A 6-inch bedding layer of sand was assumed for the ACB system, along with a geotextile, which can be attached to the bottom of the ACB mats, enabling its installation either in-the-wet or in-the-dry. Since an accurate method of installing the separator fabric underneath riprap in a significant depth of water has not yet been developed, the DT assumed that fabric would be installed under the riprap only in the areas of in-the-dry construction. The team is currently conducting slope stability analyses to delineate those areas that can be constructed in-the-dry.

11.5.3 Failure Modes

The DT assessed the revetment requirements to protect the Conveyance Channel against three potential failure modes: 1) Shear stress, 2) Seepage, and 3) Wave action. Shear stress failure is the movement of revetment material due to the hydraulic forces acting over a range of channel flows during Normal Operating Conditions. Seepage failure is the loss of fines from the underlying soil due to water movement through the revetment. Wave action failure is damage to the revetment and subsequent erosion of channel material due to wind-driven impacts from major Storm/Hurricane Conditions.

11.5.4 Revetment Sizing

The DT calculated the required sizes of riprap revetment and ACBs under both the Normal Operating Conditions and the Storm/Hurricane Conditions. The team modeled the water depth and velocity for cross-sections in each reach of the Conveyance Channel during Normal Operating Conditions with a flow of 75,000 cfs. Based on the resulting water depths and depth-averaged velocities, the DT sized riprap revetment for the various locations within the cross-section using the EM 1110-2-1601 protocol. The results showed that (under the LADOTD classification system) 10-lb stone riprap with layer thicknesses of 1-foot and 1.5-feet would be sufficient for the areas constructed in-the-dry and in-the-wet, respectively. Using the same data, the team calculated the Factor of Safety for various ACBs based on the National Concrete Masonry Association design procedure. The calculations showed that a 4-inch thick ACB would be sufficient to withstand the Normal Operating Conditions with a Factor of Safety of 3.3.

The DT is currently modeling the effects of Storm/Hurricane events on the conditions within the Conveyance Channel. Since that work is not yet complete, the results of earlier modeling performed by HDR were used to estimate the revetment requirements. HDR obtained the following results for the maximum wave heights from two 1-D cases run using the ACES software for a 50-Year return period:

Table 11-1: HDR Model Results from Storm\Hurricane Conditions

Case	WSE Exceedance Probability	WSE (ft NAVD88)	Maximum Wave Height (ft)	Wave Period (sec)
1	10%	1.85	2.2	3.7
2	2%	10.4	6.0	4.7

The maximum wave heights occur for a very short distance along the Conveyance Channel starting at the Barataria Bay end, in the center of the channel. HDR's graphical depiction of the data shows that the wave heights never exceed 0.33-ft along the channel slopes and rapidly attenuate along the length of the channel to just over 1.3-ft in the center of the channel. Based on the industry standard Hudson and van der Meer formulas the riprap sizes to resist the wave forces at the entrance to the channel were determined by HDR to be: 30-lb stone for the 10% probability event and 250-lb stone for the 2% probability event. The DT will investigate the armoring requirements for the intake and outfall ends of the channel in the next phase; the subject work addresses only the main reach of the channel itself.

For the main reach of the channel, based on the relatively small 0.33-ft waves on the channel slopes the 10-lb stone is proposed as sufficient protection. The 10-lb stone is also recommended for the channel bottom because the 30-foot water depth prevents the forces from the 1.3-ft waves at the surface from reaching the bottom. For the ACBs, the DT assumed that a 4-inch ACB block will be sufficient across the entire cross-section for both the Normal Operating Conditions as well as for both Storm\Hurricane events. All of these calculations will be recomputed once the DT completes the modeling of the Storm/Hurricane conditions.

11.5.5 Revetment Friction Coefficient

The frictional coefficient, n, in Manning's equation for open channel flow is inversely proportional to the volumetric flowrate through the channel. E.g., a 10% reduction in n results in a 10% increase in flow. The DT researched n values for various revetment materials from numerous sources. For a finished concrete surface, n = 0.013 is commonly used, while for 6-inch riprap, n = 0.035 is typical. The size of the riprap affects the n value, e.g., for "nominal conditions", 1-inch gravel n = 0.030 while for 12-inch stone n = 0.040. The concrete ACBs do not butt perfectly together, creating a checkboard of gaps across the mattress which raises the n value. The typical value quoted by ACB manufacturers is n = 0.020.

The n value is also a function of the depth of flow; the shallower the water, the larger the n. Thus, the n value for the same material would be less on the channel bottom, under 30-feet of water, than near the surface in only a couple of feet of water. Another factor affecting the n value in the Conveyance Channel is the potential sediment accumulation, filling the gaps and voids, and perhaps even covering the entire surface of the revetment. The DT will continue to research the appropriate n value to use, based on additional literature searches, calculations, modeling of the sedimentation process, and possibly physical modeling of revetment with and without accumulated sediment.

11.5.6 Construction Considerations and Costs

Review of construction considerations and estimated costs of each system can be found in **Appendix N.**

11.5.7 Revetment Configuration

The depth of the channel bottom isolates it from the effects of significant storm events. Therefore, the Normal Operating Conditions govern its design. Since the 10-lb riprap is much less expensive that ACBs and because of the difficulty of aligning the ACBs on the bottom, 10-lb riprap is recommended for the channel bottom. The channel slope, stability berm, and levee will experience the wind-driven wave forces during major storm events. However, since the DT has not modeled the effect of the Storm\Hurricane Conditions on the Conveyance Channel and the HDR graphic shows rapid attenuation of the wave heights, the current design recommendation for the majority of the Conveyance Channel is the use of 10-lb riprap throughout the entire cross-section. The riprap was chosen over the ACB system since proof of performance of an ACB system under such conditions has not been documented yet.

All of the riprap will be installed over a dual filter layer comprised of 6 inches of No. 57 stone plus 2 feet of sand. All areas constructed in-the-dry will have geotextile separator fabric installed. The DT will continue to investigate feasible ways of installing fabric in the wet. The recommended revetment protection system for the in-the-wet construction conditions is thus:

Table 11-2: Recommended Revetment Configuration In-the-Wet Construction

Cross-Section Location	Protective Revetment		Filter Layer[1]	
	Material	Thickness	Material	Thickness
Channel Bottom	10-lb Riprap	1.5-ft	No. 57 Stone	0.5-ft
			Sand	2-ft
Channel Slope	10-lb Riprap	1.5-ft	No. 57 Stone	0.5-ft
			Sand	2-ft
Stability Berm	10-lb Riprap	1.5-ft	No. 57 Stone	0.5-ft
			Sand	2-ft
Bottom ½ Levee	10-lb Riprap	1.5-ft	No. 57 Stone	0.5-ft
			Sand	2-ft
Top ½ Levee	HPTRM	N/A	N/A	N/A

1. If a feasible method of installing the fabric in-the-wet is developed a layer of geotextile filter fabric will be installed above and below each of the sand layers. Where construction can be performed in-the-dry, the geotextile layers will be installed.

11.5.8 Path Forward

The following activities will be performed to progress the design:

- The DT will collect additional geotechnical data and perform laboratory testing and analyses. This will enable refinement of the required filter layers and will inform the selection of the optimum revetment materials, sizes, and layer thicknesses.
- The DT will perform geotechnical stability analyses to delineate areas that can be constructed in-the-dry and define the sequence of construction events required to keep a stable excavated slope (in-the-dry) with an adjacent levee section.
- The DT will perform hydrodynamic modeling of Storm/Hurricane Conditions and define the effects on the Conveyance Channel. The team will select a design storm and design a revetment system to withstand such conditions.
- The DT will perform sediment transport modeling within the Conveyance Channel. The results will be used to select an appropriate n value and model the performance of various revetment configurations.

- The DT may perform physical modeling to measure the n value of riprap and/or ACB with various amounts of sediment deposition. The results will be used along with the sediment transport modeling to select the most cost-effective revetment system.
- The DT will continue to investigate potential methods for the installation of geotextiles and other filter components under water.
- The DT will refine the revetment configuration using multiple riprap and/or ACB sizes across the channel cross-section.
- The DT will estimate the maintenance costs for the various revetment systems and calculate life-cycle costs for comparison of alternatives.

11.5.9 Recommendations

11.5.9.1 Revetment

The recommended armoring system is described in **Section 11.5.7**. The Manning's "n" value will be verified in physical modeling performed in the next design phase. The modeling will include the recommended riprap and the effects of a sustained silt layer covering the riprap. Numerical models will be revised as needed. Armoring enhancements to sustain surge effects at the basin outlet will be developed in the next design phase.

11.5.9.2 Channel Geometry

The recommended channel geometry is described in **Section 8.6**. The 300 ft bottom width at EL-25 and side slopes at 4H on1V is recommended for current boundary conditions and also future conditions. The excavated channel provides sufficient suitable material for levee construction.

11.5.9.3 Levee Design Grade

The DT recommends a Design Grade EL 15.6 for the hurricane levees that extend from the Diversion Gate Structure to the USACE NOV 5a tie in. The levee segment to the basin side of the NOV 5a tie-in, will be constructed for conveyance requirements only; a design Grade of EL 9.5 is recommended. The conveyance water surface elevation, considering future conditions, at the basin end is EL 6.2. A freeboard of 3 feet was added to the conveyance stage, and the design grade was rounded to EL 9.5. The recommendation for the hurricane grade of EL 15.6 considered risk reduction (protection levels), cost, available material, available Right of Way, and the 100-year level of protection proposed by the Alliance Refinery. The main concern is flood protection for Plaquemines Parish. The USACE NOV projects constructed post Katrina used a 50 year future design grade. All major structures built along the NOV levee system south of Oakville, LA were built to the 50 year future design grade. USACE levees would be increased to the same grade over time if funding was sufficient. In building to EL15.6, the MBSD project would be matching the highest level of protection. With the elimination of the back structure, the recommended EL 15.6 grade exceeds the current NOV 5a levee project by 6 feet, an apparent risk reduction measure. The channel excavation will provide a sufficient amount of suitable material to construct Levees to EL15.6 considering all settlement and related overbuild. The unit cost of levee material will not need to be increased to include borrow pits or imported material. The proposed Right of Way of 800 feet each side of Channel C/L is adequate to cover the footprint for the levee section at EL 15.6. If the NOV Levee on the upriver side of the diversion later were to be raised to a 100-year level of protection, that grade is EL 15.1, not accounting for future SLR or regional subsidence. The recommended 50-year future design grade slightly exceeds that grade. The cost increase to construct to the recommended EL 15.6 compared to EL 12.1 is approximately $17.9 million. For the reasons included herein, the DT considers the added cost worth the value added. On a percentage basis, the total cost of the hurricane protection is $276.0 million; the increase represents a 6.5% increase. In comparison, the back structure's construction cost is estimated at $276.6 million, not including the cost to construct the parallel guide levees, so it is still the more economical alternative.

12. OUTFALL TRANSITION FEATURE

12.1 General Design Approach

The outfall transition feature (or outfall channel or outfall ramp) is considered the area on the basin side of the existing NOV Levee that transitions the Conveyance Channel to the natural ground within the basin. The design of the outfall channel considers two primary features. The first and primary feature is the slope transition between the Conveyance Channel and the natural ground within the basin to reduce the head loss. The analysis is performed with hydraulic models and includes an iterative process to optimize the transition. The second feature is the scour protection near the NOV Levees and the transition channel.

A hydraulic and cost analysis of the outfall ramp configuration has been conducted to guide the selection of the final ramp design. The primary function of the outfall ramp is to provide a gradual transition from the Conveyance Channel to the basin. The invert of the Conveyance Channel is approximately EL -25 and the basin elevation near the outfall is approximately EL -4. The ramp is intended to be a temporary feature of the design. It is expected that the diversion discharge will eventual erode a channel into the basin based on the results of the TWIG's Basin Wide Model and Outfall Management Models. Thus, the role of the outfall ramp is to provide an initial transition during the first few years of operation or until a channel is eroded. The ramp configurations were evaluated based on two metrics, the head loss and the capital dredging costs.

12.2 Hydraulic Design

The hydraulic analysis of the outfall transition feature was described in **Section 8.8**.

The analysis indicated that the head loss due to the transition feature did not depend significantly on the half-flare angle (the angle that the ramp widened as it extended into the basin). The head loss was dependent on the length of the ramp, with decreasing changes as the ramp approached 4,000 to 5,000 feet. A summary of the head losses for each ramp assuming a 10 degree half-flare angle, are summarized in Table 12-1 and shown graphically in Figure 12-1.

Table 12-1: Summary of Stage Impacts

Ramp Length (feet)	Upstream Stage (ft, NAVD88)	Tailwater Stage (ft, NAVD88)	Head Loss* (ft, NAVD88)	Relative Difference** (feet)
500 ft	6.13	2.84	3.30	1.06
1000 ft	5.63	2.84	2.79	0.55
1500 ft	5.42	2.84	2.58	0.34
2000 ft	5.31	2.84	2.48	0.23
3000 ft	5.19	2.84	2.36	0.11
4000 ft	5.08	2.84	2.24	0.00
5000 ft	5.08	2.84	2.24	0.00

*Head Loss does not include velocity (difference in stage only)

**Compared to Head Loss for the 5000-foot ramp length

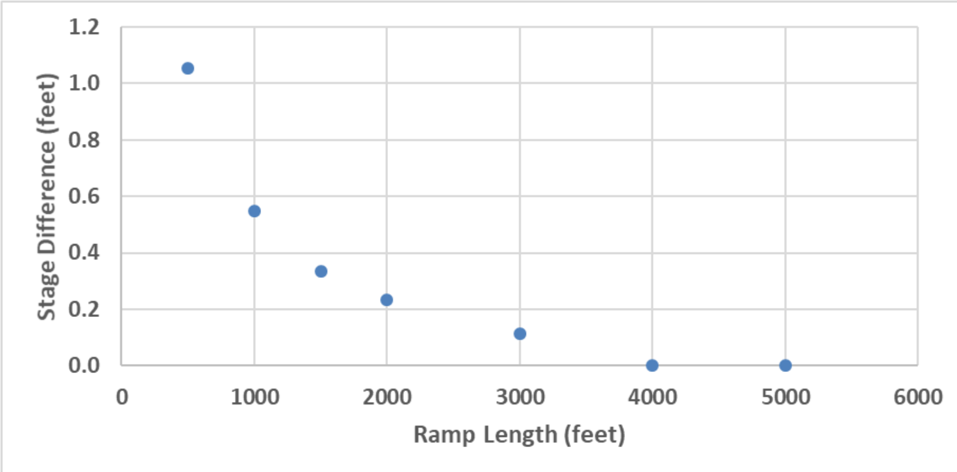


Figure 12-1: Difference in Head Loss (compared to 5,000-foot ramp length)

The footprint of each ramp alternative and the dredge volume required to construct each ramp configuration are provided in Table 12-2.

Table 12-2: Summary of Head Loss and Dredging Requirements

Length (ft)	Flare Half-Angle (deg)	Relative Difference (feet)	Footprint Area (ft^2)	Dredge Volume (cy)
500	10	1.06	321,000	89,900
1000	10	0.55	679,000	195,300
1500	10	0.34	1,163,000	335,100
2000	10	0.23	1,693,000	483,300
3000	10	0.11	3,096,000	866,900
4000	10	0.00	4,826,000	1,329,900
5000	10	0.00	6,891,000	1,874,700

12.3 Armoring and Toe Sheeting

With high velocities within the Conveyance Channel, scour protection will be required near the NOV Levees of the outfall. The revetment sizing within the Outfall Transition Feature is similar to the Conveyance Channel and is selected based on velocities. Scour protection based on wave energy was not considered as water depth in the channel prevents the wave forces from reaching the bottom. The effects of storm/hurricane will be further modeled and incorporated during the next phase of design.

Depth averaged velocities were analyzed within the outfall channel and considered comparable or reduced to the Conveyance Channel. See Figure 12-2 for depth averaged velocities.

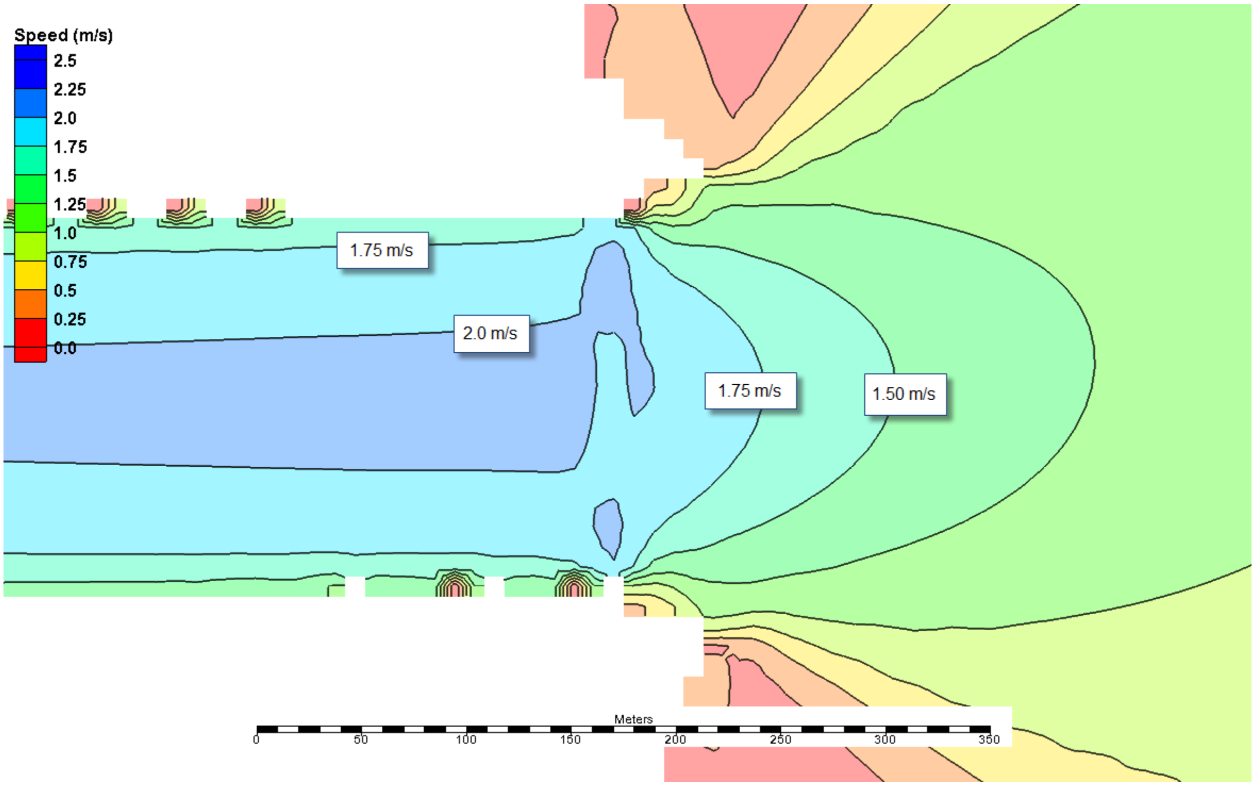


Figure 12-2: Depth Averaged Velocities within Outfall

As the flow within the channel transitions into the basin, velocities are reduced. Therefore, 10lb riprap is proposed for the Outfall Transition Feature similar to the invert of the Conveyance Channel. The armoring will be installed from the existing NOV Levee to EL -20. This armoring is to protect the integrity of the existing NOV Levee and the Shell pipeline. The existing Shell pipeline is located on the flood side of the NOV Levee at a shallow depth. The pipeline will be relocated to below the Outfall Transition Feature prior to construction and operation of the diversion. The pipeline relocation should be sufficient for scour protection of the pipeline, although the armoring proposed for the NOV Levee will provide an extra level of protection. As the flow extends past the Outfall Transition Feature, the intent of the diversion is to build its new channel to deliver sediments into the basin. Therefore, scour protection along the ramp between the EL -20 and the natural ground is not proposed.

The protection measures along the existing NOV Levee is proposed at 250-pound riprap. This is based on the 50-Year storm event and sized as a part of the Conveyance Channel and levees armoring design. The armoring section along the NOV is proposed for a distance of 100 linear feet past the tie in point of the NOV Levee and the Conveyance Channel levee.

In addition to the riprap armoring, toe sheeting at the transition point will be installed near Station 140+00. Sheets will extend across the Conveyance Channel invert to the crown of the Conveyance Channel levee. Sheeting is proposed at PZ-27 and will have a top EL -27 with a tip EL -57. Sheet pile will be capped with a riprap protection that includes 6 inches of bedding stone and 18 inches of 10-pound riprap. Sheets will be stair stepped up the slopes of the Conveyance Channel at 5-foot increments. Figure 12-3 shows the toe sheeting detail. A cross section of the toe sheeting is shown in the BOD Plans.

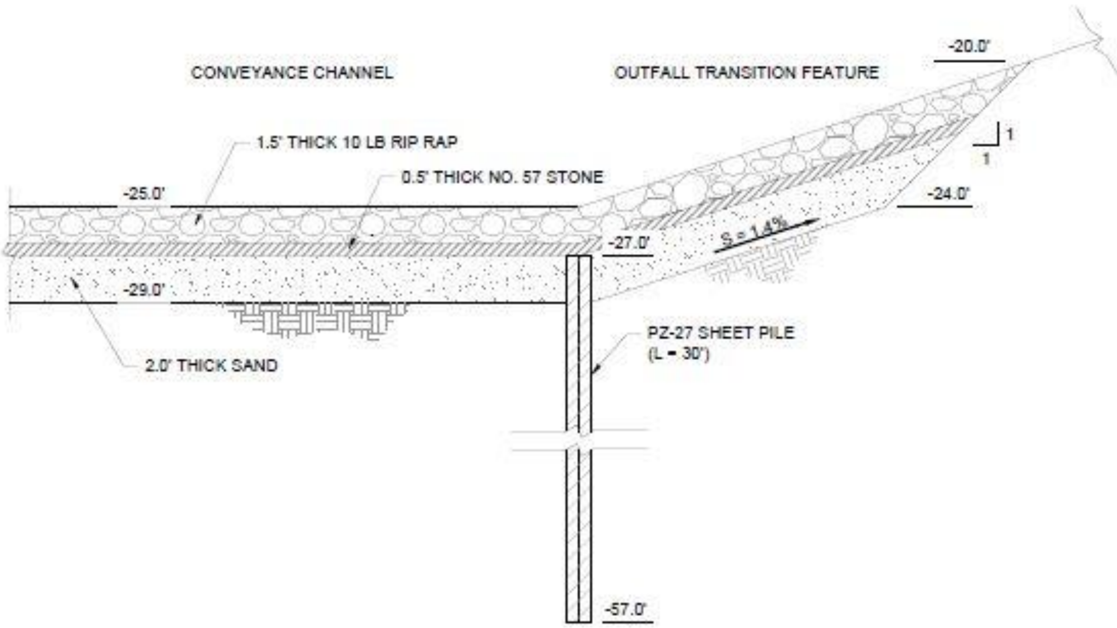


Figure 12-3: Toe Sheeting Detail

13. HWY 23 ROADWAY AND BRIDGE

13.1 General

Hwy 23 is a north-to-south state highway that serves both Plaquemines and Jefferson Parishes. It is also known as Belle Chasse Highway, Lafayette Street, and the West Bank Expressway at different locations along its length. Hwy 23 connects Gretna and Venice. Between Belle Chasse and Venice, the highway is the main thoroughfare along the western bank of the Mississippi River. This route provides the only access in and out of Plaquemines and lower Jefferson Parishes and is a State of Louisiana evacuation route during hurricane season. Hwy 23 is approximately 74 miles long. Within the area of the project, the roadway is a four-lane rural arterial asphalt composite roadway with 4 feet wide inside and 10 feet wide outside shoulders and a 42 feet wide depressed grass median. The existing typical section is shown in **Appendix D**.

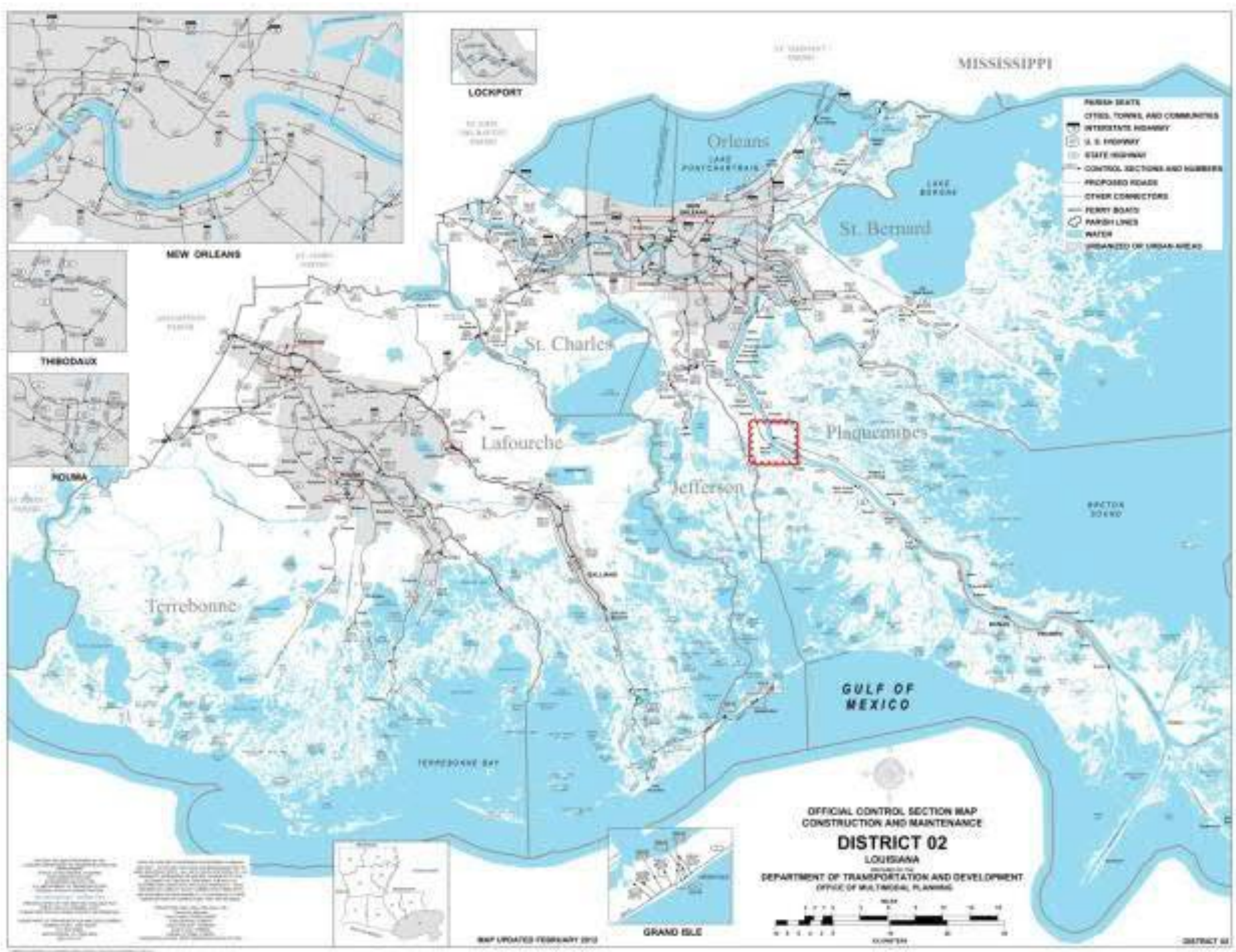


Figure 13-1: Location Map

Source: LADOTD (2012)

The area outlined in red is the location of the MBSD, which is south of the ConocoPhillips Alliance Refinery and north of the town of Ironton in Plaquemines Parish. The portion of Hwy 23 in this area would be affected by the project.

13.2 Design Approach

In BOD Project Phase, the DT was tasked to perform a traffic study and review highway alignment alternatives that update the proposed highway and bridge work to current LADOTD standards. Due to the design changes in the channel, the roadway geometrics will require further refinement in future design phases. Three alternatives were developed and analyzed utilizing the Conveyance Channel geometry established prior to Design Workshop Nos. 1 and 2. These alternatives considered right of way acquisition, maintenance of traffic, constructability, and cost.

13.3 Roadway and Bridge Design Criteria

13.3.1 List of References

The roadway and bridge would be designed in accordance with LADOTD standards and specifications. The following published design standards and manuals are to be used during the design of the Hwy 23 reconstruction:

- LADOTD Roadway Design Procedures and Details (often referred to as the Roadway Design Manual), latest edition
- LADOTD Minimum Design Guidelines dated March 6, 2017
- AASHTO A Policy on Geometric Design of Highways and Streets, 2011 Edition
- AASHTO Roadside Design Guide, 4th Edition
- AASHTO Highway Safety Manual, 2012 Edition
- Engineering Directives and Standards Manual (EDSMs)
- LADOTD Guidelines for Conducting a Safety Analysis for Transportation Management Plans and Other Work Zone Activities
- LADOTD Traffic Management Plan
- LADOTD Construction Plans Quality Control/Quality Assurance Manual v2013
- LADOTD Hydraulics Manual
- LADOTD Erosion Control Guidelines
- LADOTD Bridge Design and Evaluation Manual
- Highway Capacity Manual, 2010 Edition
- Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD), 2009 Edition with revisions 1 and 2 in 2012
- LADOTD Highway Specifications Workbook
- LADOTD Louisiana Standard Specifications for Roads and Bridges, 2016 Edition
- LADOTD Standard Plans and Details
- Current Federal Regulations (CFRs)
- LADOTD Location and Survey Manual

13.3.2 Design Criteria

13.3.2.1 Roadway Design Criteria

Hwy 23 is classified as a Rural Minor Arterial. Table 13.1 presents the selected roadway design criteria selected from the Minimum Design Guidelines, last updated on March 6, 2017.

Table 13-1: Selected Design Criteria for Hwy 23

Item no.	Item	Rural Minor Arterial (LA 23)	Local Roads	Ramps
1	Design speed (miles per hour)	65	30	50
2	Number of lanes	4	2	1
3	Travel lane width (feet)	12	11	15
4	Shoulders			
	Two-lane facility	N/A	2	N/A
	Divided facility inside shoulder	4	N/A	5 (paved)
	Divided facility outside shoulder	10	N/A	6 (paved)
5	Median			
	Depressed	< 64 ft with median barrier	N/A	N/A
	Raised	Not applicable	N/A	N/A
	Two-way left-turn lane	Not applicable	12 feet min.	N/A
6	Fore slope (vertical-horizontal)	1:6	1:4	1:6
7	Back slope (vertical-horizontal)	1:4	1:3	1:4
8	Pavement Cross Slope (%)			
	Cross Slope in Tangent	2.5	2.5	2.5
	Max Cross over Crown (Travel Lanes)	5	5	5
	Max Cross over Crown (Shoulder)	7	7	7
9	Stopping sight distance (feet) (AASHTO Green Book)	645	200	425
10	Maximum superelevation (%)	8	8	8
11	Minimum radius (feet)	12900 (NC)	3240 (NC)	8150 (NC)
		7553 (RC)	1876 (RC)	4770 (RC)
		1,480 (Full Super)	214 (Full Super)	758 (Full Super)
12	Lateral Offset	1.5	1.5	1.5
13	Maximum grade (%)	3	5	5
14	Minimum vertical clearance (feet)	16’-6”	16’-6”	16’-6”
15	Minimum horizontal clearance (feet) (from edge of travel lane)	30	7	10
16	Bridge design live load	LADOTD BDEM	LADOTD BDEM	LADOTD BDEM
17	Width of bridges (min.) (face to face of bridge rail at gutter line) (feet)	Approach Travel Lanes+Full Shoulder Width	Approach Travel Lanes+4 feet	Approach Travel Lanes+Full Shoulder Width

13.3.2.2 Bridge Design Criteria

In addition to the minimum vertical clearance to a roadway surface stated in Section 3.1, the following additional minimum vertical clearances will apply:

- Minimum vertical clearance to the top of a levee floodwall shall be 5 feet from low chord
- Clearances for Navigation in channel
  - Minimum Vertical Clearance shall be 25 feet from Max. Water Surface of EL 2 to low chord.
  - Minimum Horizontal Clearance between pier bents shall be 120 feet.

The highway and bridge will be designed and constructed to current LADOTD standards.

13.4 Roadway and Bridge Geometrics

Three horizontal alignment alternatives were developed and analyzed utilizing the Conveyance Channel geometry established prior to Design Workshop Nos. 1 and 2. All alternatives generally have the same profile which provides for 3.0% maximum approach grades, a 1,280 foot long crest curve at the midpoint of the structure, and 480 foot long sag curves that transition the grade back to the existing roadway elevations on either side. These alternatives considered right of way acquisition, maintenance of traffic, constructability, and cost. Plans are included in **Appendix D**.

The three alternatives can be summarized as follows:

- Alternative 1 provides for one bridge structure centered on the existing right-of-way centerline that carries two lanes of traffic in each direction separated by a median barrier. It transitions to two bridge structures on the south approach in order to transition back to the existing roadway typical section at the end of the bridge. Access ramps provide access to the levee roads and maintain access to properties on each side of the right of way and also would be used for the maintenance of traffic during construction.
- Alternative 2 provides for one bridge structure centered on the existing right-of-way centerline that carries two lanes of traffic in each direction separated by a median barrier. The transitions from the proposed bridge typical section and existing roadway occur outside the bridge approaches on the at grade roadway. Access ramps provide access to the levee roads and maintain access to properties on each side of the right of way and also would be used for the maintenance of traffic during construction.
- Alternative 3 provides for one bridge positioned east of the southbound lanes. Access ramps provide access to the levee roads and maintain access to properties on each side of the right of way. Maintenance of traffic would occur with both directions of traffic on the existing southbound lanes.

13.4.1 Preferred Alternative

The preferred alternative, Alternative 3, begins at Station 388+00 as a 4-lane asphalt rural arterial highway. Utilizing the 2,800-foot radius curve beginning at Station 391+19.71, the roadway transitions through the length of the curve (856.23 feet) from its existing typical roadway section with a 44-foot wide depressed median to the proposed typical section for the bridge which includes two 12-foot wide lanes in both directions, 10 foot outside shoulders, and 4 foot inside shoulders separated by a 2-foot wide median barrier. This transition exceeds the required transition length of 585 feet. A concrete median barrier that starts along the northbound lanes will be used to protect between oncoming traffic.

The ramps to provide access to the adjacent properties on the north side of the Conveyance Channel begin at Station 402+00. The bridge centerline shifts to the east side of the right of way to reduce impact to transmission lines and construction along the west ROW line and maintain two way traffic on the southbound lanes during bridge construction. The mainline highway crosses over the Conveyance Channel. An extension of 5 feet of deck will be on the outside of the existing cross section to anchor a relocated water line. Further investigation will occur to confirm whether the waterline can be supported by the girders underneath the deck. If possible, the deck width will be reduced. On the south approach of the bridge there is a curve beginning at Station 422+56.68 with a radius of 7,668.44 feet at the bridge centerline. This allows for a superelevation of 2.5% in the southbound lane. The deck maintains the cross slope across the northbound lanes. The transition of the south bound lanes occurs over a distance of 310 feet with the transition beginning 257 feet prior to the PC. The transition out the curve is 230 feet long with 184 feet after the PT. The additional length on the bridge is to prevent a ponding area caused by the combination of the longitudinal grade and the cross slope transition. Thus, only the southbound lanes will be surperelevated. The main highway will transition the median width back to the original section between the two curves at Station 428+93.12 and Station 449+92.63. The access ramps for the south side of the Conveyance Channel ties into the mainline roadway near Station 439+50. The project ends at Station 450+00.

Alongside both ends of the bridge, there will be levee access ramps in both directions, each of which will have a 4-foot wide inside shoulder, a 15-foot wide lane, and a 6-foot wide outside shoulder. Starting at Station 400+99.67, the southbound off-ramp will depart from the roadway at a 3.5 degree angle and extend 1,235.7 feet until it reaches the levee of the canal. The southbound on ramp will extend 1,371.45 ft. and enter back on to the roadway at Station 439+50 at a 3.5 degree angle. Both southbound ramps will utilize the existing southbound lane pavement and only divert from the existing road when merging into the relocated southbound roadway. Thus, the project will only require ROW on the east side in order to fit the northbound access ramps. The northbound on ramp will exit the roadway at a 3.5 degree angle from Station 402+00 and extend 1,394.87 feet until it reaches the northern levee road. The northbound off ramp will extend 1,231.9 feet and enter the roadway at Station 439+50 at a 3.5 degree angle. Alternative 3 allows for construction of the bridge to occur east of the detoured traffic which will be maintained in the southbound lanes. Northbound traffic would be detoured to the existing southbound lanes and the southbound traffic would be reduced to one lane.

Ramps that are not on the existing developed roadway will require surcharged fill and muck excavation in order to provide a stable embankment and base for the roadway. The pavement sections for the highway and ramps and the necessary specifications for the subgrade material for the new roadways are as stated in the geotechnical recommendations in Section 9 of this report. Preliminary roadway typical sections and geometrics can be found in the drawings in **Appendix D**.

13.5 Traffic Study Summary

13.5.1 Scope

The DT conducted a traffic analysis report for the MBSD Project Area which included the highway and all of the intersections, commercial driveways, and median openings along Hwy 23 from Ravenna Road to the Plaquemines Parish Access Road. The study includes traffic counts, peak hours, and a safety study to ensure that the proposed bridge project over the MBSD will meet the capacity of future road demand. A copy of its current progress is included in **Appendix M**.

13.5.2 Field Visit

The DT conducted a field visit on June 1, 2018 to visually inspect the corridor. Within the project area, road and pavement markings including outside lane edge rumble strips were in good condition. During the visit, the DT reviewed the two main intersections along the corridor. A visual review at the intersection of Hwy 23 and Ravenna Road did not indicate any issues with line of sight or signs and pavement markings. W. Ravenna Road is a gravel road with no surface markings or signs while E. Ravenna Road is an asphalt paved roadway with signs and pavement markings. During the visit, East Ravenna Road was observed to have several commercial trucks making a left turn from Hwy 23. A visual review at the Intersection of Hwy 23 and Ironton Road also did not indicate any issues with line of sight, signage and marking, or artificial lighting. No queueing was observed at any of the intersections. The documentation of this visit can be found in the Traffic Study in **Appendix M**.

13.5.3 Analysis Summary

13.5.3.1 Peak Hours

As a part of the traffic analysis report, 7 day 24 hour and approach counts were taken in order to determine peak periods and peak hours for the corridor. A 7 day, 24 hour count was taken on Hwy 23 at the approximate location of the proposed bridge. Additionally, several approach counts were taken along Hwy 23; including four at the intersection of Hwy 23 and Ravenna Road, three at the intersection of Hwy 23 and Ironton Road, and three at the intersection of Hwy 23 and Plaquemines Parish Access Road. Using the traffic counts, the peak periods were determined to be 6:00 AM – 9:00 AM and 3:00 PM – 6:00 PM. The peak hours of the corridor were analyzed using the Tuesday, Wednesday, and Thursday counts and resulted in corridor peak hours of 6:45 AM – 7:45 AM and 4:00 PM – 5:00 PM.

13.5.3.2 Network Analysis Existing Conditions

An existing network analysis was conducted for the corridor. The network includes intersections and median turn-arounds from Ravenna Road to the Plaquemines Parish Access Road. A VISTRO model was created to analyze each intersection within the corridor and the Highway Capacity Manual (HCM) 6th Edition methodology was used for analysis and reporting. The analysis used the existing corridor geometry and the traffic counts that were collected in May 2018. The findings of the analysis are presented as delay values that are expressed by a grade based upon level of service (LOS) ranging from LOS A, the best, to LOS F, the worst. Generally, LOS D or better is acceptable. Hwy 23 at Ravenna Road and Ironton Road are the two main intersections along the study corridor. Hwy 23 at Ravenna Road is a four legged unsignalized intersection located within the northern limits of the project. The intersection resulted in an overall LOS B with the overall delay of 11.3 seconds. Hwy 23 at Ironton Road is a three-legged unsignalized intersection located within the southern limits of the project. The intersection resulted in an overall LOS B with a delay of 10.2 seconds. The analysis shows that throughout the corridor there is no LOS below B, thus the corridor operates at an acceptable LOS and there is no heavy queuing.

13.5.3.3 Safety Analysis

In order to identify trends and locations of past accidents along the corridor that can be used to propose countermeasures as part of alternatives that will improve the safety of the corridor, the DT performed a safety crash analysis. The DT reviewed the crash data from 2012 to 2016 within the LADOTD Crash 1 Database. The data was further analyzed using collision diagrams. There were 19 total crashes during the four year period. The most frequent crash type within the study area was non-collision crashes. Non-collision crashes accounted for 9 of the 18 recorded crashes. The non-collision crashes have a rate of 52.6% of the total crashes which is much higher than the state average of 18.8% for similar type roadways. The over represented crashes could potentially be due to the presence of wildlife crossing and the increased potential for vehicle-wildlife crashes. Of the nine non-collision crashes, five of them were animal related. In addition, there were two (2) crashes associated with a construction detour that was present during the time of the accident. The construction has since been completed. The second most frequent crashes were rear-end crashes which did not exceed the state average percentage of 38.5%. The three (3) other types of crashes were minimal in number in comparison to state averages. The addition of a bridge will provide some access control within the project limits that should reduce animals on the roadway. Construction sequencing will be reviewed with the CMAR contractor to determine opportunities to minimize accidents within the construction work zone and detour.

13.6 Detour and Maintenance of Traffic

A preliminary sequence of construction has been developed that utilizes the southbound pavement to maintain both directions traffic during the construction of the bridge. The bridge itself will not require phased construction since traffic will be maintained west of the bridge construction. Localized shifts will be required to maintain the tie in. A Typical Plan and Section in the vicinity of the bridge construction is shown with the set of Drawings in **Appendix D**. A full definition of the maintenance of traffic will occur in coordination with the CMAR contractor in the next design phase.

The preliminary sequence of construction is as follows:

Phase I

1. Construct the construction detour crossovers.
2. Relocate utilities from the east side of right-of-way.
3. Reduce southbound traffic to one lane and shift southbound traffic to shoulder.
4. Shift northbound traffic to the southbound lanes.
5. Place surcharge fill for northbound ramps and levee road crossings on both sides of the Conveyance Channel

Phase II

1. Remove Hwy 23 northbound lanes and place fill for relocated Hwy 23 Roadway
2. Construct floodwalls on LADOTD right-of-way
3. Construct Hwy 23 Bridge, 24-inch waterline relocation on bridge, and relocated highway with median barrier from Station 397+00 to Station 409+03 and Station 430+79 to Station 438+00.
4. Construct northbound ramps on both sides on the Conveyance Channel.
5. Construct remaining segments of median barrier north and south of the Conveyance Channel
6. Shift Hwy 23 traffic to the bridge.

Phase III

1. Remove southbound Hwy 23 pavement from Station 393+00 to Station 405+00, Station 414+00 to Station 426+00, and Station 435+00 to Station 445+00.
2. Construct remaining floodwall across LADOTD right-of way.
3. Complete southbound roadway tie-ins and southbound ramp connections and tie-ins to the haul roads.
4. Place southbound roadway wearing course.

13.7 Bridge Structure

13.7.1 Structural Engineering

The proposed bridge structure begins at Station 409+03 and ends at Station 430+79, and overall length of 2,176 feet. It will consist of 17 spans that are 128 feet long each. The bridge clearance over the levee roads will be at least 16 feet, 6 inches at the high point of the roadway. The controlling clearance is 25 feet above a Water Elevation of 2 (NGVD) which is centered at Station 420+00. There is at least 7 feet of clearance above top of the Conveyance Channel floodwalls of 15.6 feet NGVD. A preliminary set of Type, Size, and Location Drawings can be found in **Appendix D**.

The superstructure would consist of an 8-inch concrete bridge deck with a 4-inch haunch and ten lines of 63-inch tall LG prestressed concrete girders. Concrete barrier rails will be the current standard 36-inch MASH compliant straight sloped barriers.

The substructure would consist of two controlling bent types. Outside the levee sections of the Conveyance Channel, the bents would have 42-inch diameter columns with a 48-inch by 48-inch bent cap. Inside the levee sections, the bents would consist of 60 inch diameter columns with a 72-inch by 72-inch cap.

Foundations are anticipated to consist of pile cap footings under each column with 5 steel H-piles. Outside the levees, the foundations will consist of strip footings with 4 H-piles. Further discussion of the pile foundations can be found in Chapter 9 and will be further refined upon completion of the borings during the design phase.

At grade abutments and approach slabs would be constructed to LADOTD standard details. The north abutment PGL is located at Station 409+03 and at EL 10.675. The south abutment PGL is located at Station 430+79 and at EL 11.244. Bearing seat elevations were also evaluated along with the haunch/girder interaction. The north abutment has the lowest bearing seat elevation of 3.016. LADOTD requires a minimum 4-inch concrete bearing seat. Assuming that the abutment cap would be around 30 inches tall that would mean that the top of pile elevations at the north abutment would be approximately EL 0.183. At the south abutment, the lowest bearing seat elevation is EL 3.840. Assuming that the abutment cap would be around 30 inches tall that would mean that the top of pile elevations at abutment 18 would be approximately EL 1.

13.7.2 Scour Analyses

Scour Analyses will be performed in Phase 2.

14. NOGC RAILROAD BRIDGE CROSSING

14.1 Introduction

The purpose of this chapter is to document the alternatives analysis of various proposed railroad alignments and railroad bridge options that were considered during the BOD phase of work.

The New Orleans Gulf Coast Railroad (NOGC), a subsidiary of the Rio Grande Pacific Corporation, is a 32-mile-long railroad that serves Jefferson and Plaquemines Parishes and interchanges with the Union Pacific Railroad (UPRR) in Westwego, Louisiana (1.5 miles east of the Avondale Yard). It is the only railroad operating on the Westbank of the metro New Orleans area. NOGC currently serves more than 20 switching and industrial customers including the Port of Plaquemines. Predominant shipments include a variety of food products, oils, grains, petroleum products, chemicals, and steel products. Major shippers on NOGC include Delta Terminal (Kinder Morgan), Chevron Oronite Division, and CHS Terminal Grain Elevator. For a substantial portion of its route, NOGC parallels and is immediately adjacent to Hwy 23. Currently, the railroad track terminates approximately 1,500 feet south of the centerline of the proposed Conveyance Channel. NOGC plans to extend the rail south upon agreements of future development that requires railroad service. Regardless, the current length of track needs to be maintained during construction of the Conveyance Channel in order to accommodate switching operations at the Alliance Refinery just north of the MBSD Project.

The 2014 Base Design realigned the railroad track to parallel Hwy 23. The Railroad Bridge would cross the MBSD Conveyance Channel immediately to the river side (east) of the Hwy 23 Bridge alignment. Both highway and rail would require bridges with similar span lengths to traverse the channel.

14.2 Summary of Conceptual Layouts

14.2.1 Design Criteria and Background

Several alternative alignments were considered in this phase of design. Drawings depicting the alternative alignments are **Appendix D**. The DT and CPRA proposed maintaining the rail on its current alignment. In a meeting attended by both NOGC and Rio Grande representatives, held on 15 Feb 2018, railroad personnel indicated that maintaining the current MRL alignment would also be their preference.

The vertical and horizontal alignments are designed in accordance with AREMA and UPRR design criteria. Alternatives were designed for a train speed of 25 MPH. The rail would span the Conveyance Channel supported on the walls of the Intake U-Frame structure. Of particular importance are the hydraulic criteria for bridges. In accordance with UPRR guidelines, the low chord shall be at or above the 50-Year flood event and the subgrade shall be placed at the 100-Year flood event. The subgrade is defined as being 2’-3” below the Top of Rail. The MBSD Intake Structure experiences both riverine and hurricane flood events. The greater of the riverine flowline and hurricane 50-Year Stillwater elevation is EL 14.6. The greater of the riverine design grade and hurricane 100-Year Still Water elevation is EL 17.6. The noted elevations include additional height for sea level rise. Alternatively, the bridge crossing could be placed within a flood proof bridge that would include floodwalls constructed to an elevation above the noted flood stages.

14.2.2 Alternative 1

Alternative 1 is taken from the 2014 BOD. The alignment turns out towards Hwy 23 and parallels the proposed Hwy 23 Bridge crossing. The top of rail over the Conveyance Channel is at EL 24.9, the low chord is at approx. EL 14. The low chord was based on providing 2 feet of clearance over the proposed floodwall. The top of floodwall was set at EL 10. The total length of the rail relocation is 8,520 linear feet, the total raised approach length is 4,330 linear feet, and the length of the main span Conveyance Channel crossing is 1,010 linear feet. The design grade was set at 1.5%. The alignment includes a reverse curve on the north side of the MBSD channel. The reason for turning the alignment out to Hwy 23 was not stated in the 2014 BOD Phase.

14.2.3 Alternative 2

Alternative 2 maintains the current MRL alignment. The low chord of EL 8 was set slightly above the water stage with the Mississippi River flowing at the Project design grade of 1,000,000 cfs. The top of rail over the diversion structure was set at EL 12.5. The low chord elevation was made possible by passing the rail through a flood proof bridge. The flood proof bridge walls will be built to the authorized riverine flood stage EL 16.4 or potentially to the higher hurricane grade at EL 20.1. The bridge spans will be built into and supported by the diversion Intake Structure. The lower rail elevation is preferred to minimize the rail relocation extending beyond the proposed MBSD ROW lines. There is consideration for making one of the spans removable. This would allow access for work barges as needed for future MBSD maintenance which would be an infrequent event. AREMA tunnel criteria and UPRR horizontal and vertical clearance was used to set the flood proof bridge geometry. The width of the bridge was increased to allow for a maintenance road. The maximum Grade was set at 1.0%. The total length of the relocated line is 2,980 linear feet, 1,200 linear feet will be a pile founded raised approach. The advantage of this alternative is its minimal impact to adjacent properties.

14.2.4 Alternatives 2b and 2c

Similar to Alternative 2, Alternatives 2b and 2c maintain the current MRL Alignment. Alternative 2b has a low chord at EL 20.1 which is at the highest Hurricane Design Grade under consideration. The top of rail is at EL 25.1. Alternative 2c has a low chord at EL 16.4 which is at the current, authorized Mississippi River Design Grade. The top of rail is at EL 21.4. Note that the current reach of the MR levees is only federally authorized as riverine protection and are no higher than EL 16.4. The level of flood protection acceptable to the USACE will dictate the selection. A floodproof bridge would not be required. The bridge would be supported by the Diversion Intake Structure piers. Several spans of approach ramps would be required before an earthen embankment could be used. The maximum Grade was set at 1.25% for both alternatives. The total length of Alternative 2b is 5,030 linear feet, the length of the pile founded raised approach is 3,100 linear feet. The total length of Alternative 2c is 4,400 linear feet, the length of the pile founded raised approach is 2,500 linear feet. Alternatives 2b and 2c do protrude further out into the adjacent property at 3,000 linear feet and 2,500 linear feet from channel centerline respectively. The benefit is that the flood proofing of the bridge would not be required as each would be above the selected Design Grade.

14.2.5 Alternative 3

Alternative 3 maintains the current MRL Alignment. The railroad track would be removed for construction of submerged culverts that would be the Intake Structure for the MBSD project. Upon construction, the track would be reconstructed along its existing alignment and grade. Since the submerged culverts were not selected for further design, this alternative is no longer under consideration.

14.2.6 Alternative 4

Alternative 4 consists of 2,200 feet of railroad track along the north side parallel to the MBSD Conveyance Channel. It was considered as an alternative to maintain the railroad switching operations at the Alliance refinery but would not provide an opportunity for NOGC to extend the track without extensive rework. It will be necessary to maintain railroad operations during construction of the Conveyance Channel.

14.3 Sequence of Construction

A preliminary sequence of construction would be as follows:

1. Prior to construction of the Intake Structure and the Conveyance Channel and levees, construct the temporary marshalling track along the north Conveyance Channel levee.
2. Cut and remove a 160-foot segment of the existing track at the intersection of the existing track and the temporary marshalling track.
3. Install the No. 10 turnout at the intersection location. Provide a lockout mechanism so that the existing track cannot be used.
4. Remove the remainder of the track in conflict with the Conveyance Channel.
5. Place embankment approaches on each side of the canal.
6. Upon completion of the U-channel Intake Structure, construct bridge spans and set on top of the U-Frame structure. Make sure the structure is watertight.
7. Construct subballast up to bridge structure.
8. Construction the approach slabs.
9. Lay first lift of ballast throughout the length of the new track.
10. Install ties and second lift of ballast.
11. Install rails by welding rail strings on site and install atop the ties up to the middle span. Install track from north to south on the north approach and south to north on the south approach.
12. Install the rails and the mitered joints for the removable span.
13. Install bumping post or hill.
14. Upon completion of the new track, remove the turnout and replace segment with straight track.
15. Remove the temporary marshalling track once new bridge track is in operation.

14.4 Recommendation

The DT recommended the floodproof bridge mainly because the overall length of the elevated bridge extended only slightly beyond the proposed Right of Way (ROW) boundary. The increase in rail height at the ROW boundary was only 8”above the existing grade. The lower floodproof bridge was also less expensive and allowed an at-grade crossing to the river within the proposed ROW. Along with the shorter approach lengths, fewer piles would be driven near the USACE Levee toe. The USACE has restrictions on piles near the levee toe and prohibits piles within the levee footprint. CPRA preferred the Alternative 2c which has the low chord on the wall top of the U-Frame structure at EL 16.4. At EL 16.4, the bridge would not need to include flood protection. The DT does not oppose the CPRA selection but notes that the cost is $23,210,500 greater than the floodproof bridge alternative and extends approximately 800 ft further past the proposed ROW. Note that the cost of the alternatives have increased significantly since Workshop No. 2. This was due to an increase in approach length as needed to comply with the latest railroad vertical curve criteria, and a second track was added at the request the NOGC Railroad. The increased costs do not exceed the cost of the 2014 Base Design alternative and do not alter the relative ranking of alternatives.

15. MECHANICAL ENGINEERING

15.1 Description of Gated Structure Mechanical Systems

There are two common types of gate lifting systems; electric wire rope hoists and hydraulic cylinders hoists. With either system, there is a hoist on either side of the gate which must be synchronized when lifting the gate. The DT is recommending the wire rope hoist system. The electric wire rope hoist can be done either mechanically with a common shaft or electrically. Mechanically, the hoist drums are synchronized by means of a line shaft connecting the machinery on each side. Electrically, they are synchronized by an electronic system with sensors, on the motor or gear drive which counts rotations and compares and adjusts the hoist motors speed required for synchronization. With the electric synchronizing system, two identical hoists, each with their own variable speed electric motor, brake and gear dive are required. Mechanically, synchronizing the wire rope drums using a line shaft reduces the number of hoist components such as gear drives, motors and brakes, since most of drive is located on one side of the gate and the torque needed to drive the opposite drum is transmitted by the synchronizing shaft. This arrangement reduces the overall capacity requirements of the hoists and construction and maintenance costs. The reliability of the synchronizing shaft is much higher than the electrical synchronizing system since it is not prone to failure from lighting strikes, energy surges, or environmental causes as is the electronic system. The drawback is the need for an overhead walkway bridge or girder to support the shaft. The gate will have infrequent operation, potentially not operating for 4-6 months per year during low water season. The low use, mechanical synchronization, ability to stop and lock the gate in any position without the reliance on a continuously operating drive unit, overwhelmingly favors use of an electric wire rope hoist with a synchronizing shaft. The DT is recommending the more reliable synchronizing shaft.

The drive system will be powered by a 15 HP electric motor located in each control house. The motors primary power source is commercial electric. Remote operation controls are located in the Safe House. A 50 KW back up diesel generator is included on the Safe House platform, dedicated to gate operations.

16. ELECTRICAL ENGINEERING

16.1 Description of Electrical Systems

The electrical power demands for the site will be provided primarily by the commercial utility provider, with standby power provided by multiple on-site generator sets (as described in Section 16.4 below).

Provisions for connecting a trailer-mounted or roll-up generator will also be provided.

Anticipated systems to be included in the design are power distribution (normal and standby), interior and exterior lighting, grounding, and lightning protection systems.

16.2 Electrical Site Distribution

While final loads are yet to be determined, a preliminary load tally has been developed, and it is envisioned that a 200 kVA, 3-phase service will be brought to the site for power distribution. Given the relatively small total power requirement, it is proposed that service be taken at 208-volts, 3-phase, 600-amps, so that intermediate transformation from 480-volts to 208Y/120-volts will not be required, thus saving floor space and equipment costs. This decision will be revisited as the design progresses.

Main power distribution equipment will be installed at a minimum elevation of 6 inches above the base flood elevation, or 3 feet above the highest existing adjacent grade (HEAG), whichever is higher. The equipment will either be located in the Admin Building, the Shops Building, or in a separate Utility / Generator Building. Final decision on equipment location will be based on final site / building layouts, building and floor slab elevations, and building construction types. If a separate utility building is selected, the building will be rated to withstand 150 MPH sustained winds, minimum.

Based on the total preliminary electrical loads, it is anticipated that service will originate from pole-mounted transformers. Service to the main distribution equipment will be routed underground. Electrical service will be in accordance with Entergy requirements.

From the main distribution equipment, power will be distributed underground to the gate structure, support buildings, Safe House, and the emergency crane, should one be required. Distribution equipment for the gate structure will be located within the Diversion Gate Control House.

16.3 Lighting

16.3.1 Gate Structure

Marine Grade, LED floodlights mounted to and / or near the gate structure will provide illumination of the gates for night observation. The gate structure access walkways will be illuminated by marine grade, stanchion-mounted LED fixtures. Floodlights and access walkway lights will be controlled manually and independently from one another via local on/off switches.

Design will include provisions for manually controlling gate structure flood lighting (on/off) from the SCADA system.

16.3.2 Control House and Gate Structure Approach

Walkways to the control house(s) and gate structure will be illuminated by a combination of exterior, marine grade, wall-mounted LED "wall packs" and pole-mounted, marine grade, LED area lighting fixtures. Fixtures will be designed to illuminate approaches to an average of 1 FC along the approach path and will be automatically controlled by a photocell.

16.3.3 Control House

Industrial, surface-mount, IP67-rated LED fixtures will be specified for interior lighting of the control house. Lighting controls will be manual-only. For operator safety, UL924, battery-powered emergency lighting will be specified for the interior of the Control House to provide up to 90-minutes of illumination in the absence of utility or generator power.

An exterior, marine-grade, photocell-controlled LED wall pack located over the entrance door will provide entry/exit lighting. In the absence of utility or generator power, a wall pack will provide up to 90 minutes of emergency egress lighting. Power for egress lighting will originate from an internal battery or separate inverter.

16.3.4 Administration Building

Interior lighting will consist mainly of recessed 2 feet by 4 feet LED fixtures controlled by a combination of manual toggle switches and occupancy sensors. Additional lighting over the conference table may be considered if presentations are expected in the Conference Room.

Exterior, marine-grade, photocell-controlled LED wall packs located over or adjacent to each entrance / exit door will provide entry/exit lighting. In the absence of utility or generator power, wall packs will provide up to 90 minutes of emergency egress lighting. Power for egress lighting will originate from an internal battery or separate inverter.

16.3.5 Shop Building

Interior lighting will consist mainly of surface- or chain-mounted, industrial style LED fixtures in work areas and recessed 2 feet by 4 feet LED fixtures in administrative areas. Lighting will be controlled by a combination of manual toggle switches and occupancy sensors. Additional lighting over the conference table may be considered if presentations are expected in the Conference Room. Boat shed lighting will consist of industrial, surface-mount, IP67-rated LED fixtures. Special lighting requirements for the Soils Lab will determined as the designs progress.

Exterior, marine-grade, photocell-controlled LED wall packs located over or adjacent to each entrance / exit door will provide entry/exit lighting. In the absence of utility or generator power, wall packs will provide up to 90 minutes of emergency egress lighting. Power for egress lighting will originate from an internal battery or separate inverter.

16.3.6 Generator Building

Interior lighting will consist mainly of surface- or chain-mounted, industrial style LED fixtures. Lighting controls will be manual-only.

Exterior, marine-grade, photocell-controlled LED wall packs located over or adjacent to each entrance / exit door will provide entry/exit lighting. In the absence of utility or generator power, wall packs will provide up to 90 minutes of emergency egress lighting. Power for egress lighting will originate from an internal battery or separate inverter.

16.3.7 Obstruction Lighting

The need for obstruction lighting will be evaluated once cofferdam and gate structure drawings progress and the need for a communication tower is determined.

16.4 Power (Identified Electrical Loads)

16.4.1 Gate Structure

Other than the power required to the Gate Structure for the gate motors, general purpose receptacles will be located near each gate motor gear operator for connection of a portable drill.

16.4.2 Control House and Gate Structure Approach

Walkways to the control house(s) and gate structure will include general purpose receptacles.

16.4.3 Control House

Loads for the Control House will include general purpose receptacles for service, power for the Gate Controls and SCADA System UPS, power for ventilation, and power for the Surveillance System associated with remote operation of the diversion structure.

16.4.4 Administration Building

Identified electrical loads include general purpose receptacles, Communication / Ethernet equipment, air-conditioning and heating equipment, Security Systems, site lighting, reproduction equipment (copy machine), and standard Break Room appliances (refrigerator, microwave, coffee maker). Total load is estimated at 20 kW.

16.4.5 Shop Building

Loads within the Shops Building as less defined than in other buildings at this time. We have currently estimated the load of the building to be around 50 kW, which includes general purpose receptacles, ventilation (for the service bays, work areas, and shed), air-conditioning and heating (for the administrative areas and the Soils Lab), a 5 ton hoist, a 5 HP air compressor, a drill press, and an arc-welder.

16.4.6 Generator Building

Other than power required for generator auxiliary systems (heaters and battery chargers), power is limited to general purpose receptacles for service.

16.5 Standby Generators

16.5.1 Standby Power System Overview

At this time, it is anticipated that two generators will be included in the design: one dedicated to the Diversion Gate Structure motors, and the other for the remaining critical loads in the Administration Building, Shop Building, and Safe House.

Generators will be housed within a building having a slab elevation equal to that of the Gate Structure Control House or Safe House, whichever is higher. The building will be rated to withstand a minimum of 150 MPH sustained winds.

Any and all required generators will be configured as separately derived systems, and associated transfer equipment will be 4-pole (neutral-switching).

Design will include provisions for connection of a portable (roll-up) generator.

A generator building will be provided. If a diesel engine generator is selected, the fuel tank will be designed to UL 2085 (ballistic-rated). A tank sized to provide a minimum of 72 hours of run time at full load will be required, but a larger tank may be desired, based on tank accessibility post-storm. If a diesel engine generator is selected, a fuel polishing system will also be specified to keep fuel fresh.

16.5.2 Standby Generator Set for Gate Motors

At present, it is anticipated that the gate structure will consist of 3 gates, each driven by a single 15 HP electric motor through a cable assembly. Operating mode during loss of utility power will be on a gate-by-gate basis. That is to say, only one gate motor will be operated at a time when operating on backup generator power.

In order to start and operate a single gate motor, a 35 kW generator set is required. Generator set size could potentially be reduced, depending on the motor starting method selected. However, for the purposes of this preliminary sizing exercise, across-the-line motor starting was assumed.

Generator set controls will be configured such that the generator will automatically start only when gate operation is necessary. For extended utility power outages (greater than 12 hours), a generator exerciser circuit will automatically start (exercise) the generator once each day for 30 minutes (time and duration programmable) so that generator set batteries can remain charged and the generator set controls can remain functional.

The generator set will be diesel-fueled and have a sub-base tank sized for 12 hours of run time at full load. Anticipating a gate travel time of no more than 2 hours each, a tank sized for 12 hours at full load would allow for two complete operations of each gate. Locating the tank below the generator set will eliminate the need for additional fuel distribution equipment and controls from a separate tank.

To keep the diesel fuel fresh, a Fuel Polishing system will be specified.

16.5.3 Standby Generator Set for Safe House and Other Critical Loads

The following loads have been identified for connection to this standby power source:

- All Safe House Loads: Required load is estimated to be around 25 kW, with roughly 15 of the 25 kW coming from an instantaneous water heater. If a standard tank heater is used, then the load requirement can be reduced.
- Gate Structure Ancillary Loads: Flood Lighting and Access Walkway lighting; current estimate of load is 2 kW.
- Control House: Required load is estimated to be 2.5 kW and consists of the Gate Controls (including the SCADA System), surveillance cameras for remote gate operation, Control House ventilation, and Control House lighting.

- Administration Building: Selected receptacles for PCs, telephones, and other network equipment, in addition to emergency lighting circuits and power for security systems (access control and CCTV) make up the loads identified in this building for generator backup. The total estimate of these loads is 6.5 kW.
- Shop Building: Interior emergency lighting in the building, estimated at 3 kW, is the only load in the building currently identified for backup power.

Based on the identified loads, a minimum generator size of 40 kW is required. However, based on expected minimum loads, a 50 kW generator is recommended. This will provide some additional capacity and, with selected loads temporarily disabled or not used (such as the instantaneous water heater), can also act as a secondary backup source for the gate structure.

Generator set controls will be standard, configured to start the generator set whenever a utility power loss is sensed, and keep the generator set operational until utility power is restored and cool-down cycles are complete.

The generator set will be diesel-fueled and have a sub-base tank sized for 72 hours of run time at full load. Locating the tank below the generator set will eliminate the need for additional fuel distribution equipment and controls from a separate tank. An access platform, the top of which will be set to the same elevation as the top of the fuel tank, will be specified to facilitate service and maintenance of the generator set.

To keep the diesel fuel fresh, a Fuel Polishing system will be specified.

16.6 Gate Drive System

Gate drive system type will be electric. Power and control of the gate motors will originate from a motor control center located in the Control House for the gate structure. A transfer switch will be located within or adjacent to the motor control center for automatic starting and transfer of power to the dedicated standby source whenever gate operation is required.

16.7 Grounding and Lightning Protection

A lightning protection system will be specified for all buildings and enclosures that house electrical distribution equipment, including the gate control house(s). Ground rings will be specified around buildings housing distribution equipment, electrical services, and outdoor generating equipment.

All electrical equipment will be grounded. The fuel tank, if required, will be bonded to the grounding system, and a ground ring will be specified around it as well.

Distribution equipment will be specified with integral surge suppression to mitigate damage from voltage transients.

17. INSTRUMENTATION AND CONTROLS

17.1 Gate Structure Instrumentation and Controls

Control power will be either 120-volts AC or 24-volts DC (voltage to be determined). In either case, standby generator power, and redundant sources of power for the controls, will be specified. Redundant sources will consist of redundant power supplies and UPS backup.

17.2 Diversion Gate Structure Instrumentation and Controls and Back Gate Actuation

Controls will be PLC-based with a manual, hard-wired backup system, should the PLC fail. Design will attempt to limit any single point of failure. Gate position will be monitored by limit switches; type of limit switch to be specified will depend in large part upon the gate geometry, construction, and machinery, and thus has not yet been selected. Gates will be able to be controlled locally from either the Control Room or the Safe House. A requirement for remote (off-site) control is not anticipated at this time.

17.3 Control Room(s)

Gate control equipment and local operator interfaces will be housed within the adjacent control room. Basic operator interfaces (pushbuttons and indicating lamps) are anticipated, since control will be limited to opening and closing of each gate. LED indicators will be specified for each gate position and each monitored alarm condition.

17.4 SCADA and Communication System

It is anticipated that a SCADA system will be specified for the ability to remotely monitor alarms and various river and basin conditions; however, a finalized list of conditions to be monitored has not yet been developed. We further anticipate that the SCADA system will connect to the PLC gate controls for monitoring of gate positions, and that off-site communication will be achieved via Ethernet communication modules for connection to a utility-provided “Metro Ethernet”.

It is still undetermined at this time if the SCADA System will be part of another, existing system, or a new, stand-alone system. In either case, design will specify coordination of the SCADA System for this structure, particularly the user interfaces and HMI, with the one installed at the Mid-Breton Diversion Structure to provide a single, consistent user interface. Furthermore, the details of this system will likely not be fully addressed until the 60% submittal phase.

17.5 Surveillance System

IP-based, pan-tilt-zoom surveillance cameras will be included in the design. The cameras will serve the purpose of securing the reservation with the option of providing internet-based, live visual images of the reservation for remote viewing.

17.6 Access Control Room System

The need for an access control system is yet to be determined. If required, the system will provide dry contact outputs to the SCADA System for remote alarm monitoring.

17.7 Alarm Systems Emergency Power

The SCADA system will be used to transmit alarms offsite. It is anticipated that the following alarms will be monitored:

- Gate controls not in PLC Mode.
- Gate open/close timeout (if a gate does not fully open or close, as indicated by limit switch, within a set time period).
- Loss of utility power.
- Loss of control power (on battery backup).
- Generator low fuel.
- Generator fuel leak detection.
- Generator engine alarms and pre-alarms, including those for low oil pressure, high oil pressure, low coolant level, high coolant temperature, over-speed, and over-crank.
- Generator starting system alarms, including low battery voltage and battery charger failure.
- Generator controls not in auto.

18. ARCHITECTURE

This work will be performed in the 30% design phase.

19. UTILITY RELOCATIONS

19.1 General

Utility relocations are often required during the construction of new civil works projects, and relocations can either be permanent or temporary based on the construction proposed. DT will work with the CMAR and the PMT to identify all utility conflicts within the proposed construction limits and any conflicts within the temporary workspace, which includes both access routes and temporary laydown areas. Below is a list of steps that should be performed to initiate a relocation.

- Identify all the utilities within the project area by:
  - Performing a desktop survey utilizing GIS and in-house data. Websites to be used for MBSD include:
    - Sonris GIS Database
    - DT in-house data
    - 2014 Baseline Report
  - Develop list of utility owners within the proposed MBSD Right-of-Way and the temporary workspace for the project
  - Obtain existing Right-of-Way plats, documents, and as-built data on all utilities identified in the MBSD construction limits.
  - Perform a site visit to confirm utility location per the desktop study
  - Develop a survey plan to obtain/confirm detailed information on utility location and depth.
    - Survey plan shall follow Subsurface Utility Engineering (SUE) standards of practice per ASCE 38-02
- Once MBSD project alternatives are selected, develop a Base Plan showing topographic data and the MBSD Project features for Project Owner to use for initial contact with utility owner
  - A request should be made to utility owner to provide a mark-up of their utility location.
- Develop a MBSD Project Fact Sheet providing utility owners with general project information.
- Develop priority list based on critical path relocations. This list shall be further developed in conjunction with CMAR during the 30% Design Phase

19.2 Coordination w/ Owners

Initial contact with utility owners was made during the 15% BOD phase to determine their point of contact and if their utility is within the MBSD project area. Contact only involved emails and/or phone. No face to face meetings have been performed. Once the primary alternatives for the intake configuration and invert and the channel geometry are determined, a kickoff meeting with utility owners will be scheduled.

The plan and schedule for the utility coordination is to be refined during the 30% Design Phase. Initial plan for contact should include:

- Either DT, on behalf of CPRA, or the CPRA Team shall submit the Base Plan and Project Fact Sheet developed during the 15% BOD Phase to the utility owner.
  - In this submittal, a face-to-face kickoff meeting should be requested.
- Develop conceptual mitigation plan to be presented to utility owners during kickoff meeting.
  - Relocation plan (permanent and/or temporary)
  - Pipeline protection plans (i.e. air bridge, casing, structural fill, etc.)

- Develop schedule for MBSD project features and requested schedule for relocation
    - Determine path forward by DT, CPRA Team, and utility owners to achieve schedule.
- Document all utility relocation meetings (external and internal)

The plan for additional meetings will be planned during the 30% Design Phase based on initial kickoff meeting.

19.3 Dispositions

Below is a list of potential utility companies located in the project area. These utilities will be assessed during the site visit and developed into a prioritized list.

Table 19-1: Utility List

Utility Type	Owner	Description
Electric	Entergy	A distribution line on each side of Hwy 23
Electric	Entergy	A transmission line on the west side with steel poles
Water	Plaquemines Parish	20" PVC beginning south of W. Ravenna Road & running west side of Hwy 23
Water	Plaquemines Parish	16" AC running on west side of Hwy 23
Water	Plaquemines Parish	A windmill / water well to be capped
Water	Inframark Services	16" AC line
Pipeline	Shell Pipeline Co.	20" Nairn to Norco Pipeline - Crude
Pipeline	High Point Gas Transmission	12" Natural Gas
Pipeline	Harvest Midstream	Line north of project site, near the Alliance Refinery
Pipeline	Chalmette La Liquids/ Sulphur River Exploration	16" Propylene Line
Pipeline	American Midstream Assets	12" Gas Pipeline
Communications	AT&T Communication	Fiber optic and copper telephone cables
Communication	CMA Communications	Fiber optic and coaxial cables

Table 19-2: Utility Contact List

Utility Company	Contact	Phone Number	E-mail
AT&T Communication	Barry Barrillaux	504-364-6807	bb0533@att.com
ATMOS Energy	Brian Blum	504-425-4799 504-214-6356 (c)	brian.blum@atmosenergy.com
CMA Communications	Darren Guillot	504-669-9623 (c)	darren.guillot@cableone.biz
CMA Communications	David Herring		david.herring@cableone.biz
Inframark Services	Troy Phillips	504-392-4177 504-912-2673 (c)	troy.phillips@inframark.com
Entergy Distribution	Mike Kenny	504-365-2984	mkenny@entergy.com
Entergy Overhead Transmission	Jimmy Sholar	504-219-4204	JSHOLAR@entergy.com
Shell Pipeline Co.,LP	Tammy Pimley	504-425-4799	
American Midstream Assets	Dan Fayard	504-849-2217 985-807-8272 (c)	dan.fayard@jacobs.com
Chalmette La Liquids/ Sulphur River Exploration	Greg Vujovich	214-373-1091 214-505-4849 (c)	gvujovich@sulphurriver.com
Harvest Midstream	Tony Arellano	504-912-4426	aarellano@harvestmidstream.com
Rio Grande Pacific/ New Orleans & Gulf Coast Railway	Johnny Hydes	504-458-1075	
Rio Grande Pacific/ New Orleans & Gulf Coast Railway	Matthew Mattiza	817-737-5885 ext 3122	mmattiza@rgpc.com

20. SECONDARY SITE FEATURES

20.1 Reservation

The Diversion Structure will require support personnel and physical plant facilities to operate and maintain the structure and gates, maintenance and daily operation of the project throughout its useful life and will thus require necessary buildings like an administration office, operation shops, safe house and control house with all necessary mechanical/electrical apparatus, standby emergency power equipment, access roadways, levee access (roadways) and a boat launch etc. This will be accommodated by a separate security contained area with all above including parking for and access to all areas of the project which is hereby referred to as the “reservation” area and is to be located on the south side of the Gated Diversion Structure. The reservation area is approximately 3,000 feet north Hwy 23 between Ironton and Myrtle Grove in Plaquemine Parish. The design criteria for buildings structures will be per ASCE 7-Minimum Design Loads for Buildings and Other Structures and road and drainage structures per LADOTD standards.

The site layout for the diversion reservation area and support facilities will be designed as a 12-inch thick limestone aggregate surface with 12 inches (minimum) sand subbase with geogrid and geotextile fabric and will allow for ease of construction during levee, structure and channel maintenance activities. Reservation slab total dimensions will be approximately 274’ x 160’ and will require approximately 6 feet of fill embankment to bring the final parking/drive grade from existing (EL 4.0 +/-) to approximate EL 10.5 around the buildings and to BFE of EL 10 at perimeter (low point). The entire reservation fill area will be considered for surcharging or wick drained to be determined by geotechnical analysis.

Also, included will be subsurface drainage structures (catch basins, drop inlets, RCP culverts approximately 15 inches to 48 inches diameter) through the concrete area to a drainage ditch outfall then connecting to LA 23 ditch drain system, utility service such as sewer (treatment plant and lift station as per the building and occupant requirements), water service line to tie in with parish water distribution system via min. 12-inch diameter lines (4,000 feet +/- of PVC-900) with a minimum of 4 fire hydrants located around the roadway perimeter, power distribution throughout (via local power company and building requirements per section 16, telephone/cable etc., security fencing (8-inch chain link and 12 foot long gates at entrance areas), parking lot (light pole standards) lighting through limits of the parking and access roads and separate building lighting, 12 parking spots with 2 ADA spots, 4-foot sidewalks and appropriate signage. The radii and turning movements and curb design assumption are using WB 40 tractor trailer and a 40 turning radius. Reservation access roads design assumption to be with 2-inch asphalt wearing on 12-inch stone aggregate and 12-inch compacted sand subbase with swale drainage from Hwy 23.

20.2 Buildings

The reservation site will include several buildings on pile supported slab on grade at assumed EL 11.5 (BFE=10), including a safe house structure with fuel tank platform and control house structures described as such:

1. Diversion Gated Structure (Control House) located on the conveyance structure walls above the gate apparatus; Access to the Control houses and structure decks are not ADA compliant. Control house dimensions are being determined and include gate machinery and control panel. Given the infrequent operation, controls are not to be extended to the adjacent admin building.

SCADA monitoring will be connected to the Western Closure Complex. Neither potable water nor restrooms are going to be present at the Control House units.

2. Administration Building. We recommend accommodations for staffing the entire year; the admin building will include two offices, admin office/reception area, a small conference area, kitchenette and restrooms. The admin building is separate building but directly adjacent to and connected to the shops building with a common firewall. ADA compliant. The structure is to be brick veneer with standing seam metal hip roof approximately 1,500 square feet included on reservation at EL 11.5.

3. Shops (Operation & Maintenance) Building. The shops building will be operational all year, with an increase in staff during the 6-month operation period. Structure will be metal building with R panel exterior and will include a service bay, work area, conference area with kitchen, and restrooms. The shops building shall also include shed area for lawn equipment and a boat shed and room for a soils lab of 12 feet by 20 feet. Two stories, approximately 70 feet by 70 feet. There will be an overhead 5-ton crane in shop. No provisions are included for sleeping quarters. It is assumed that a second shift can be added to man the structure during periods of peak operation.

4. Safe House- The safe house will be built at the riverside of the shop building not at the gate and at the MRL Design Grade EL 16.4; will be sized to contain 3 beds, a small work area, restrooms and the remote gate control panel. The safe house shall be approximately 600 square feet in area; the 2 diesel generators for backup power (20KW-safe house, 60KW-gate back up) located on the safe house platform and feed off the same 7-day fuel tank also on the safe house elevated platform. Additional fuel supply will be placed at the BFE (EL 10) and vented above EL 16.4. Safe house will be located as to have a clear site vision in both directions and impact resistant windows rated for hurricane and bullet proof protection.

20.3 Ancillary Site Features

1. Back Structure. The back structure has been removed from project (for now). There will be a platform for a soils lab required for the sediment flume and soils lab located between the parking area and dock. A parking area and a boat ramp are located on the north side in line with the existing back levee. The Platform and parking area will be built up to EL 10. The boat ramp and access will be designed to accommodate a 35-foot boat and turn around area same.

2. Site layout. The access roads from Hwy 23 will be designed as 2-inch asphalt wearing on 12-inch thick aggregate surface 24-foot wide with geogrid and geotextile fabric with 12-inch minimum sand subbase on the south side of levee crown on south side of the conveyance. The access road will tie into the local road that parallels Hwy 23 approximately 3,000 feet to the west. Layouts for facility utilities, fire protection, and security fencing will be included on the site work drawings. West of Hwy 23 access for operation and maintenance shall be along the levee crown. The levee crown shall be asphalt.

3. Boat Dock. The ramp shall be 20 feet wide and constructed of 8-inch concrete slab on 18-inch noncompacted aggregate and 6-inch concrete precast panels submerged. The ramp will extend to EL -8 (+/-) in the river. Access will be from a 15-foot wide access 12-inch thick limestone surface path that extends from the Boat Ramp and traverse the MRL at a 10% vertical grade. The access ramp extends to the access bridge.

4. Access Bridge over the conveyance structure will be a 24-foot wide prestressed concrete bridge that extends over, and is supported on, the gated structure. The low chord rests on the top of wall at EL 16.4. The center span shall be designed as removable. The access bridge shall be designed to support a 300 Ton crane at an operating loading. The access bridge ends at the BFE = EL 10.0.

21. ANTICIPATED CONSTRUCTION METHODS

The major diversion component alternatives selected during BOD Phase are: Open Channel Intake with the invert EL -40, a Diversion Gate Structure with tainter gates, an earthen trapezoidal Conveyance Channel with a constant invert EL -25 and with guide levees dual-purposed to also serve as Hurricane Protection, and a 1,500-foot long Outfall Transition Feature. The DT's opinion is that the Open Channel Intake's training walls that extend into the Mississippi River will be constructed inside of localized, braced retaining structures by casting in place the reinforced concrete walls. Certain segments of these walls may also be constructed by lifting precast concrete components into place and connecting them in the wet. The specifics will be determined with the CMAR, after the CMAR joins the project. Floating concrete components into position was a potential construction technique for the U-Frame alternatives, which were eliminated during BOD Phase. While the Open Channel Alternative also has a U-Frame segment, it starts at the MRL and extends to the Diversion Gate Structure, which is located landward of the MRL. These HW components and the Transition Segment to the Conveyance Channel will be constructed inside an open, dewatered excavation and behind a structural cofferdam near the MRL. The DT anticipates that these components will be constructed using traditional cast-in-place techniques.

The DT has designed conceptually the Conveyance Channel excavation to be constructed either fully in the wet using a combination of drag lines and bucket-dredging, or by excavating some portion by using draglines to remove the upper organic layers, and then progressively dewatering while further excavating with mechanical excavators, and completing the excavation by bucket-dredging. The DT will tailor the detailed design to accommodate the CMAR's means and methods during Phase 2. Channel armoring likely will be placed in the wet. T-Wall segments within the Conveyance Channel limits are expected to be constructed using traditional cast-in-place techniques with either open cutting localized excavations or by installing structural shoring systems. The closures of the Timber Canal and the Back Levee Canal are anticipated to be constructed by the placement of a combination of granular core and a concrete blanket cap placed in the wet. The Timber Canal closures also can be constructed by placement of temporary dikes and dewatering. In the dry construction of the Back Levee Canal closures likely will destabilize the existing NOV Levee.

Certain section of the Hurricane/Guide Levees will be constructed using a subsurface wick drain system with overlying drainage layer and staged construction to accelerate consolidation of the in-situ subsurface soils and construction with a planned overbuild to account for the majority of predicted future settlement. Other sections may be constructed without the need for wick drains, but preloading will be required. The construction technique selection will be schedule-driven.

The DT anticipates that the inverted siphon will be constructed with a combination of open cut excavations and structural shoring systems. The siphon inlet and outlet will be constructed with traditional cast-in-place techniques.

The Outfall Transition Feature will be constructed by dredging and placement of riprap armoring in the wet.

The other major project features are the two bridges. The Hwy 23 Bridge will be constructed using standard bridge construction techniques. The pilings supporting intermediate piers/bents within the Conveyance Channel may be installed using a follower prior to excavation, or may be installed after excavating the Conveyance Channel at this location. This can be done either way, but will influence the layout of the Hwy 23 detour. The design of the piers/bents will be driven by the Contractor's intended methods of their construction. Designs can be developed that allow their construction without having to dewater the Channel excavation, but must not produce unacceptable head losses to diversion flows. Girders will be standard AASHTO type precast girders and the deck will be cast in place. The railroad bridge superstructure, assuming it is located at or above the MRL authorized crown will likely be steel but the deck on which the rails will be installed potentially being concrete. The concrete would be cast in place. Pile-supported ridge approach segments will likely be precast concrete or steel in accordance with UP standards.

22. EARLY CONSTRUCTION OPPORTUNITIES

In an effort to reduce the overall construction schedule, the DT investigated several early construction start opportunities that could potentially begin prior to or in parallel with major project construction operations. Early construction opportunities may benefit the project by allowing the CMAR team to increase efficiency of the review and construction processes for non-critical path items; by taking advantage of good weather to avoid slipping the overall project schedule; and by saving 4% of the construction cost annually, considering deflation. The process of identifying these opportunities included consideration for each opportunity's estimated early design start date and duration, early construction start date and duration, prerequisites required, advantages, disadvantages, potential cost savings, overall schedule reduction and risk reduction to the project. CPRA provided information regarding each opportunity's EIS impacts and right-of-way status. The DT estimated rough order-of-magnitude construction costs for each opportunity.

At the beginning of the BOD Phase, the DT identified sixteen early construction opportunities, which are described in the Early Construction Opportunities memo and table presented in **Appendix S**. During review, the project management team determined that most of these opportunities were subject to Section 10/404 permits and Section 408 permissions, which eliminated them from early construction consideration. The only viable early construction opportunities include pile load testing, partial purchasing of pile materials and pre-purchasing of electrical and mechanical equipment/materials.

23. ENGINEER'S CONSTRUCTION COST ESTIMATES

23.1 Cost Estimating Methodology and Assumptions

The construction cost estimate for the MBSD Project was developed using Microsoft Excel and generally uses the standard approaches for estimate structure regarding labor, equipment, materials, crews, unit prices, quotes, sub- and prime contractor markups. Developed costs were supplemented with quotes bid data, and AE estimates. The costs for project features not conceptually designed during the BOD Phase were estimated using the 2014 Basis of Design's cost estimate, escalated to the projected mid-point of construction. The intent is to provide or convey a "fair and reasonable" estimate that depicts the local market conditions.

During the BOD Phase, first, Class 5 comparative construction cost estimates were developed to facilitate alternatives analyses of the individual major project features for use in populating the decision matrices developed for Alternatives Workshop No. 2. The overall project cost was estimated by combining the costs of the selected alternatives for the purpose of evaluating whether overall cost was increasing, and if so whether sufficient construction funds are available. After selecting the preferred alternatives for each of the major diversion components, a Class 3 cost estimate was developed for the entire project. A description of the methodology and assumptions of the cost estimating effort is contained herein.

The construction site is located in Southern Louisiana and is accessible from either land, water, or both depending on the project feature. For land access, the region is accessible from Hwy 23, as appropriate for each project location. From water, access is available via the Mississippi River and the Barataria Basin.

All anticipated construction work is common to south Louisiana. In addition, all major construction materials - including structural steel and concrete, steel sheet piling and pipe, and steel and concrete piling are readily available. All earthen fill is obtained from local borrow (either truck-hauled or adjacent borrow). The riprap and bedding material can be barged to the site and placed directly or off-loaded, and truck-hauled for placement. Material cost quotes are used on major construction items when available. Recent quotes include concrete, steel and concrete piling, rock, gravel and sand.

Local and state taxes are applied to materials. The work will be performed in Plaquemines Parish which has a tax rate of 8.95%.

It is assumed that there will not be an economically saturated market. It is known at this time that the contract acquisition strategy is a CMAR contract.

In regards to labor shortages, it is assumed there will be a normal labor market and there will be no issues finding the required labor to complete the job. The local labor market wages are above the local Davis-Bacon Wage Determination. Labor rates used are based upon local information and payroll data available to estimators with experience in this type of construction in the local area.

Major crew and productivity rates are developed by estimators familiar with this type of work. When appropriate, R.S. Means was also referenced. All of the work is typical to South Louisiana. Major crews include clearing and grubbing, hauling, earthwork, piling, and concrete. Most crew work hours are assumed to be 10 hours/day 6 days/week which is typical to large scale civil works-type projects in the area.

Equipment rates used are based from the latest U.S. Army Corps of Engineers Equipment Manual, EP-1110-1-8, Region III. Adjustments are made for fuel and facility capital cost of money (FCCM). Reasonable use of owned versus rental rates was considered based on typical contractor usage and local equipment availability. Fuel costs (gasoline, on and off-road diesel) were based on local market averages for on-road and off-road use in Plaquemines Parish, Louisiana.

Mobilization and demobilization costs are based on the assumption that most of the contractors will be coming from within South Louisiana or the Gulf Coast region. For the cost estimates 3% of the construction cost was used to account for mobilization and demobilization.

Bond is estimated to be 1% of the construction costs.

The estimate uses a field office overhead rate of 10%. This number is based on historical studies and experience for similar civil works type of construction. Field office overhead includes: superintendent, office manager, pickups, periodic travel, costs, communications, temporary offices (contractor and government), office furniture, office supplies, computers and software, as-built drawings and minor designs, tool trailers, staging setup, camp and kitchen maintenance and utilities, utility service, toilets, safety equipment, security and fencing, small hand and power tools, project signs, traffic control, surveys, temp fuel tank station, generators, compressors, lighting, and minor miscellaneous.

For the Class 5 cost estimate, profit was estimated to be 8% which was considered reasonable when taking into account the degree of risk, difficulty of the work, the Contractor's investment, the size of the job, and the period of performance.

For the Class 5 cost estimate, home office overhead was estimated to be 7%. This number was based upon estimating and negotiating experience, and consultation with local construction representatives.

For the Class 3 cost estimate, additional information was available from the CMAR which resulted in using a combined profit and home office overhead rate of 10%.

For the Class 3 cost estimate, guidance was provided from the CMAR on what work would be subcontracted out. The estimate includes a 2% support markup on items being subcontracted out based on input from the CMAR.

The estimate includes no costs for any potential Hazardous, Toxic, and Radioactive Waste (HTRW) concerns.

Relocation costs are defined as the relocation of utilities required for project purposes. In cases where potential significant impacts were known, costs were included within the cost estimate.

Cost associated with EDC as well as supervision and administration during construction (S&A) is not included in the Class 5 cost estimate because it does not affect the alternatives analysis. EDC and S&A are not included in the Class 3 estimate of the selected alternative.

BOD Phase estimated construction costs do not address potential upsizing of the River Intake, the necessity of which has not yet been determined.

23.1.1 Cost Estimates for Alternatives Workshop No. 2

The cost estimates for the MBSD Project's Alternatives Workshop No. 2 are considered to Class 5 type estimates that were prepared utilizing Microsoft Excel. These cost estimates are considered to be rough-order-of-magnitude estimates, although some of the alternatives were further along in the design process than others, and some previous cost estimates were available which improve estimate reliability. Class 5 estimated costs used for the alternatives screening process are relative comparisons on a component-specific basis. Only cost differentiators associated with the individual alternatives being compared where included.

According to the American Association of Cost Engineers as referenced in the CPRA Mississippi River Mid-Basin Sediment Diversion Program: Cost Estimating Plan, the requested Class 5 level of estimate is defined as follows:

> "Class 5: These estimates are prepared based on limited information. Class 5 estimates generally use stochastic estimating methods such as cost/capacity curves and factors, scale of operations factors, and other parametric and modeling techniques. The typical expected accuracy range for this class estimate is –20 to –50 percent on the low side and +30 to +100 percent on the high side."

23.1.2 Cost Estimate for Selected Alternative

Class 3 type cost estimates were prepared for the selected alternative in the BOD Phase using Microsoft Excel which will address specific construction procedures for the various line items in the estimate to as much detail as could reasonably be developed within the task order's schedule. The estimated costs are based upon an analysis of each line item evaluating quantity, production rate, time, equipment, labor, materials and supplies. The cost estimates reflect current and applicable pricing. These estimates, as well as a summary of the O&M costs for the selected alternative, are provided in **Appendix F.**

According to the American Association of Cost Engineers, as referenced in the CPRA Mississippi River Mid-Basin Sediment Diversion Program: Cost Estimating Plan, the requested Class 3 level of estimate is defined as follows:

> "Class 3: These estimates are generally prepared to form the basis for budget authorization, appropriation, and/or funding. As such, they typically form the initial control estimate against which all actual costs and resources will be monitored. Class 3 estimates generally involve more deterministic estimating methods than stochastic methods. They usually involve predominant use of unit cost line items, although these may be at an assembly level of detail rather than individual components. Factoring and other stochastic methods may be used to estimate less-significant areas of the project. The typical expected accuracy range for this class estimate is -10 to -20 percent on the low side and +10 to +30 percent on the high side."

23.1.3 Cost Comparison for MRL and Guide Levee Design Grades

In evaluating design grade alternatives for the Conveyance Channel Levees and the MRL, the DT compared the estimated construction costs for each. The design grades considered for the Conveyance Channel Levees were EL 15.6 and EL 12.1; the EL 15.6 alternative is approximately $20 million more expensive than the EL 12.1 alternative. For the MRL, design grades of EL 20.1 and EL 16.4 were evaluated; the EL 20.1 alternative is approximately $3.7 million more expensive than the EL 16.4 alternative. See **Appendix F** for details of the cost comparisons.

23.1.4 Cost Escalation in the Mid-Barataria Sediment Diversion Cost Estimates

Early in the BOD Phase, the DT submitted a Technical Memo entitled “Cost Escalation Factors” to the Project Management Team. This memo explained the process of determining escalation factors and included a recommendation of escalation factors specific to the MBSD Project. A copy of this memo is included in **Appendix F**.

The escalation factor used to escalate the HDR unit prices from March 2014 to June 2018 using the CWCCIS is 1.07 or 7%. The calculation and indices used are included in the table below.

Table 23-1: Escalation Factors for Estimate Update

<table>
<tr><th rowspan="3">Account</th><th>HDR Estimate Date</th><th>Current Estimate Date</th><th rowspan="3">Escalation Factor</th><th rowspan="3">Escalation Percent Increase</th></tr>
<tr><th>Mar-14</th><th>Jun-18</th></tr>
<tr><th>Index</th><th>Index</th></tr>
<tr><td>Composite All Accts</td><td>802.53</td><td>854.52</td><td>1.065</td><td>6.5%</td></tr>
<tr><td colspan="3">Recommended for Use:</td><td>1.07</td><td>7%</td></tr>
</table>

The Class 5 type cost estimates for the Mid-Barataria Sediment Diversion Project’s Alternatives Workshop No. 2 did not include programmatic costs, such as E&D, construction monitoring and administration, and engineering support during construction. In addition, the estimates for Workshop No. 2 do not include the programmatic costs to be provided by the CPRA for mitigation and real estate. The reason for not including them is that these costs did not impact the results of the alternatives analyses occurring at Workshop No. 2. These costs are also not included in the Class 3 estimates prepared following Workshop No. 2.

23.1.5 Other Costs in the Mid-Barataria Sediment Diversion Cost Estimate

The Class 5 type cost estimates for the Mid-Barataria Sediment Diversion Project’s Alternatives Workshop No. 2 did not include costs for E&D, construction supervision and administration, and engineering during construction. In addition, the estimates for Workshop No. 2 do not include the costs to be provided by the CPRA for mitigation and real estate. The reason for not including them is that these costs did not impact the results of the alternatives analyses occurring at Workshop No. 2. These costs are also not included in the Class 3 estimates prepared following Workshop No. 2.

23.2 Cost Data Sources

Specifically for the Class 5 costs estimates developed for Workshop No. 2, there are three different estimating approaches used. They are as follows:

1. Independently verify and escalate the unit prices from an existing MBSD estimate from HDR dated March 2014 when appropriate.
2. Reference RS Means to determine unit prices for certain line items.
3. Reference publicly available bid data for pricing.

The Class 3 cost estimate reflects current and applicable pricing and addresses specific construction procedures for the various line items in the estimate to as much detail as is available at the time of the estimate. The estimated costs are based upon an analysis of each line item evaluating quantity, production rate, time, equipment, labor, materials and in-house knowledge and experience of design and cost engineers who either personally designed or estimated similar projects.

23.3 Comparative Estimates for Alternative Workshops

The cost estimates prepared for Workshop No. 2 are included in **Appendix F**.

23.4 Contingencies

In an attempt to identify and quantify the project cost risks at each level of design the cost estimating team in coordination with the DT has developed the following contingency structure.

For the Class 5 type cost estimates:

50% contingency: Higher than normal level of uncertainty
40% contingency: Normal level of uncertainty
30% contingency: Lower than normal level of uncertainty

For the Class 3 type cost estimates:

50% contingency: Higher than normal level of uncertainty
40% contingency: Normal level of uncertainty
30% contingency: Lower than normal level of uncertainty

Generally, design completion, design complexity, and construction difficulty and complexity were considered when assigning contingencies for the project cost features. When determining contingencies, the designers provided the cost estimating team with levels of certainty surrounding the design information at the time of the cost estimate. The cost estimators used professional judgment regarding quantifying the cost risk and corresponding contingencies associated with the uncertainty surrounding the design details.

23.5 Life Cycle Construction Cost Estimate of Selected Components

The Class 5 type cost estimates for the MBSD Project's Alternatives Workshop No. 2 include rough order of magnitude estimates of Life Cycle Costs over 50 years including operations and maintenance. The scope of the life cycle costs to be included for the project features was determined by the design engineers and resident experts based on historical knowledge of similar structures. Costs were determined from sources available on the internet and local and state governments that operate and maintain similar structures and/or project features. A summary of the life cycle costs for the selected alternatives is included in **Appendix F.**

23.6 Construction Schedule

It is estimated that the construction project will occur over a 5 year period of time and begin in June 2021 and end in June 2026. It is assumed that there will be concurrent construction of various project features in order to meet this construction schedule.

24. BENEFICIAL USE OF EXCESS MATERIALS

24.1 General

As an ancillary component to the construction of MBSD, the project will excavate millions of cubic yards of earthen material. Material that is considered suitable for levee construction will be used for construction of the Conveyance Channel levees and the temporary reroute of the MRL levee system. Material deemed unsuitable for use in levees will be used to provide benefits in the form of marsh creation or restoration. The DT will analyze two (2) alternative sites and prepare a detailed design approach for the preferred alternative.

24.2 References and Publications

- CPRA Marsh Creation Design Guidelines
- (BA-0164) Bayou Dupont Marsh Creation & Terracing
  - Geotechnical Report – Geo Engineers (10-14-14)
  - Draft Bid Set – Moffatt Nichol (2-25-16)
- (BA-0043-EB) Long Distance Sediment Pipeline Project
  - Geotechnical Report – Fugro Consultants (11-29-11)
- (BA-0039) Bayou Dupont Sediment Delivery System
  - Bid Plans – CPRA (8-11-2008)

24.3 Material Allocation

Material excavated from the Conveyance Channel and the Outfall Transition Feature will be used as earthen fill associated with the MBSD structure and conveyance levee or beneficially used for marsh creation. For the purposes of this section of the 15% BODR, material deemed unsuitable for levee construction is to be used for beneficial use of material (BUM). This is based on geotechnical data collected during the 2014 study. The below table quantifies the available, unsuitable material to be used for marsh creation.

Table 24-1: Material Allocation

MBSD Feature	Unsuitable Material (CY)
Conveyance Channel	515,472
Outfall	764,063
Total	**1,279,535**

24.4 Alternative Analysis

Two alternatives were evaluated for disposal of the Beneficial Use of Excess Material (BUM). Both sites are within an approximated three (3) miles from the Outfall Transition Feature. The first alternative considered is the Bayou Dupont BUM Alternative. The Wilkinson Canal Marsh Creation Alternative is the other consideration for placement of BUM. See **Appendix D** for a map showing the two alternatives in relation to the MBSD Project site.

24.4.1 15% Design Assumptions

During the 15% BOD Phase, minimal data was collected within the two alternative sites. The assumptions described within this section, provides the information currently being used in assessing these alternatives.

1. Survey data collected by TBS during the (BA-0043-EB) Long Distance Sediment Pipeline Project was used for assessing potential elevations within the Bayou Dupont BUM Alternative. It should be noted that this data is approximately 7 years old and since then, (BA-0164) Bayou Dupont Marsh Creation & Terracing – Phase III has been constructed within the neighboring area.
2. TBS performed a one (1) day exploratory survey to collect three (3) transects along the Wilkinson Canal Marsh Creation Alternative. No other existing elevation data was found within this area to be used for the 15% BOD Phase.
3. Geotechnical data from (BA-0039) Bayou Dupont Sediment Delivery System, (BA-0164) Bayou Dupont Marsh Creation & Terracing – Phase III, and (BA-0043-EB) Long Distance Sediment Pipeline. The geotechnical design showed variations in fill height between EL 2.0 (BA-0039), 2.5 (BA-0164), and 3.0 (BA-0043-EB).
4. Geotechnical investigations were not performed as a part of the 15% BOD Phase for BUM. Therefore, an average of the existing investigation performed within the Bayou Dupont area was used for the conceptual design and comparison of alternatives. Construction Marsh Fill Elevations are currently estimated at EL 2.5.
5. It is estimated that the Conveyance Channel and the Outfall Transition Feature will be dredged with an approximate 18" portable cutter head dredge. This will be further defined and evaluated during the 30% Design Phase with the CMAR contractor.
6. Estimated cut to fill ratio of 1.5 to 1 was used for the loss of dredge material from the borrow area to the fill site for the 15% BOD Phase. This is the same cut to fill ratio proposed for the BA-0043-EB LDSP Project. The LDSP Project used a 30" dredge and had 100% of the borrow area located within the Mississippi River. The cut to fill ration will be reevaluated with the geotechnical analysis once the CMAR is involved during the 30% Phase. A 1.5 to 1 cut to fill ration is considered conservative and may be reduced during design.
7. Estimated cut to fill ration for the construction of the containment dikes is estimated at 2.0 to 1.0. This is to account for shrinkage and settlement losses during construction. This will be further evaluated during the 30% design phase.

24.4.2 Bayou Dupont BUM Alternative

The Bayou Dupont BUM (BDBUM) Alternative is located in Jefferson Parish, LA and is bounded on the north by BA-0039 Increment II along the Chenier Traverse Bayou, the east by an unnamed canal and the BA-0043-EB Pipeline Corridor Extension, open water to the south, and a combination of broken marsh and open water to the west. The fill site falls within the River Rest, LLC property boundary. The BDBUM Alternative is located approximately 2.0 miles from the Outfall Transition Feature. This is the closest distance the dredge will be to the fill site. An additional 2 miles of Conveyance Channel will put the maximum distance of the borrow area to the fill site at approximately 4.0 miles. Booster pumps will be required to reach the fill site from the max distance. Temporary workspace will be required for a booster pump and will be included as a part of the permitted workspace. Locations of the booster pumps will be determined during the 30% design phase with the CMAR contractor with consideration given to access and water depth.

The Construction Marsh Fill Elevation is estimated at EL 2.5 based on recent geotechnical assessments within the area. Existing survey data (BA-0043-EB) was used to create a 3D surface model within the proposed fill site to evaluate the fill required. Natural ground elevations averaged EL 2.5. The overall acreage proposed for the BDBUM Alternative is approximately 119 acres.

24.4.3 Wilkinson Canal Marsh Creation Alternative

The Wilkinson Canal Marsh Creation (WCMC) Alternative is bounded on the south by the northern bank of Wilkinson Canal, the east by the Shell 20-Inch Delta pipeline and the BUM from the Wilkinson Canal Pump Station, and broken marsh and open water on the north and west. This alternative proposes to rebuild the northern spoil bank of Wilkinson Canal and construct a marsh platform that potentially could reduce the sediments discharged from the MBSD Project from entering Wilkinson Canal. The BUM area stretches approximately 1.6 miles from the boundary of Myrtle Grove Marina to south where Wilkinson Canal begins to angle slightly southeast toward Bayou McCutchen and Lake Laurier.

The dredge pipeline corridor is approximately 2.7 miles from the Outfall Transition Feature to the northern area of the WCMC fill site. There is also an additional 2.0 miles of conveyance corridor channel to reach the borrow material near the Intake Structure and 1.6 miles to reach the southern side of the WCMC fill site. Therefore the dredge pipeline corridor may vary from 2.7 miles to 6.3 miles pending construction operations. Although it is estimated that the dredge pipeline will not exceed more than 4.3 miles, which is the distance from the Outfall Transition Feature to the southern end of the WCMC, fill site. At least one booster pump will be required. Locations will be determined during the 30% design phase.

The Construction Marsh Fill Elevation is estimated at an EL 2.5 based on the same geotechnical data used for the BDBUM Alternative since geotechnical data within the Wilkinson Canal area was not available. This will also allow for similar comparison to BDBUM Alternative. Survey data was collected along 3 transects that traversed the proposed marsh creation area in the upper region, middle region and southern region of the 1.6 mile fill site. The most conservative cross section (i.e. deepest cross section) was used in evaluating the fill area for the 15% BOD Phase. Due to shallow water depths in comparison to the BDBUM Alternative, the overall acreage proposed for the WCMC Alternative is approximately 156 acres.

24.5 Design Approach

The design of the marsh creation area will follow CPRA's Marsh Creation Design Guidelines released in April 2018. During the 15% BOD Phase, a desktop site analysis was performed, conceptual layout, existing data gap analysis and data collection plan. The design approach described within this report will provide the framework for data collection task, design calculations, and construction plans.

24.5.1 Data Collection Services

Upon approval of the Data Collection Plan, acquisition of the data required for design will commence. Data within the MBSD project features being used for BUM has been collected within the 15% BOD Phase and is not included in this approach. The surveys required for marsh creation design will include the following field investigations:

1. Marsh Creation Area Survey
   a. Topographic and bathymetric surveys of transects

b. Magnetometer surveys of transects
c. Healthy marsh elevation surveys
d. Marsh shoreline surveys
e. Hazard Investigation (pipelines)
f. Containment dike / Perimeter Surveys

2. Dredge Pipeline Corridor Surveys – topographic, bathymetric, and magnetometer
3. Geotechnical Investigation of Marsh Creation Area – combination of borings and CPTs within the fill area and containment dike alignment.
4. Environmental surveys and cultural resource investigations will be performed by the EIS consultant and coordinated with the DT.
5. Deliverables will include Survey Methodology Report, field notes, point files, survey maps, and preliminary geotechnical investigation data report (GIDR). The data collected and presented within this report will be the foundation for building the BODR.

24.5.2 Preliminary Design Phase

24.5.2.1 Geotechnical Design

The geotechnical engineering report (GER) will utilize the boring logs and CPT logs presented in the GIDR. The soil samples will undergo a laboratory testing program to determine soil strength and material characteristics for the project features. This includes the standard test for marsh creation as well as specialized testing on dredged material such as settling column test and low-stress consolidation tests for composite samples prepared from the borrow area. Engineering for marsh creation design will focus on the following features:

1. Earthen Containment Dikes
   - Perform stability analysis to evaluate the geometry required for stable dike configuration (construction elevation, side slopes, and crown width);
   - Provide settlement curves, including immediate and consolidation settlement due to self-weight compaction and subsurface soils;
   - Provide recommendations related to setup time required for the newly placed material before dredged material slurry is placed in containment area;
   - Provide construction sequencing recommendations; and
   - Provide bearing capacity recommendations.
2. Marsh Creation Sites
   - Perform settlement evaluations using Primary Consolidation, Secondary Compression, and Desiccation of Dredged Fill (PSDDF) for the dredged material slurry and settlement programs for the foundation soils starting with initial placement, then on selected intervals after placement;
   - Provide settlement curves for selected marsh fill elevations scenarios projecting settlement over the 20-Year project life for subsurface soils and self-weight consolidation of the dredged material. S&ME will evaluate the maximum, and minimum design elevation, then interpolate between these values to get the remaining curves; and
   - Provide dewatering recommendations for fill materials, as required.

24.5.2.2 Marsh Inundation Assessment

The two primary goals in this assessment are to determine the Construction Marsh Fill Elevation (CMFE) and the Target Marsh Elevation (TME). The percent inundation will be established based on local MHHW/MLLW elevations and will be adjusted over the course of the project life with calculating the Eustatic Sea Level Rise (ESLR). The inundation graph will be overlaid with the settling curve to determine the optimum CMFE for the project. This calculation will be compared with Healthy Marsh Elevation surveys conducted as a part of the quality control.

i. Preliminary Design Report

The results from engineering tasks will be combined into a single comprehensive decision document. The document will contain major design features and volumes. Project cross-sections and platform areas will be included. We will summarize the science and engineering calculations in support of the project design within the document. 30% construction plans for the marsh creation will accompany the design report.

ii. Final Design Phase

This submittal will use the information submitted and approved in the BODR. Deliverables will include construction plans, technical specifications, material take-offs, and a final design report. Throughout the various design phases of the project, the DT and the construction team will be working together to minimize the risk associated with predicted performance versus actual performance.

N2 – Appendix B
Draft Eastern Oyster White Paper

Appendix B

Oyster Analysis

Louisiana Trustee Implementation Group

Eastern Oyster White Paper:

Mid-Barataria Sediment Diversion

January 2020

Page

List of Figures

Page

List of Tables

Page

Note to Readers

Please note that this white paper separates out the essential components of an analysis for eastern oysters (*Crassostrea virginica*) in the Barataria Basin related to the proposed Mid-Barataria Sediment Diversion Project (MBSD). This white paper depends on the background developed in other documents (e.g., Environmental Impact Statement, Essential Fish Habitat Analysis, Draft Phase II Restoration Plan). This includes the background associated with the Delft3D model, Ecopath with Ecosim (EwE) and Comprehensive Aquatic Systems Model (CASM) development, Habitat Suitability Index (HSI) model development, and a description of the MBSD alternatives (Soniat, 2012; GEC, 2019; Louisiana TIG, 2019; Rose et al., 2019; TWI, 2019). This white paper also references habitat impacts from the proposed MBSD that were analyzed in previous documents but does not go through the specific details associated with those habitat impacts. Specific information that is directly related to understanding eastern oyster habitat is pulled forward, as necessary.

Finally, this white paper focuses on changes in habitat from the proposed MBSD operations; specifically, the Future with Project (FWP) Alternative 1 (75k cubic feet per second [cfs]), or the "Preferred Alternative." The Preferred Alternative will be compared to Future without Project (FWOP). Comparison to other alternatives will be undertaken once the initial review of this white paper is completed.

1 Background Related to Eastern Oyster

The Barataria Basin was historically nourished by sediment and freshwater input from the Mississippi River, which has been largely circumvented by the construction of levees and control structures over the last century. In present day, most of the riverine sediment load is deposited within the Mississippi River or the depths of the Gulf of Mexico via the Birdfoot Delta, rather than within the Barataria Basin (Gagliano et al. 1981 *as cited in* Soniat et al. 2013). This deprivation of sediment load has contributed to significant wetland losses within the Barataria Basin, a condition exacerbated by the Deepwater Horizon oil spill, large storm events, subsidence, sea level rise, and dredging of oil and gas canals (Turner 1997), among other factors.

The Coastal Protection and Restoration Authority of Louisiana (CPRA) is proposing to construct, operate, and maintain the proposed MBSD to restore and sustain the Barataria Basin ecosystem for the benefit of coastal Louisiana communities and resources, as well as the broader northern Gulf of Mexico (CPRA, 2017). The MBSD consists of a river diversion intended to convey sediment, freshwater, and nutrients from the Mississippi River at approximate River Mile (RM) 60.7 in the vicinity of the town of Ironton, Plaquemines Parish, Louisiana, to the Barataria Basin. After passing through an intake structure, the sediment-laden water would be transported through a conveyance channel to an outfall area in the Barataria Basin located in Plaquemines and Jefferson parishes.

The proposed MBSD project area includes the hydrologic boundaries of the Barataria Basin and the western portion of the lower Mississippi River Delta Basin (Figure 1). Water quality and sediment changes across Barataria Basin and the Mississippi River Delta have been analyzed by a Delft3D basin-wide model that uses historical hydrograph information within the estuary to compare various alternative scenarios (TWI, 2019). Figure 1 provides the various hydrograph locations used in the Delft3D model.

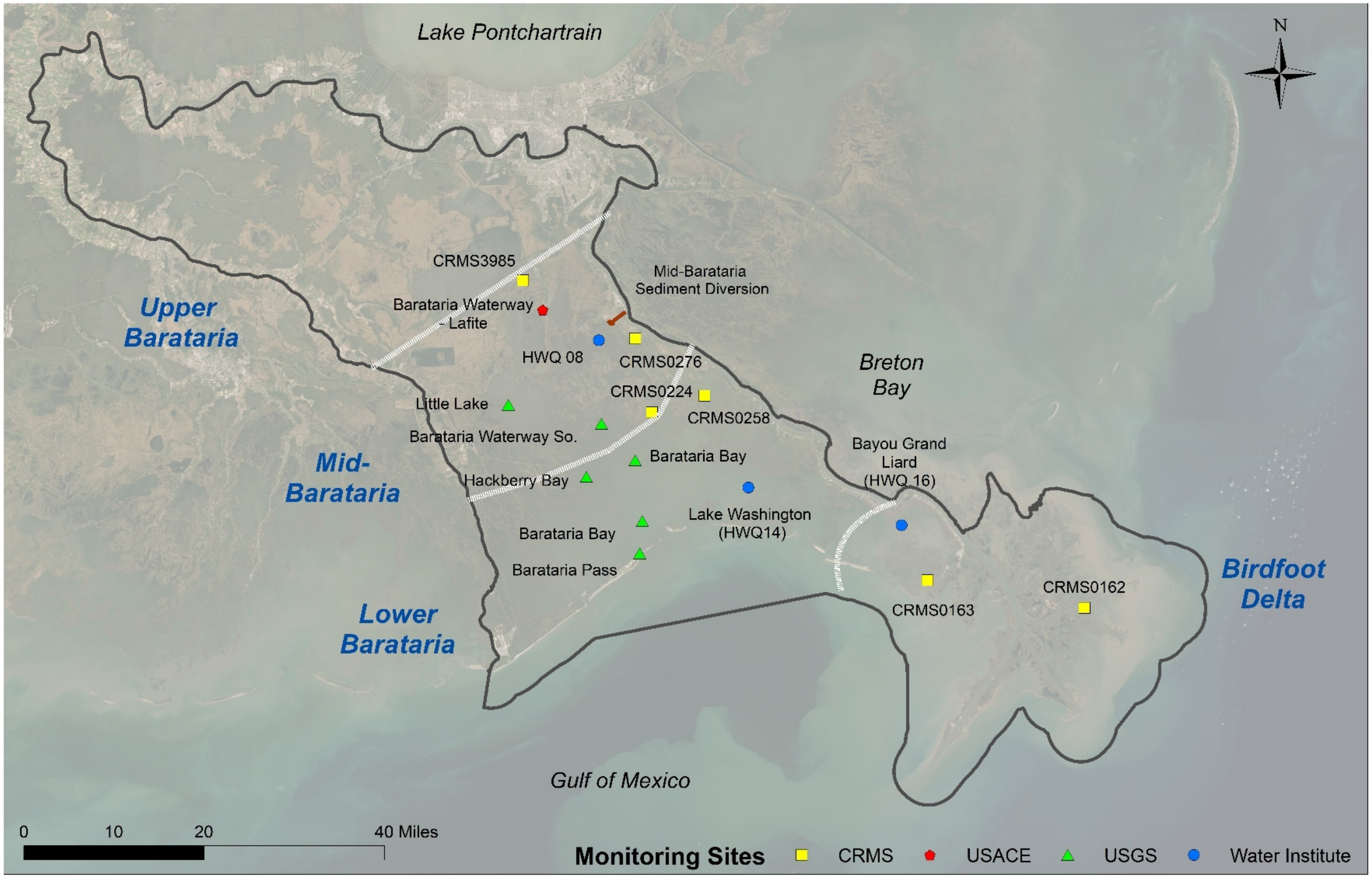


Figure 1. Project Boundaries and Hydrograph Locations and Geographic References.
Source: modified from The Water Institute of the Gulf

1.1 Changes in Available Habitat

The purpose of the MBSD is “to restore for injuries caused by the DWH [Deepwater Horizon] oil spill by implementing a large-scale sediment diversion in the Barataria Basin that will reconnect and re-establish sustainable deltaic processes between the Mississippi River and the Barataria Basin through the delivery of sediment, freshwater, and nutrients to support the long-term viability of existing and planned coastal restoration efforts” (GEC, 2019). Land formation and land loss is a balance between sediment inputs to the system from the Mississippi River compared to subsidence, sea level rise, and erosion. The primary drivers of habitat changes throughout the study area due to the MBSD are salinity, water temperature, and land formation/reduced wetland loss. Many of these characteristics are also forecast to change as a result of future climate and sea level conditions. Figure 2 illustrates the major trends of these drivers of change in the FWOP and FWP scenarios.

According to Melancon et al. (1998) oyster harvesters have noted that the loss of coastal wetlands has led to the creation of new oyster reefs further inland than was the case historically. Building additional wetland habitat under the Preferred Alternative scenario will change habitat that is newly and increasingly suitable for eastern oysters under the FWOP scenario back to habitat that is either less suitable or unsuitable. Oysters are tolerant of a wide range of salinity concentrations (i.e., 5 to 40 parts per thousand [ppt]), however formation of dense oyster reefs is primarily at intermediate salinities (10 to 20 ppt) (Shumway 1996). The amount of freshwater needed to suspend and distribute river sediment into the Basin under the Preferred Alternative scenario will push optimal annual and seasonal salinity areas for oysters seaward. This change will negatively affect several areas that support oyster reefs and public seed grounds, which have become established in recent decades as a result of Mississippi River management regimes. In contrast, without the project, continuation of current River management and factors such as sea level rise may push optimal salinity zones further landward and closer to current sources of freshwater input into Barataria Basin.

The sediment diversion may function to not only build new land but also to increase and sustain the elevation of existing marshes (Carle et al., 2015). Modeling results project a net gain of approximately 6,000 ac of wetland habitat in Barataria Basin in the first 10 years under the Preferred Alternative scenario. By the fourth decade of operations (modeled as 2050–2059), the Preferred Alternative is projected to be responsible for building and sustaining approximately 17,000 more ac wetlands in the Barataria Basin than if the project is not built . Most of the remaining marsh under FWP is projected to be in the central portion of the basin in the vicinity of the diversion outfall area. The overall quantity of marsh in the Barataria Basin is projected to decrease over time under both FWP and FWOP scenarios, however, under the FWP approximately 20% of the marsh remaining in Barataria Basin after 50 years will be tidal freshwater marshes near the diversion that are attributable to the operation of the MBSD. Similarly, salinity levels will generally decrease throughout the Basin in the FWP scenario. For example, the predicted salinity ranges at Grand Isle, LA (USGS 73802516) suggest that salinity pattern will shift slightly, the onset of spring decreases in salinity will become approximately 1 month earlier. Average monthly salinities at this location reach their minimum between February and April, when the MBSD is operating close to maximum capacity, and salinities are projected to be reduced between 3 and 5 ppt during these months as a result of the MBSD project from approximately 12 to 7 ppt in March and from 6 to 3 ppt in April. The projected values are monthly average values integrating the entire water column and area within the model grid cells. It may be expected that salinity values on and near the bottom would be higher than the presented average values and that short term fluctuations of salinities (i.e., higher and lower) would occur based on water column stratification and complex circulation patterns exhibited in the lower Barataria Basin.)

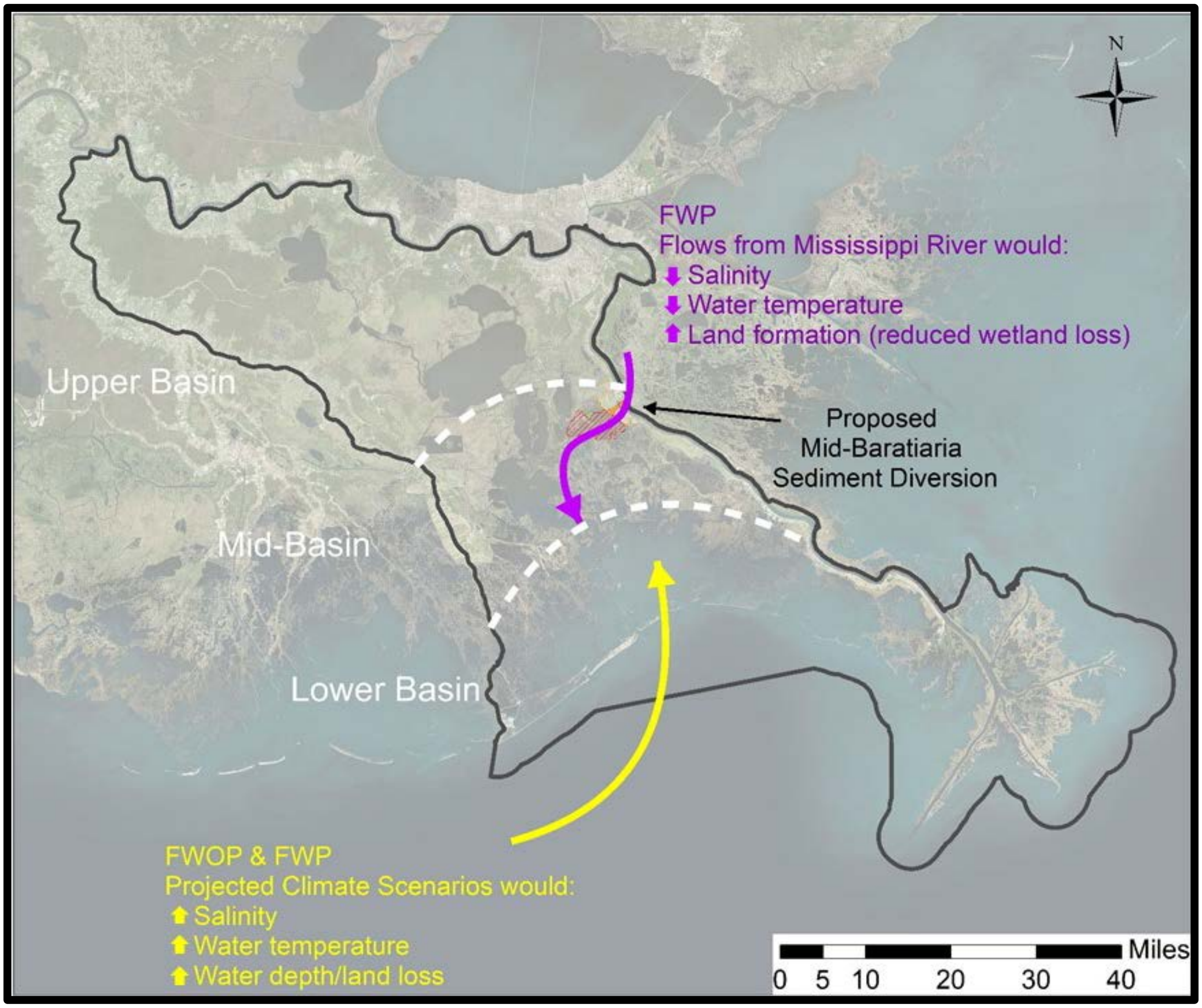


Figure 2. FWP and FWOP Effects on Habitat in the MBSD Affected Area

1.2 Eastern Oyster Life History Cycle

Eastern oysters, as adults, are sessile bivalves that form reefs or beds within estuaries. Oyster beds, including reefs constructed with cultch, provide shelter, food, or spawning substrate for many species (Plunket and LaPeyre, 2005). Oysters are also unique in that they create their own habitat, especially in environments that lack other natural hard-bottom, such as coastal Louisiana (Soniat et al 2012). The basic oyster life history cycle starts with the adult stage (Figure 3). Spawning adult oysters release sperm and eggs into the water column, where fertilization occurs. The fertilized eggs quickly hatch into larvae–also called veliger. During this two-week phase, the larvae float, feed on very small algae, and rely on wind and currents (with some directed movement) to carry them until they find a place to settle. The settling action is called setting or spatfall. Oyster larvae choose settlement locations based on physical cues (e.g., presence of hard substrate or cultch) and chemical cues emitted from adult oyster shells (Brumbaugh et al., 2006; Zivkovik, 2010). Because the settled oysters will not have another chance to move, it is critical to find a location that will ensure they can survive and grow to adulthood. As larvae, oysters feed on phytoplankton. As spat, oysters feed on algae by filtering water through their gills and structures (labial palps) located in front of the mouth (Wallace et al., 2008). Adult oysters are also filter-feeding organisms that feed primarily on phytoplankton in the water column.

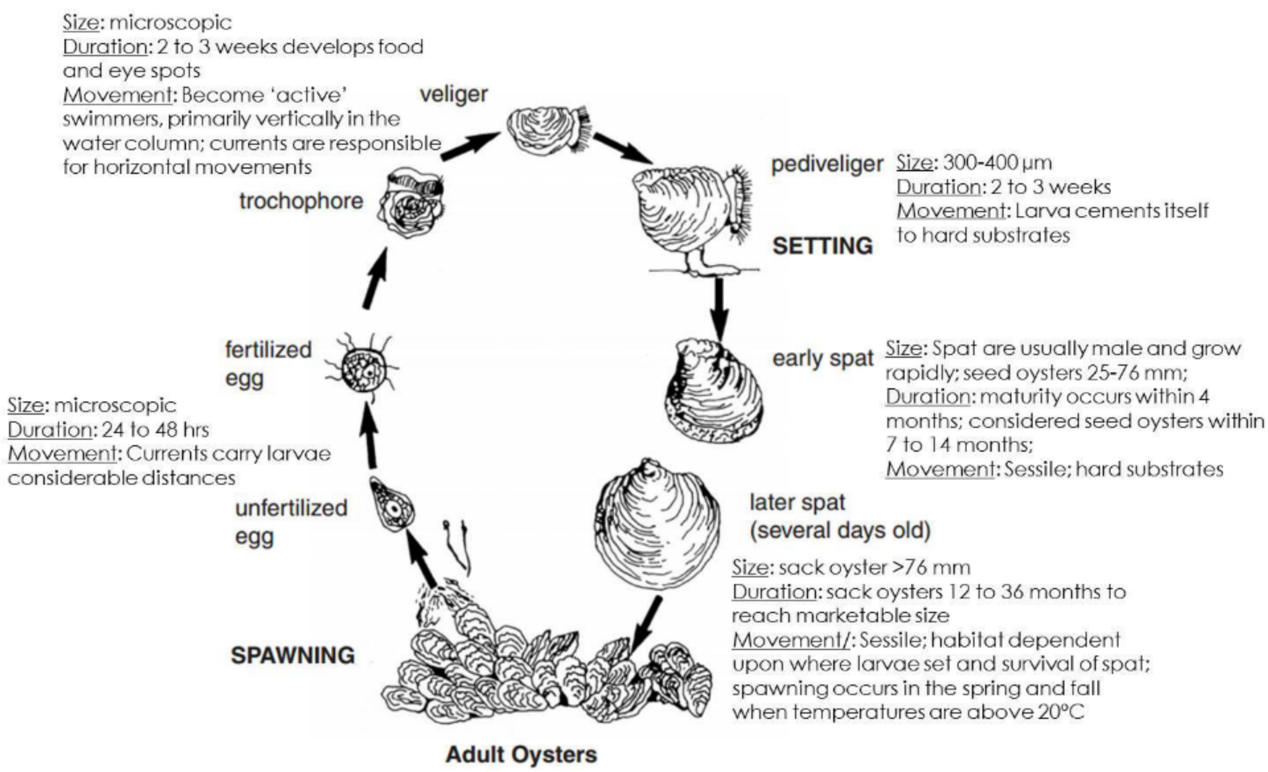


Figure 3. Eastern Oyster Life Stages Diagram.
Sources: Lorio and Malone, 1994 as modified by Hijuelos et al., 2017

Spawning generally occurs when salinities are higher than 10 ppt and water temperatures exceed 20°C (Table 1), with two spawning events typically occurring in the spring (stimulated by rising temperatures) and fall (stimulated by falling temperatures) (Stanley and Sellers, 1986). Spatfall generally peaks from May through August (Kilgen et al., 1989), and in the fall after the second spawning event. Growth of eastern oysters generally increases in August and September after spawning, but temperature, salinity, intertidal exposure, turbidity, and availability of food (i.e., phytoplankton density and quality) all play an important role in oyster growth rates (Lorio and Malone, 1994). A current strong enough to supply food but not substantially re-suspend sediment is necessary for survival of eastern oysters (Sellers and Stanley, 1984; EOBRT, 2007). Sellers and Stanley (1984) reported optimal growth of oysters with tidal flows of 156 to 260 cm/sec or higher in Mississippi. According to Lowe et al. (2017), optimal growth conditions for oysters include a temperature range of 20.0 to 26.3°C and a salinity range of 10.7 to 16.1 ppt. Note that this optimal growth condition is a narrower range compared to the temperature and salinity ranges for general adult survival (Table 1).

Table 1. Summary of Water Quality Tolerances and Optimal Ranges for Eastern Oysters

Life Stage	Salinity Tolerance (ppt)	Optimal Salinity (ppt)	Temperature Tolerance (°C)	Optimal Temperature (°C)	Optimal Land/ Depth (m)
Spawning	2.0-40.0	13.0-20.0	20.0-30.0	25.0-30.0	--
Larvae	5.0-39.0	8.0-27.5	20.0-32.0	20.0-32.0	0.5-3.0
Juvenile	2.0-43.5	8.0-15.0	20.0-32.0	20.0-30.0	0.5-3.0
Adults	2.0-43.5	5.0-40.0	1.0-49.0	20.0-30.0	0.5-3.0

Tolerance range = identifies the range where the organism is able to survive in natural or laboratory settings.
Optimal range = identifies the range where the organism is not experiencing consequential stress, and where maximal growth, abundance, or activity occurs.
Sources: Loosanoff, 1953; Davis and Calabrese, 1964; Hijuelos et al., 2017

Shumway (1996) characterizes distinct types of oyster reefs based on salinity levels. Oysters that experience salinity ranges of 0 to 15 ppt tend to be sparse due to high mortality rates and grow slowly forming small rounded whitish shells. Spatfall and growth are both slow in this zone. Where salinity fluctuates between 10 and 20 ppt, oyster populations are dense with high growth and reproduction rates. In areas where salinity is approximately 25 ppt, growth rates and reproductive potential are high, however competition, predation, and disease are also high. Density is low and growth is slow at ocean salinities. At low salinity sites below 3 ppt, oysters valve closure may occur and feeding may be reduced (Shumway 1996). Oyster mortality rates at low salinities appear to be much lower when temperatures are low with oysters surviving periods of up to 115 days at salinities below 3 ppt when temperatures are below 12^{o} C. However, oysters mortality is much higher when temperatures are high with oysters surviving less than 15 days when temperatures are above 23^{o} C (Shumway 1996). Experimental studies suggest that there may be a threshold of less than 1 week below 2 ppt when temperatures exceed 28^{o} C (Southworth et al. 2017). Average monthly temperatures are predicted to exceed 28^{o} C between June and September in Barataria Basin (TWI 2019). La Peyre et al (2009) found no difference in oyster survival at sites with 75, 6, 3 and 0 days below 3 ppt. However, growth rates were much lower at the site with 75 days below 3 ppt.

Eastern oyster distribution and abundance is also controlled by predation and disease, which are also salinity- and temperature-dependent. Predation by oyster drills (*Stramonita haemastoma*) tends to increase in higher salinities (>15 ppt) (Pattillo et al., 1995). Similarly, the prevalence of the protozoan parasite Dermo (*Perkinsus marinus*) increases with higher temperatures and salinities (Barnes et al., 2007), typically peaking during the summer months (Oyster Technical Task Force, 2012).

Note that the current HSI model (described below; TWI 2019) was designed to identify areas where self-sustaining oyster populations may exist. Therefore, factors influencing multiple life history stages are included. For example, conditions required for spawning are considered (i.e., SI_2 of the model) and the values associated with other salinity functions (SI_3 and SI_4) are applicable to both juvenile and adult oysters.

1.3 Commercial Oyster Operations

Eastern oysters are an important commercial species in Louisiana. Louisiana regularly leads the U.S. in oyster production, with an annual averaged contribution of 34% by weight of the nation's total landings from 1996 through 2016 (LDWF, 2019). Louisiana has approximately 687,966 hectares (ha) (1.7 million acres (ac))) of public oyster grounds and 163,493 ha (404,000 ac) of private leases, although not all of this area is covered by oyster reef (LDWF, 2019). The Louisiana Department of Wildlife and Fisheries (LDWF) manages the statewide oyster fishery for public oyster areas. The public oyster grounds are primarily designated as public oyster seed grounds (POSGs) or public oyster seed reservations (POSRs). Seed oysters (<75 mm in height) from the public oyster areas are transplanted to private oyster leases and grown out to market size. The public oyster areas are also harvested for market-size oysters (≥75 mm height). While the public oyster areas are still important seed sources, by 2016, 95% of all oysters landed in Louisiana came from private oyster leases (LDWF, 2019). Declines in salinities at public oyster grounds have been a contributing factor to reductions in production from these areas. Other environmental factors, including changes in sedimentation rates, have contributed to decreased oyster productivity in the Gulf of Mexico (e.g., Powell 2017 and Soniat et al. 2019).

LDWF manages public oyster areas within individual Coastal Study Areas (CSAs), and conducts an assessment of oyster seed stock and market-size oysters annually (LDWF, 2019). LDWF places oysters into 5-millimeter (mm) size groups and divides them into three categories: spat (<25 mm), seed (25-74 mm), and sack (market-size; > 75 mm) oysters. The average number of oysters multiplied by the reef acreage is converted into a barrel (bbl) unit of measure (1 bbl equals 2 sacks, 3 bushels, 720 seed oysters or 360 market-size oysters). On average in Louisiana, it takes about 18 months to reach harvestable size from seed (Wicker, 1979; Stanley and Sellers, 1986; Lorio and Malone, 1994; Banks et al., 2016). Monitoring of the public oyster areas occurs year-round but is more intense during the spawning months (May to June and September to October) and during annual public oyster stock assessment activities each summer and tri-annual oyster density samples throughout Barataria Basin.

The Barataria Basin is part of CSA 3. In the Barataria Basin, there is a total of 73,010 ha (180,400 ac) of public oyster areas or leases (Figure 4). Public oyster areas account for 23% (16,623 ha) of the oyster ground in Barataria Basin, and include the Little Lake POSG, Hackberry Bay POSR, and Barataria Bay POSG. Oyster availability on the public grounds in the Barataria Basin is largely driven by the status of Hackberry Bay POSR, which was designated by the Louisiana Legislature in 1944. The Hackberry Bay POSR consists of both a natural reef and cultch plants placed on top of historical reefs. Cultch plants include different types of substrate, such as crushed concrete, shucked shell, reef shell, clam shell, Kentucky limestone, and Bahamian limestone (LDWF, 2019).

The Hackberry Bay POSR production is highly dependent on when and where cultch plants are placed in the bay as well as seasonal salinities. Oyster standing stock and production is tracked as barrels (bbls) which are the equivalent of two oyster sacks or 3 bushels (Banks et al., 2016). In 2017, oyster stock on the Hackberry Bay POSR was an estimated 8,902 bbls across approximately 133 ha (330 ac) of suitable substrate from natural reefs and cultch plants. Seed stock showed a 52.1% decrease compared to 2016 and a 49.5% decrease from the average of the last 10 years (LDWF, 2019), presumably due to high harvest removal rates. Market-size oysters also decreased, showing a 13.7% decrease from 2016 (at 5,361 bbls) but an increase of 9.7% from the previous 10-year average. Throughout the Hackberry Bay POSR there was a decrease in oyster seed stock except at the 2008 Hackberry Bay cultch plant, which had a total of 1,292.8 bbls (36.5% of total seed).

The Little Lake POSG was created by the Wildlife and Fisheries Commission in 2007 from an area that previously contained private oyster leases that fell within the Davis Pond freshwater diversion impact area and were purchased prior to the opening of the diversion (Banks et al., 2016). This site is vulnerable to depressed salinities from rainfall and stormwater discharge, inflow from the Intracoastal Waterway, and discharge from Davis Pond. The Little Lake POSG is generally unproductive due to the freshwater input in this area. While some hard bottom exists in this site (Figure 5), no cultch plants or quantified (areally defined) hard bottom habitat exists in Little Lake POSG. When higher salinities exist, the Little Lake POSG can provide an additional area for production of seed and sack oysters, but it is generally unreliable as a seed ground.

Barataria Bay POSG was designated to create a seed ground down-estuary that could be productive in years with high freshwater input. The site has approximately 16 ha (40 ac) of cultch plant. However, it is vulnerable to predators such as oyster drills and the parasite *P. marinus* (Dermo) during periods of higher salinities. This site is available to be used when salinity concentrations in Barataria Basin tend to be fresher, whether due to rainfall, natural forces, or diversion operations (LDWF, 2015). Note that natural forces affecting oyster habitat sometimes include persistent SE winds during high river outputs that depress salinities in this area.

Commercial harvesters collect oysters from public grounds and private leased areas. Private leases represent an increasing share of the oyster production. For private leases, commercial harvesters historically collect seed oysters from Louisiana's public oyster areas and then take them to private leases to grow out to market size (Banks et al., 2016). During 2019 an unprecedented flood event occurred in the Mississippi River which comprised the longest lasting flood on record and caused prolonged flooding impacts to the Gulf of Mexico. Significant mortality of oysters occurred in multiple growing areas affected by the flood event with mortalities estimated to average 42.6% in Barataria Basin from March to August 2019, far higher than typical yearly mortality related losses (C. Bourque, Personal Communication, December 20, 2019). Mortalities were likely due to a combination of factors including sedimentation, low salinity, and anoxic conditions associated with floodwaters.

Oysters are harvested in one of three methods – scraper or dredge[1], tongs, or by hand, with the largest number of commercial licenses and poundage collected using scrapers.

[1] In 2016 Louisiana legislation officially changed the name of dredge to scraper.

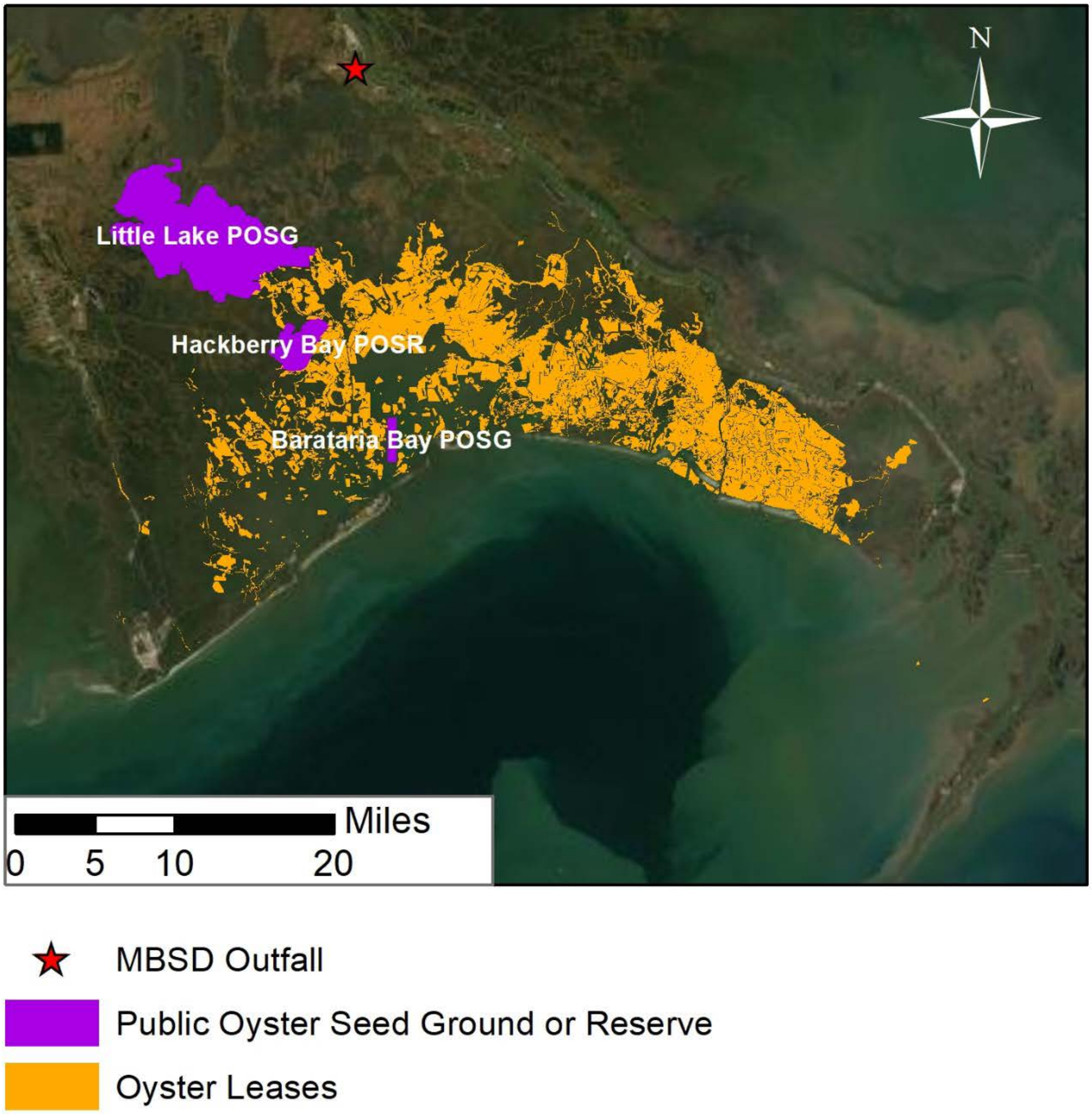


Figure 4. Locations of Oyster Leases, Public Oyster Seed Grounds, and Public Oyster Seed Reservations in Barataria Basin and the Mississippi River Delta Basin.
Source: USGS and Louisiana DNR

Private leases in the Barataria Basin account for 77% (56,387 ha) of the oyster ground with public seed ground or reservations comprising the balance. Private leases are located within the mid and lower portion of Barataria Basin (Figure 4). Because oysters in Barataria Basin are harvested from natural settlement of oyster seed, their distribution in the estuary depends upon larval settlement and spat survival. Louisiana has established a 3-inch (75 mm) minimum size for direct harvest of -market oysters on public reefs with no restriction on private leases, and harvests are reported as the volume or weight (pounds) of oysters harvested. Between 2000 and 2014, total landings in Barataria Basin have averaged 2.9 million bbls per year with a high of 4.35 million bbls in 2014 and a low of 918,167 bbls in 2002. Barataria basin comprised an average of 23% of the Louisiana oyster harvest between 2000 and 2014, with a low of 7% in 2002 and a high of 35% in 2012 of the state's oyster production coming from Barataria Basin (Banks et al., 2016).

Finally, there are oyster reefs located along the fringes of marsh habitat. Fringing oyster reef populations historically were not substantially harvested because they are generally inaccessible to commercial harvesters. There is some harvest along oyster reefs that fringe private leases, but this is limited to hand collection or tongs (i.e., not capable of using dredges). Therefore, the total amount produced from these areas for sale is limited due to the time it takes to collect the oysters. Although generally inaccessible, fringing oyster reefs are a stable source of larvae to subtidal reefs within the Barataria Basin (Murray et al., 2015). Shoreline oiling and related cleanup efforts during the DWH oil spill caused large reductions in cover of fringing oysters within approximately 500 feet of marsh habitat (Powers et al., 2015). Reduction of oyster cover along the shoreline translates directly to fewer adult oysters that would be produced over time in the marsh habitats and reduced larvae to recruit to harvestable beds (Roman, 2015).

1.4 Habitat Suitability Index Model

HSI models predict the quality or suitability of habitat for a given species and life stage based on known affinities and relationships between habitat conditions and existing measures of abundance or catch. Changes to eastern oyster distribution and abundance are primarily linked to water quality changes across Barataria Basin and the Mississippi River Delta. HSI models were used to describe suitability of habitat conditions (e.g., presence of hard substrate) for a suite of key species identified by state and federal agencies. The overarching assumption in an oyster HSI model is that habitat quality "can be described as suitable salinity over suitable substrate" (Soniat et al., 2013). However, for the purposes of this study, substrate conditions were assumed to not be limiting, and the analyses instead focused on identifying where suitable salinity conditions for oysters could occur in the future. These areas could then be enhanced with the application of cultch to provide substrate for larval settlement and subsequent oyster production. . Oyster growing areas in coastal Louisiana are frequently supplemented by cultch placement to provide appropriate substrates for settlement and survival, and seabed surveys indicate large areas of potential sandy and hard substrate in Barataria Bay that would be conducive for cultch placement (CB&I 2016) (Figure 5).

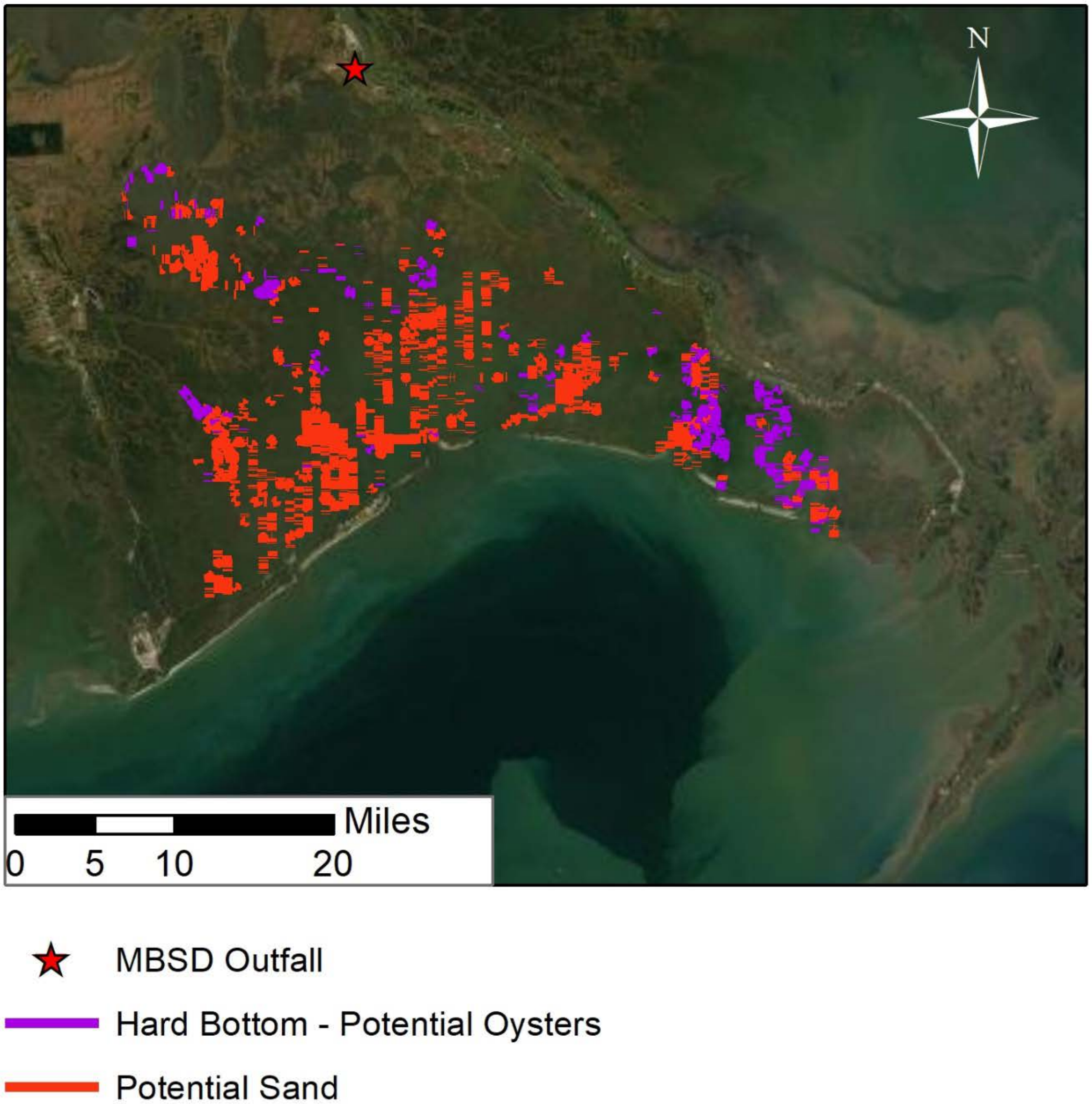


Figure 5. Seabed survey observations of potential sand or potential oyster reefs.
Source: CB&I 2016

The base HSI model for the eastern oyster was developed by Soniat (2012). The Water Institute of the Gulf (TWI) used outputs from the Delft3D simulations to generate predicted HSIs for the 75k, 50k, and 150k diversion alternatives (Alternatives 1, 3, and 5, respectively, of the FWP scenarios), as well as the FWOP scenario (TWI, 2019). Initially, these scenarios were modeled into 20 geographical based polygons to understand the spatial effects to species' habitat from changes in water quality. The polygons were created to be large enough that species movements among regions was not considered significant, yet small enough that the polygons represented differing environmental conditions. However, the polygon sizes were based on identification of habitat for *mobile* species, and these large polygons create low spatial resolution, which can result in sub-portions of the polygon driving the overall result. Because variation within these polygons can be critical to a sessile species like oysters, a revised version of the eastern oyster HSI model analyses was performed by TWI (2019) using a grid size of approximately 1.6 ha (4 ac) resolution to specifically address patterns of habitat changes for a sessile species.

The HSI model used by TWI (2019) was built from the Soniat (2012) model, although SI_1 was revised in the 2019 version. The TWI (2019) model used five variables in defining habitat suitability for adult oysters in the formula below:

$$HSI == (SI_1 * SI_2 * SI_3 * SI_4 * SI_5)^{1/5}$$

Where:

SI_1 = Suitability index for eastern oyster in relation to percent of bottom covered by cultch (Variable 1 (V_1)); while this variable originally assumed that you can't have suitable areas without suitable habitat, substrate characteristics were not available as a Delft3D basin wide output. Therefore, cultch was held as a constant and set at optimal conditions (1.0), which is consistent with the current management approach where cultch can be placed in areas without suitable, firm, sandy substrate (see Figure 5) but that are otherwise suitable to support oyster production.

SI_2 = Suitability index for eastern oyster in relation to mean salinity during the spawning season (mean ppt monthly May through September, V_2); this variable recognizes that spawning adults need a narrower range in optimal salinity compared to adult oysters.

SI_3 = Suitability index for eastern oyster in relation to the minimum monthly mean salinity (V_3); this variable recognizes that there are impacts from an influx of large amounts of freshwater.

SI_4 = Suitability index for eastern oyster in relation to mean annual salinity (grand mean of the monthly mean salinities January through December; V_4); this variable recognizes that there is an expected salinity range over which oysters exist and an optimal range in which they thrive.

SI_5 = Suitability index for eastern oyster in relation to percent land for a model cell (V_5); this variable recognizes that oysters are restricted to aquatic habitats and includes or excludes oysters as land is lost or built.

This habitat suitability model was developed as part of the 2012 and 2017 Louisiana Coastal Master Plans (Hijuelos et al. 2016). Other suitability models for eastern oysters have included additional variables for substrate firmness, predator abundance, and disease density (Cake 1983, Denapolis 2018). Systematic data is unavailable to address these variables for Barataria Basin. However, interpretation of HSI results should consider the influence of these factors in determining the ultimate suitability of habitat.

2 Habitat Use and Requirements in Barataria Basin

Eastern oysters are located within shallow, well-mixed estuaries, shallow bays, mudflats, and behind barrier islands in brackish to saline waters (Pattillo et al., 1997). As described above, oysters are sessile species that live in aggregations (reefs or beds) and have a complicated life history that depends on temperature and salinity conditions, currents, depth, food web dynamics, and the presence of hard substrates (e.g., oyster shells, remains of other mollusks, wooden material, rocks, gravel).

According to Melancon et al. (1998), there are four “oyster resource zones” within the Barataria Basin (Figure 6):

1. **Dry zone:** located in the upper regions of the basin where subtidal oysters may be found when salinities increase (brackish-marsh habitat, with some intermediate-type marsh)
2. **Wet zone:** located in the mid-to lower regions of the basin where subtidal oysters may be found when salinities are suppressed (mostly open water fringed by salt marshes)
3. **Wet-dry zone:** located in the mid-section of the basin where subtidal oysters may be consistently found due to favorable salinities (at the interface of the brackish and salt marshes, but further seaward than up-estuary)
4. **High-salinity zone:** located in the lower basin where natural oyster populations are predominantly found in intertidal and shallow water; usually <0.3 m below mean low water; where oyster populations are temporarily bedded (=mostly open water fringed by salt marshes)

In general, the zones are related to natural subtidal oyster populations that could be sustained during wet and dry estuarine conditions (periods of abundant freshwater and low Basin salinities and periods of drought and high Basin salinities). These zones are predicted to shift over time and as a result of the MBSD. The predicted changes in these zones are discussed in Section 4. Commercial oyster operations in Louisiana adapt to salinity changes annually. Oyster leasing grounds are roughly oriented along salinity gradients, which allows oyster harvesters to operate in wet, dry, and average years by moving seed from public oyster grounds or other leases to appropriate lease areas for growing conditions. The wet-dry zone was the most productive oyster resource zone identified by Melancon et al. (1998) in terms of commercial size oysters and had optimum salinity conditions for oysters. Freshwater input from the Mississippi River extends the wet/dry zones to the edge of the Gulf of Mexico, while periods of salinity intrusion from the Gulf push the zones up-estuary.

Oyster drills and Dermo prevalence was also roughly oriented in the different oyster resource zones and along a salinity gradient (Melancon et al., 1998). Oyster drills were mostly in the wet and high-salinity zones, and Dermo was more prevalent with increasing salinity. Both were absent in the dry zones. Brown et al. (2008, *as cited in* Rybovich, 2014) also reported an increase in black drum (*Pogonias cromis*) predation in the fall at higher salinity sites.

Adult distribution is in part determined by the factors effecting larval dispersal, settlement, and survival (Sellers and Stanley, 1984). For example, larvae do not tolerate high temperatures and have a narrower salinity tolerance range than adults (5-39 ppt vs. 2-43.5 ppt; Table 1). Tolerance of low salinity, or salinity fluctuations, is mediated at lower temperatures, but as temperatures increase, tolerance diminishes (Pattillo et al., 1995). This is important because the eastern oyster HSI model may underestimate the effects of multiple years of low oyster recruitment because it characterizes average habitat conditions and therefore does not take into account population dynamics associated with low recruitment potential over a series of years that are not suitable for oysters. If oyster production stops for a series of years, suitable substrate or shell material may become buried or lost.

Eastern oyster life history is also seasonally-dependent, and typically driven by salinity and temperature conditions within each season. This life history information was incorporated into the HSI for eastern oysters, showing that most oyster development occurs from May through September, which is coincident with salinities that are higher than 10 ppt and water temperatures that exceed 20°C. There are also differences in the prevalence of each life stage within the upper, mid, and lower portions of the Barataria Estuary by season. For example, spat setting occurs at low frequency in the lower estuary.

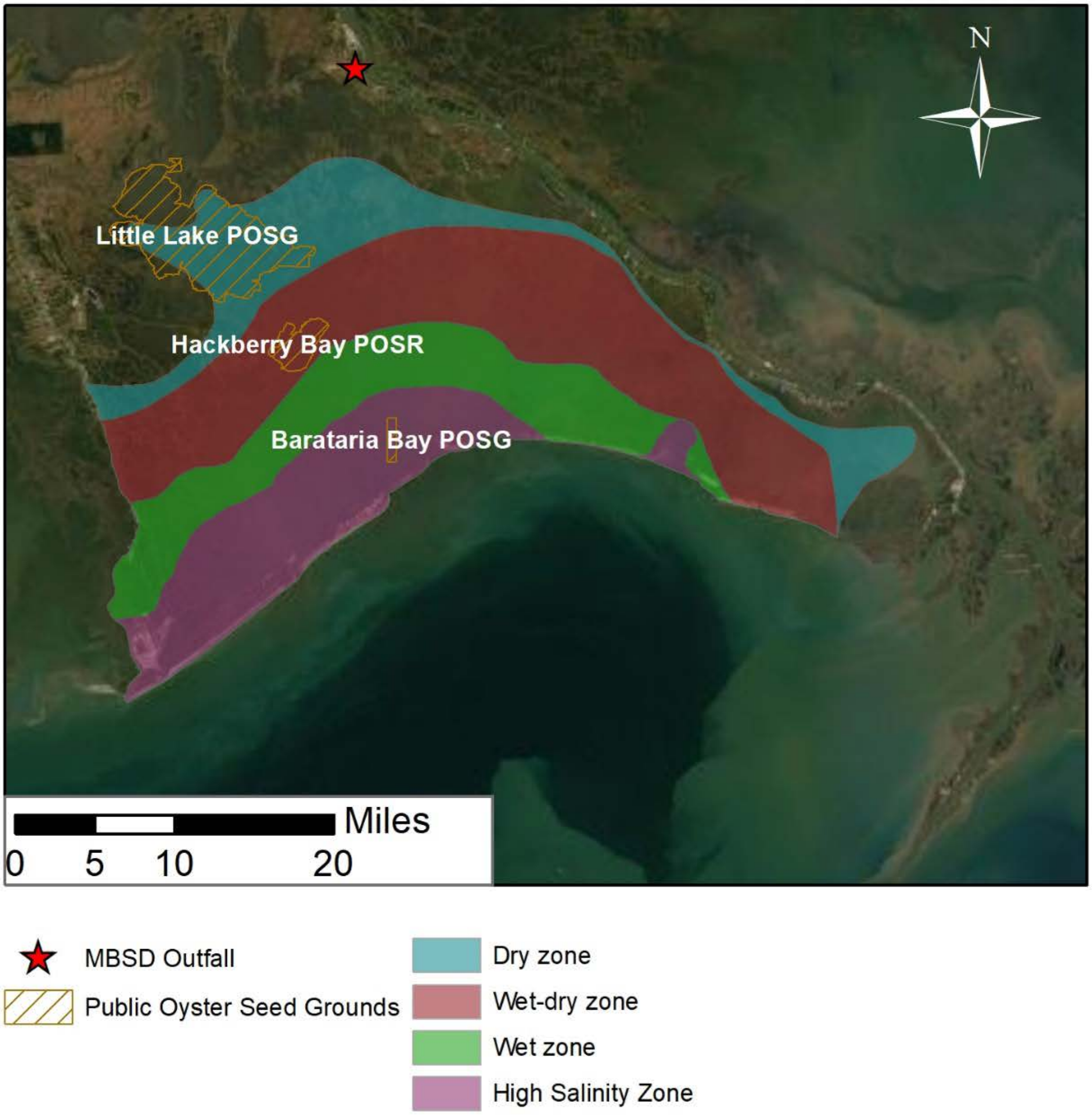


Figure 6. Oyster Resource Zones of the Mid-Barataria and Estuary.
Source: revised from Melancon et al., 1998

3 Analytical Approach

To evaluate whether, and to what extent, the Preferred Alternative may result in effects to eastern oysters, the LA TIG examined three time-periods: (1) a near-term analysis (2020-2029) that focuses on the initial decade of diversion operations, representing a time when the diversion is operating but there are minimal landscape changes; (2) a mid-term analysis (2050-2059) when the area of wetlands created by the diversion is projected to be at a peak; and (3) a long-term analysis (2070) that focuses on the end of the modeled 50-year operational period for the MBSD, when the impacts of sea-level rise are the greatest. The LA TIG also examined multiple life stages, including larval recruitment and adult growth. The LA TIG used published literature and other available data to evaluate the potential impacts of the Preferred Alternative on multiple life-stages. The HSI model used was developed by Soniat (2012), and was designed to be used with any spatial unit. The initial HSI model runs used the Soniat model with the CASM polygons (for consistency with the other species HSI analyses). A revised HSI analysis was created by TWI (2019) that used point data to delineate habitat suitability more finely. The HSI models use monthly or seasonally averaged water quality data that do not provide detailed information on seasonality and the short-term extreme conditions that could result in a potential loss of oysters.

4 Preferred Alternative Analysis: 75k cfs

The information below provides the summary of the near-term, mid-term, and long-term analyses of impacts of the operation of the proposed MBSD on eastern oyster habitat in the Barataria Basin under the Preferred Alternative. The three time periods are then summarized in the synthesis section. Following the analysis, opportunities to address potential impacts to eastern oysters from the proposed MBSD operations are presented. In general, these analyses assume that diversion operations are expected to be operating above base flows (5,000 cfs) and frequently approaching peak flows (75,000 cfs) between December and July each year, with base flows typically occurring during August-November when the head differential between the river and the basin permits base flow to occur.

4.1 Near-Term (2020 – 2029)

Operation of the diversion will affect water quality conditions throughout central and lower Barataria Basin. Water quality changes will result in indirect effects to oysters due to changes in temperature, salinity, and suspended sediments during operation at or near peak flow from December to July. Salinity is the primary driver of modeled habitat suitability for the eastern oyster, although according to Heilmayer et al. (2008), the combination of salinity and temperature has a synergistic effect on oysters. This synergistic effect can result in higher mortality rates due to low salinity concentrations (<5 ppt) when temperatures are higher (>25°C According to information presented in Rybovich (2014), there are benefits from short-term pulses of freshwater in the winter and spring (enhancement of vertical mixing and reduction of disease and predation (e.g., oyster drills), but longer-term freshets may lead to increased mortality of oysters. Significant oyster mortalities in other areas of Louisiana have been associated with high Mississippi River flows, heavy rainfall events in the spring (April-May), and freshwater events combined with higher temperatures during May-June (Banks, 2011; Rybovich, 2014). Suspended sediments are also important in terms of the potential direct impacts to oysters such as burial or reduced feeding efficiency.

Eastern oysters are sensitive to burial, and the Preferred Alternative is expected to result in sediment deposition across 1933 ha (4,778 ac) at the Little Lake POSG, which could mean a loss of oyster habitat due to burial of substrate and loss of existing oysters that provide broodstock for other areas. While the eastern portion of Little Lake POSG is predicted to experience high rates of sediment deposition (Figure 7), much of this area is predicted to receive less than 25 centimeters (cm) over the 50-year diversion analysis period, with up to approximately 5 cm of total estimated deposition in the first decade. Sediment deposition rates will vary based on sediment carried by flow from the diversion, however deposition rates in much of the bay are likely to be similar from year to year because the flow conditions through the diversion are capped at 75k CFS. If this amount of sediment were delivered rapidly to oyster grounds, it would potentially smother oysters. However, the projected 25 cm would be deposited over the course of 50 years (an average 5 mm per year). Oysters can cope with gradual sediment deposition (1-2 cm per event) (Dunnington, 1968; Karel, 1999), but Louisiana oyster harvesters have indicated that rapid siltation of 2.5 to 7.6 cm per event could cause high mortality (Van Sickle et al., 1976). In addition, spat require a clean hard substrate for attachment, and a sediment layer as little as 1 to 2 mm thick may inhibit settlement (Wilber and Clarke, 2010). Delft modeling indicates that in most (approximately 97%) existing public seed grounds or reserves and private leases that sediment deposition will increase by less than 10 cm over 50 years of MBSD operation. Under optimal growth conditions for Louisiana oysters (refer to Table 1), spat, seed, and adult oysters grow at a rate of 8.0, 6.0, or 1.5 mm per month, respectively, which would allow oyster growth to exceed projected deposition rates in the public oyster grounds (Lowe et al., 2017). While Little Lake POSG is not productive currently, it is also expected to be a site with sediment deposition that may gradually cover existing suitable substrate over time. Other public oyster grounds are farther from the diversion and predicted to experience sediment deposition rates comparable to existing rates and within the range that oysters can tolerate.

While oysters may tolerate minimal increases in sediment deposition, it is possible that oysters may not be experiencing optimal growth or settlement conditions under the Preferred Alternative. High concentration of sediment in the water column can reduce oyster feeding efficiency (Battista, 1999), which would affect growth. In addition to suspended sediment concentrations, there are specific combinations of temperatures and salinities for successful growth, reproduction, and development (Shumway, 1996; Heilmayer et al., 2008; Rybovich, 2014). While temperature is an important determinant of energy flow and growth rate, salinity imposes additional metabolic requirements that can affect growth. For example, Rybovich (2014) reported a decreasing growth rate from February through August and higher growth after September, indicating that growth rates were higher with higher salinity and lower temperatures. Other factors, including oyster reproduction which typically occurs in the fall (LDFW 2019), can affect oyster growth rates as metabolic energy is directed towards reproduction instead of growth.

As noted above, eastern oysters are sensitive to low salinities, and the projected changes in salinity from the freshwater diversion operations associated with the FWP is the primary driver in the modelled HSI results. Changes to salinity from the Preferred Alternative are most noticeable during periods of peak river flow and diversion flow (typically January to June); however, even when the diversion is operating at base flow (5,000 cfs), it would continue to exert an influence on salinity. According to the HSI model (Figure 8), there would be a significant reduction in suitable habitat in the Barataria Basin starting in the near-term and continuing through subsequent time periods for adult oysters under the Preferred Alternative compared to the FWOP scenario. Reduced salinities as a result of the MBSD project are predicted to cause HSI values to decline and indicate that much of the mid- and lower basin will not be suitable for oysters (Figure 8). Habitat surrounding the barrier islands would still provide suitable salinity conditions as indicated by the HSI, even in years with late spring high flood flow conditions, but the total area is limited and may or may not currently have the appropriate substrate for oyster settlement.

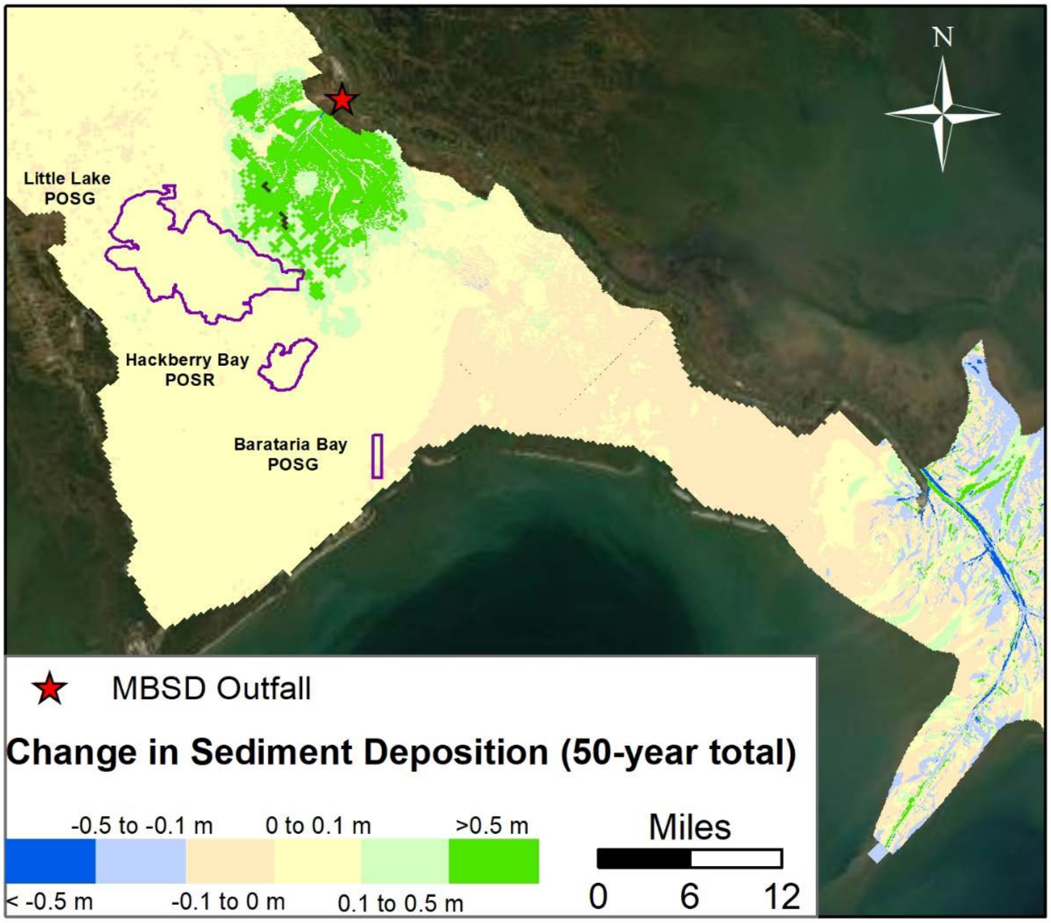


Figure 7. Change in sediment deposition rates due to MBSD project.
Source: TWI, 2019

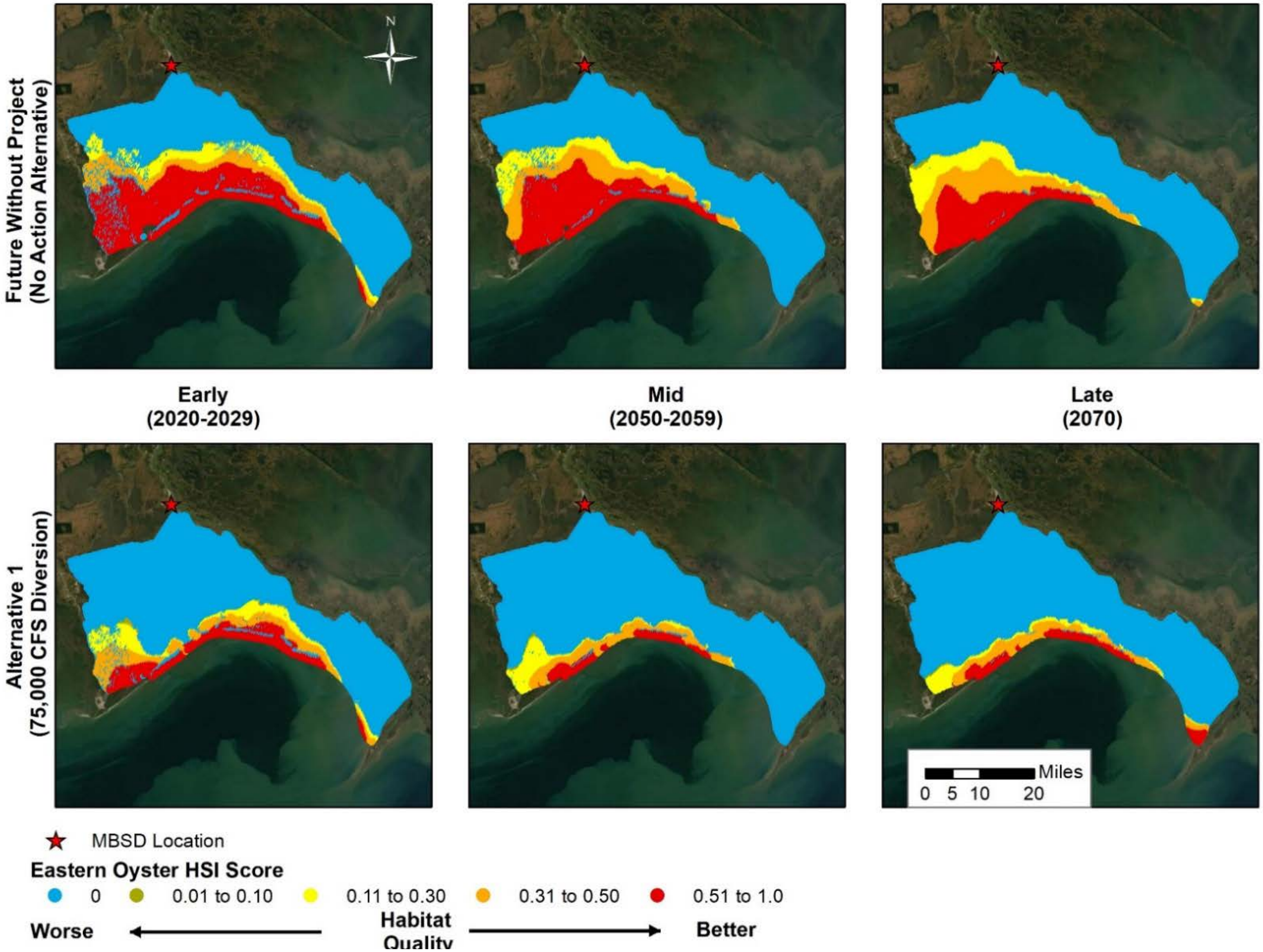


Figure 8. HSI Outputs for Future without Project and Preferred Alternative (75,000 CFS) for Three Time Periods under Spring Flood Flow Hydrograph Conditions.

Source: TWI, 2019

Note: The Preferred Alternative used the representative hydrograph for each decade's flow conditions.

Seasonal requirements of the oyster life stages are also an important consideration in terms of the timing of diversion flows and the type of hydrograph (i.e., spring flood flow conditions vs. drought conditions). For example, the spawning season begins in late May (late spring), and requires salinity >10 ppt or an optimal range between 13 and 20 ppt. If there is a significant reduction in salinity within the spawning season, spawning may not occur or larvae may not survive, thus reducing the recruitment potential within the various public oyster grounds. However, there is often a second spawning event in the fall from September to October which may provide recruitment to oyster reefs in the Barataria Basin when the diversion is typically operating at base flow and, therefore, causing a limited reduction in salinity. According to the HSI model results under spring flood flow conditions, in general, oysters located near the barrier islands would be outside of the primary effects of freshwater input to the Barataria Basin from the diversion. The remaining area of suitable habitat near the barrier islands also corresponds to what is currently the high-salinity zone identified in Melancon et al. (1998), which includes mostly open water fringed by salt marshes. This area is not known to currently have substrate with high value for oysters (i.e., it has sand substrate versus shell) and predation and disease contribute to low survivorship in these areas today. However, the current management approach is to place cultch in areas without suitable substrate but that are otherwise suitable to support oyster production, which is consistent with the needs surrounding the barrier islands. The HSI model results also do not consider larval sources and that larvae produced from higher salinity areas could provide recruits to lower salinity areas in the Barataria Basin (e.g., deepwater oyster reefs), which would reduce the overall negative impacts to the system if conditions the following year allow for survival.

The HSI model projections indicate that under drought conditions there would be less of a reduction in salinity throughout the Barataria Basin and more area of suitable habitat would be available for eastern oysters compared to wet years with late spring flood flow conditions (Figure 9). These conditions are more similar to current conditions and follow the patterns of oyster resource zones described by Melancon et al. (1998) more closely. The areas of suitable habitat would include a larger portion of the Hackberry Bay POSR and all of the Barataria Bay POSG. The Barataria Bay POSG is not currently suitable for oyster production due to the prevalence of disease and predation on oysters in this area. Lower salinity conditions in the future as a result of MBSD may provide freshets that last long enough to reduce disease and predation and facilitate oyster production in this area (La Peyre et al. 2009). The FWOP scenario is similar to existing conditions in the near term; however, in later time periods higher salinity conditions gradually extend further up-basin over time as a result of projected sea level rise and related oceanographic processes. In addition, oyster lease areas would have more options in terms of moving seed into areas with suitable growing conditions. Overall, it is evident that there is potential for spatial variability in terms of managing oyster grounds depending on the type of hydrograph experienced and the amount of freshwater entering the system.

As discussed above, and throughout the literature, oyster growth is highly influenced by salinity. Growth generally increases in August and September after spawning. Rybovich (2014) reported the highest growth rates in Breton Sound after September with higher salinities and lower temperatures. Effects from the sediment diversion typically would not begin until January and decrease or end near July. As indicated earlier, Lowe et al. (2017) reported that optimal conditions for growth of Louisiana oysters range from 10.7 to 16.1 ppt and 20.0 to 26.3°C. Salinity levels suitable for optimal growth would be limited to areas in the southern portion of the Basin near the barrier islands when MBSD is operating above baseflow under flood flow hydrograph conditions, and extending further north in drier years.

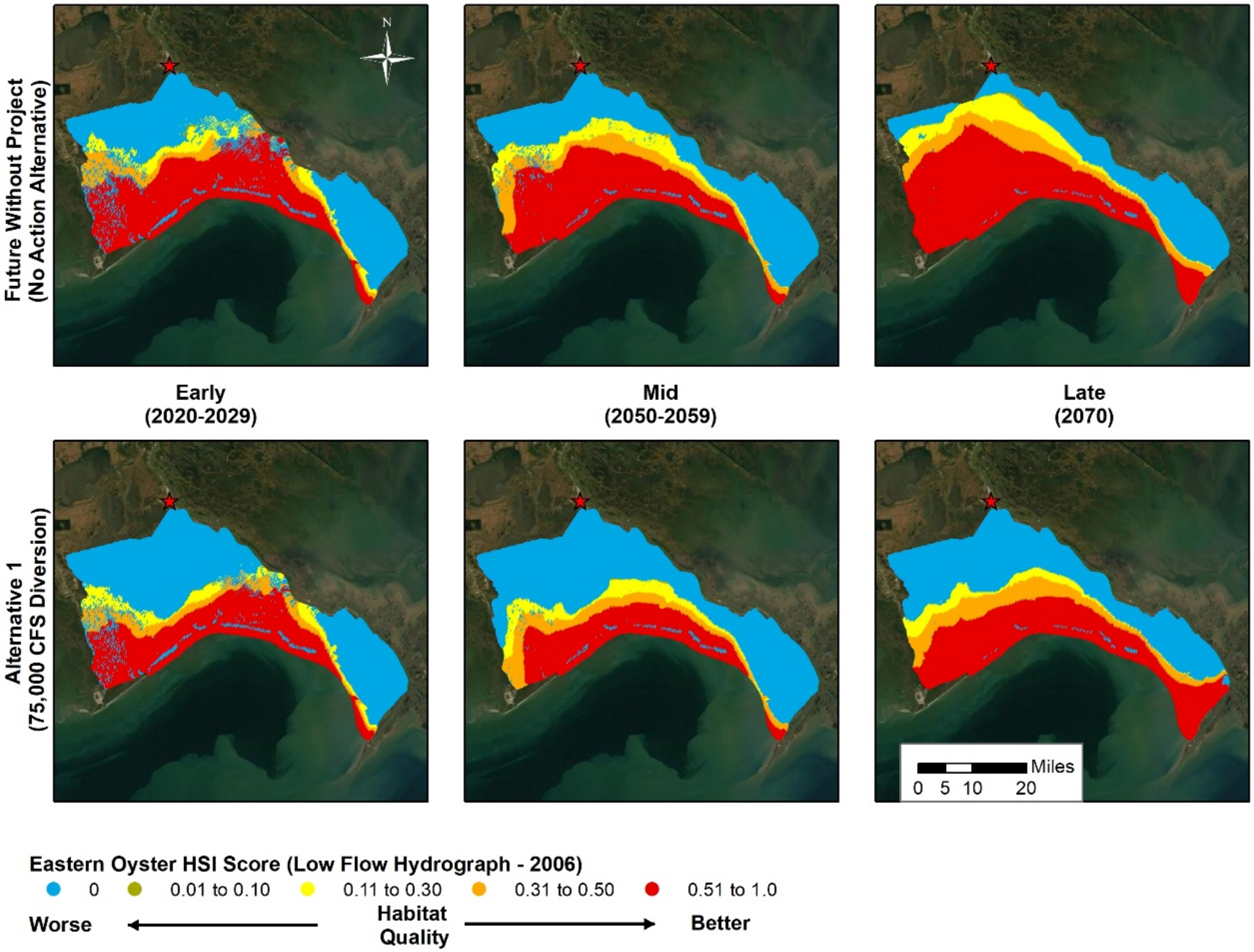


Figure 9. HSI Outputs for Future without Project and Preferred Alternative (75,000 CFS) for Three Time Periods under Drought Hydrograph Conditions.

Source: TWI, 2019

Note: The Preferred Alternative used the representative hydrograph for each decade's flow conditions.

The impacts to the existing POSGs will affect oyster propagation. Salinity at the Little Lake water quality station is projected to decrease below thresholds for oyster survival. However, this area does not appear to be reliably supporting seed production. Therefore, the loss of suitable habitat at the Little Lake POSG is not considered significant due to the limited amount of seed produced by this seed ground on an annual basis. In general, oyster production areas are expected to shift south (down-estuary) in response to decreased salinities (TWI, 2019), essentially pushing the oyster resource areas identified by Melancon et al. (1998) toward the Gulf of Mexico.

The Hackberry Bay POSR has the most extensive hard bottom structure of three public oyster grounds in Barataria Basin with approximately 133 ha (330 ac) of reef from a combination of recent cultch plants (127 ha or 315 ac) and existing reefs (6 ha or 14.7 ac). It is also currently the most productive public seed ground in Barataria Basin. Hackberry Bay POSR is located in the mid- to lower end of the basin. While this site is beyond the area where most sediment deposition effects from the diversion are predicted, water quality changes (e.g., salinity, temperature, etc.) from the diversion will still affect the Hackberry Bay area. The Hackberry Bay POSR is projected to experience salinities of <5 ppt during about 6 months per year in each decade of operation under the flood flow hydrograph scenario, which would likely result in increased mortality and decreased growth of all size classes of oysters in Hackberry Bay. As a result of these effects, Hackberry Bay POSR may not consistently support commercially viable populations of oysters in the future. While larval availability may persist in waters with suitable conditions during proposed MBSD operations, possibly through advection from fall spawning and recruitment from lower basin reefs, the compounded effect of multiple low recruitment years could substantially impact the oyster population in this POSR and areas experiencing similar conditions (i.e., private leases in the same zone of influence). The number of low salinity events decreases during drought years and may also help to maintain larval recruitment to oyster grounds, but cannot be depended on in terms of long-term viability of these areas.

In the upper and middle portions of the basin, there are sizable reductions in suitable habitat projected by the HSI model under the Preferred Alternative scenario during flood flow conditions, but there are also potential benefits to other portions of the basin (Figure 8). Soniat et al. (2013) noted that the model output of minimum salinity (SI_3) “does not describe any potential positive benefits of killing floods, such as reducing predation and disease.” It is likely that the decreased salinities from the proposed MBSD would result in more favorable salinities at the Barataria Bay POSG, which would decrease the rate of predation at the 16 ha (40 ac) existing oyster reef and possibly allow expansion over time. As identified above, predation rates and prevalence of Dermo are both higher at salinities >15 ppt and higher summer temperatures (Pattillo et al., 1995; Barnes et al., 2007). A decrease in salinity due to diversion operations during early summer months when egg hatching and spat setting is occurring may reduce the effects of predation by oyster drills and Dermo, at least within Barataria Bay POSG. Limited or no change in salinity occurs in the lower basin near the barrier islands in late Summer and early Fall (September through November).

Overall, near-term impacts to eastern oysters are large in terms of a reduction in suitable habitat, especially during the spring spawning season and during flood flow hydrograph conditions. There are also predicted to be losses to propagation at the Hackberry Bay POSR. Losses will continue at Little Lake POSG, but this area is historically unproductive in its current state, and operations of the MBSD will not substantially change the status of this seed ground. There may be some benefits to oyster survival from reduced salinity during diversion operations in the Barataria Bay POSG which would cause predation and Dermo to decrease in this area. Finally, it is possible that areas near the barrier islands could be used as seed grounds and growing areas for adults when salinities are too low throughout the rest of the Barataria

Basin, but this may require planting oysters in areas that require enhancement of existing substrate to make them more suitable. Shifts in habitat suitability may cause oyster growing and commercial harvest opportunities to become concentrated in portions of the lower basin.

4.2 Mid-Term (2050 – 2059)

As the MBSD continues to operate, reductions in salinity may reduce the spawning population of eastern oysters and the amount of natural recruitment into existing oyster reefs and seed grounds. The pattern from the HSI model within the mid-term projections is similar to the near-term projections. Relying on the representative hydrograph for this period, there is less total suitable habitat available in the Barataria Basin. The area surrounding the barrier islands represents a location where salinity influence by the Gulf of Mexico results in suitable conditions by reducing the effects of freshwater input by the diversion. Compared to the FWOP scenario, the Preferred Alternative would likely result in a substantial loss of suitable habitat at the Hackberry Bay POSR, further decrease the suitability of the Little Lake POSG, and have variable results at the Barataria Bay POSG. Similar results would be expected to occur to private leases that are similarly situated to each of these public oyster grounds. While substrate will continue to be available in Hackberry Bay and Barataria Bay areas, the water conditions (e.g., salinity) may not be conducive to recruitment or survival of all life history stages of oysters. Over time suitable substrate comprised of living or dead shell, concrete or limestone from natural recruitment or plants may be lost as shell disintegrates and other materials become buried. Cultch plants have regularly occurred in Barataria Basin to create suitable habitats, however if there is no production of oysters then suitable substrate would be lost due to burial and other processes and there would not be the financial incentive to replenish the substrate. There are some areas within the existing oyster leases that will remain suitable in the lower basin, but overall oyster populations are expected to decline.

4.3 Long-Term (2070)

Under the FWOP scenario, and in response to sea level rise, wetland loss and saltwater intrusion in the Barataria Basin are anticipated to increase over time. Compared to the FWOP, the Preferred Alternative is anticipated to decrease salinity throughout the Barataria Basin by 2070, with the strongest effects below the diversion outfall (Figure 10). The largest changes over time to salinity would occur in the mid-region of Barataria Basin, near the diversion outfall.

The magnitude of salinity changes decreases with increasing distance from the diversion outfall. The second greatest changes to salinity are anticipated to be on the north side of the barrier islands, in lower Barataria Bay, during all months where the diversion is operating above base flow. The barrier islands are an area where the basin's estuarine waters and the more saline nearshore Gulf waters mix, but additions of river flow and freshwater under the Preferred Alternative would likely move the mixing zone slightly south, and decrease salinity (by ≤6 ppt lower than the FWOP) just north of the barrier islands during the springtime months. However, the barrier islands, due to mixing with Gulf waters, have higher salinity than the rest of Barataria Basin during most of the year. The lowest monthly springtime salinity predicted at the barrier islands (USGS Station at Barataria Pass on Grand Isle) due to the Preferred Alternative is estimated to be approximately 3.1 ppt, as compared to a minimum of 5.7 ppt in the FWOP in 2070. Average salinities below 5 ppt are predicted to be maintained for 2 months (April and May) when temperatures are predicted to average 20.2^{o}2 and 24.6^{o} C. As stated earlier, the projected values are monthly average values integrating the entire water column and area within the model grid cells. It would be expected that salinity values on and near the bottom of the water column would be higher than the presented average values throughout the water column, and that short term fluctuations of salinities (i.e., higher and lower) would occur based on water column stratification and complex circulation patterns exhibited in the lower Barataria Basin. Salinity conditions south of the barrier islands are primarily driven by nearshore and oceanic processes in the Gulf, and effects due to the Preferred Alternative are constrained to the immediate vicinity of the barrier islands. Areas on the Gulf side of the barrier islands experience wind-wave exposure that limits their potential as oyster growing areas and may preclude on-bottom culture.

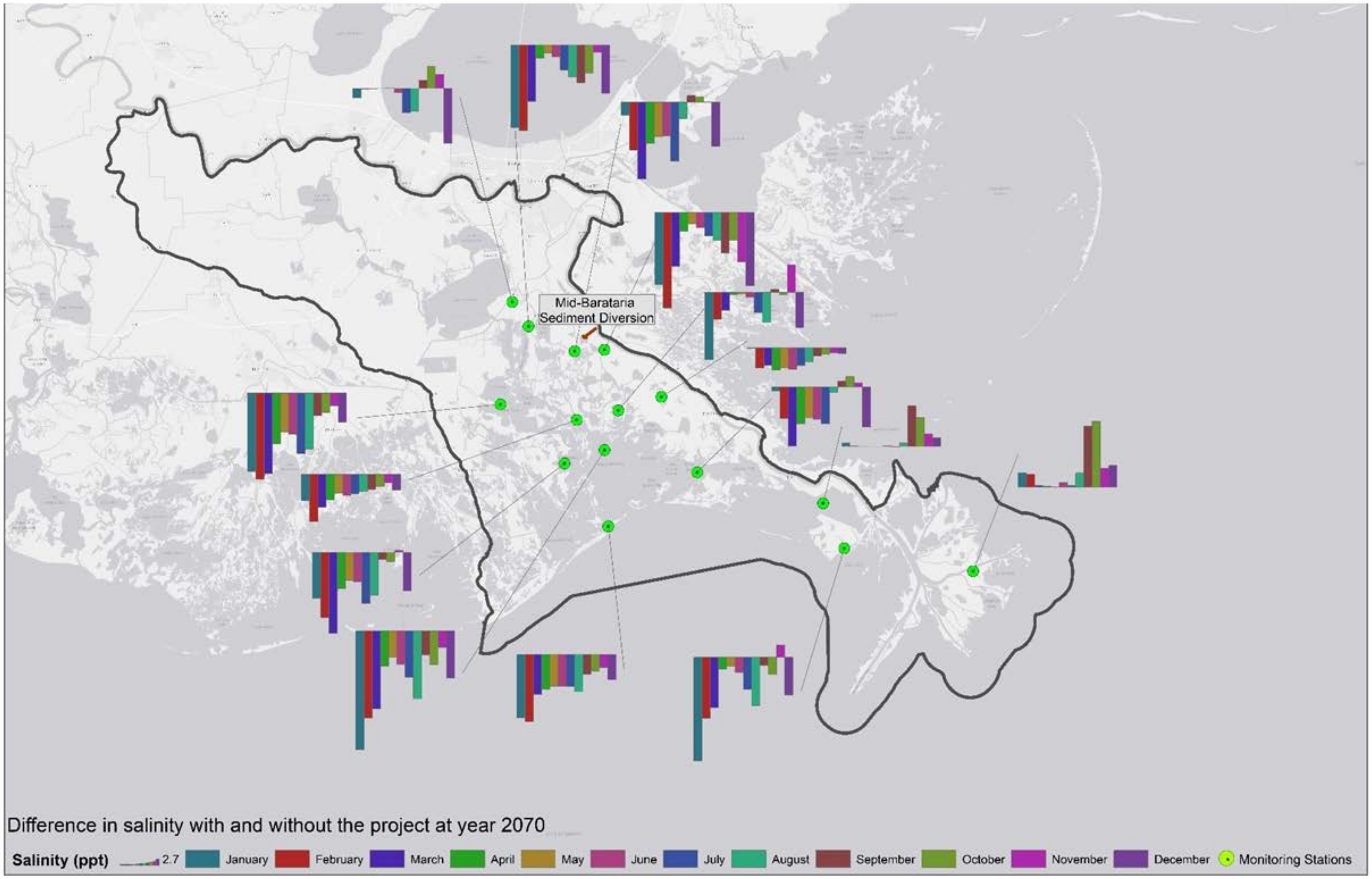


Figure 10. Effects of the Preferred Alternative on Salinity in 2070 in Barataria Basin, Compared to the FWOP Scenario.

As in the discussion for near-term and mid-term analysis of the Preferred Alternative, the lower basin near the barrier islands offers the only remaining suitable habitat within the Barataria Basin for all life history stages under flood flow hydrograph conditions. The POSGs would have the most significant losses during late spring flood years (as represented by the 2011 hydrograph), but there may be some recruitment in drier years (as represented by the 2006 hydrograph) (Figure 11). The Little Lake POSG is not currently productive and would remain unproductive in the future, so would not show a substantial change with the MBSD. Hackberry Bay POSR could have some suitable areas in dry years but may experience a total loss of oyster production from consecutive years of late spring flood events. Barataria Bay POSG may have some recruitment potential, even in flood years, but will also likely be substantially impacted by the proposed MBSD operations. Seabed surveys indicate that suitable substrate for cultch supplementation exists in portions of Barataria Bay where HSI values suggest that suitable habitat will exist in the future, including the southwest portion of Barataria Bay. Ongoing shellfish and fishery reef creation projects are creating and maintaining hard substrates near the barrier islands including areas near Bay Ronquille and Independence Island.

4.4 Synthesis

Across the three time periods, the Trustees expect that implementation of the MBSD under the Preferred Alternative would result in effects to the eastern oyster. As a sessile species, oysters are dependent on suitable habitat conditions within oyster reefs and public seed grounds. The main impacts would occur during the springtime operations of the MBSD, which will push suitable habitat toward the Gulf of Mexico and the barrier islands. Laboratory and field studies indicate that low salinity events (<5 ppt) decrease *P. marinus* (dermo) prevalence (La Peyre et al. 2009), therefore there may be benefits for oyster growing conditions to decreased salinity from the MBSD in the lower basin close to the Barataria Bay POSG. . Reducing salinities may benefit larval development and seed setting due to lower predation and disease rates when favorable environmental conditions are available.

Hackberry Bay POSR, which is the most productive seed ground currently in Barataria Basin, would experience the highest losses to recruitment and could potentially result in a total loss (or majority loss) of these areas in terms of supporting all life stages of oyster production. There may be other both negative and positive interactions that are not captured by the HSI model. For example, the HSI model focuses on adults and, therefore, salinity effects to larval and juvenile stages which are more sensitive to low salinities may be underrepresented. On the other hand, larval recruitment from areas that maintain suitable habitat could be a source of recruits during periods when salinity conditions are suitable for oyster survival and growth. As noted by Shumway (1996), through an array of physiological and behavioral mechanisms, oysters are highly tolerant of different habitats and environmental variations found in estuarine habitats which may allow oyster populations to be maintained in areas where suitable conditions are only present in some years. During Mississippi River drought years oysters may have the chance to spawn and to settle in broader geographic areas than during flood years. Sedimentation as a result of the diversion may cause some oysters and hard substrates used for oyster settlement near the outfall to be buried over time. Overall, effects from lower salinity will continue over time, and the number of oysters that are able to spawn and contribute to natural recruitment will likely decrease greatly. This will ultimately result in lower abundances of eastern oysters in the Barataria Basin under the Preferred Alternative compared to the FWOP scenario.

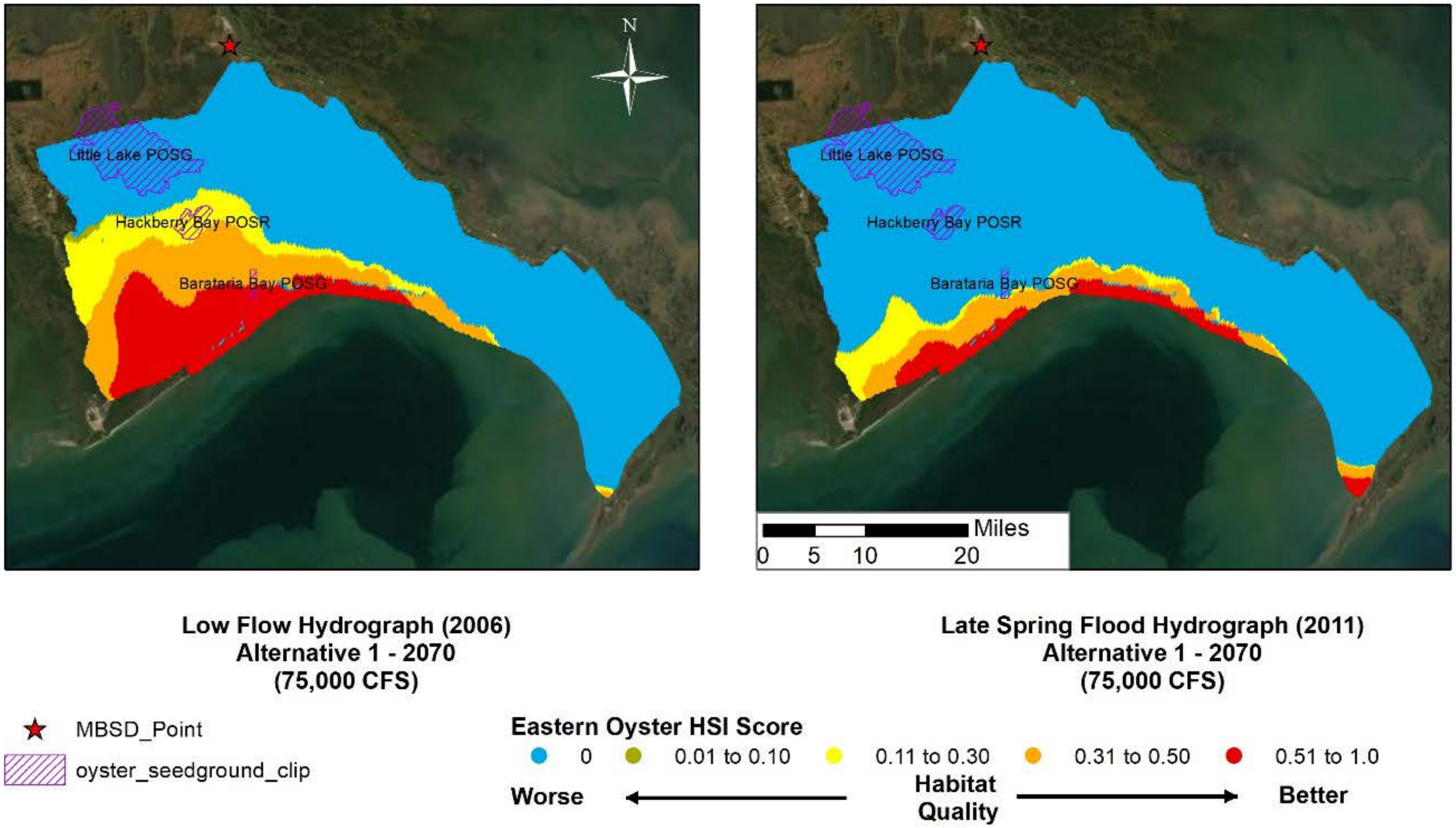


Figure 11. Comparison of HSI Outputs using a Low Mississippi River Hydrograph (2006) vs. a High Mississippi River Hydrograph (2011) for the Preferred Alternative (75,000 CFS) in year 2070.
Source: TWI, 2019

References

Banks, P.D. 2011. Comprehensive report of the 2010 oyster mortality study in Brenton Sound and Barataria Basins – May 2011. Louisiana Department of Wildlife and Fisheries, Fisheries Division.

Banks, P., S. Beck, K. Chapiesky, and J. Isaacs. 2016. Louisiana oyster: Fishery management plan. Louisiana Department of Wildlife and Fisheries, Office of Fisheries.

Barnes, T.K., A.K. Volety, K. Chartier, F.J. Mazzotti, and L. Pearlstine. 2007. A habitat suitability index model for the eastern oyster (*Crassostrea virginica*), a tool for restoration of the Caloosahatchee Estuary, Florida. Journal of Shellfish Research 26(4):949–959.

Battista, T.A. 1999. A habitat suitability index model for the Eastern oyster, Crassostrea virginica, in the Chesapeake Bay: A geographic information system approach. Master of Science, University of Maryland at College Park, Marine Estuarine Environmental Sciences Program.

Brown, K., G. George, G. Peterson, B. Thompson, and J. Cowan, Jr. 2008. Oyster predation by black drum varies spatially and seasonally. Estuaries and Coasts 31:597–604 (*as cited in* Rybovich, 2014)

Brumbaugh, R.D., M.W. Beck, L.D. Coen, L. Craig, and P. Hicks. 2006. A practitioners' guide to the design and monitoring of shellfish restoration projects: An ecosystems services approach [online report]. Arlington, VA: The Nature Conservancy. Available at: http://www.habitat.noaa.gov/pdf/tncnoaa_shellfish_hotlinks_final.pdf

Cake, Jr., E.W. 1983. Habitat suitability index models: Gulf of Mexico American Oyster. FWS/OBS-82/10.57. Washington, DC: U.S. Department of Interior Fish and Wildlife Service. 37 pp.

Carle, M.V. C.E. Sasser, and H.H. Roberts. 2015. Accretion and vegetation community change in the wax lake delta following the historic 2011 Mississippi River flood. Journal of Coastal Research 31(3):569–587.

CB&I, 2016. Report on Geophysical Surveys of Barataria Basin and Adjoining Areas: Barataria Pilot Study of System Wide Assessment and Monitoring Program (SWAMP). Boca Raton, FL: CB&I Government Solutions, Inc., 471p. (Prepared for Coastal Protection and Restoration Authority of Louisiana).

CPRA (Coastal Protection and Restoration Authority). 2017. Louisiana's Comprehensive Master Plan for a sustainable coast [online report]. Available at: http://coastal.la.gov/our-plan/2017-coastal-master-plan/ .

Davis, H.C. and A. Calabrese. 1964. Combined effects of temperature and salinity on development of eggs and growth of larvae or *M. mercenaria* and *C. virginica*. Fishery Bulletin of the U.S. Fish and Wildlife Service 63:643–655.

Denapolis, T.M.V. 2018. Legacy Habitat Suitability of eastern oysters (Crassostrea virginica) in Louisiana: a prelude to Mississippi River Delta freshwater diversions. University of New Orleans Theses and Dissertations. 2560.

Dunnington, E.A., Jr. 1968. Survival time of oysters after burial at various temperatures. Proceedings of the National Shellfisheries Association 58:101–103.

EOBRT (Eastern Oyster Biological Review Team). 2007. Status review of the eastern oyster (*Crassostrea virginica*) [online report]. Report to the National Marine Fisheries Service, Northeast Regional Office.

NOAA Tech. Memo. NMFS F/SPO-88, 105 p. Available at: http://www.nmfs.noaa.gov/pr/species/Status%20Reviews/eastern_oyster_sr_2007.pdf

Gagliano, S.M., K.J. Meyer-Arendt, and K.M. Wicker. 1981. Land loss in the Mississippi River deltaic plain. Trans. Gulf Coast Assoc. Geol. Soc. 31:295–300. (*as cited in* Soniat et al. 2013)

GEC, 2019. Draft Mid-Baratira Sediment Diversion Project EIS. Prepared by GEC for U.S. Army Corps of Engineers, New Orleans District.

Heilmayer, O., J. Digialleonardo, L. Qian, and G. Roesijadi. 2008. Stress tolerance of a subtropical *Crassostrea virginica* population to the combined effects of temperature and salinity. Estuarine, Coastal and Shelf Science 79(1):179–185.

Hijuelos, A.C., S.E. Sable, A.M. O'Connell, and J.P. Geaghan. 2017. 2017 Coastal Master Plan: Attachment C3-12: Eastern oyster, *Crassostrea virginica*, habitat suitability index model. Version Final. (pp. 1-23). Baton Rouge, Louisiana: Coastal Protection and Restoration Authority.

Karel, E. 1999. Ecological effects of dumping of dredged sediments; options for management. Journal of Coastal Conservation 5:69–80.

Kilgen, R. H., R.J. Dugas, and D. Moran. 1989. The ecology of oyster reefs of the northern Gulf of Mexico: An open file report (No. NWRC 89-03) (p. 113). Slidell, LA: National Wetlands Research Center; U.S. Fish and Wildlife Service.

LDWF (Louisiana Department of Wildlife and Fisheries). 2015. Assessment Report of the public oyster areas of Louisiana: Seed grounds and seed reservations. Oyster Data Report Series No. 21.

LDWF. 2019. Louisiana oyster: 2017 stock assessment report of the public oyster seed grounds and reservations of Louisiana. Oyster Data Report Series No. 23.

Loosanoff, V.L. 1953. Behavior of oysters in water of low salinities. Proceedings of the National Shellfisheries Association 43:135–151.

Lorio, W. and S. Malone. 1994. Southern Regional Aquaculture Center: The cultivation of American oysters (Crassostrea virginica). SRAC Publication No. 432 [online resource]. Available at: https://pdfs.semanticscholar.org/4bf6/87a81c58b79ced2dd04ebbbca1eac64aab50.pdf?_ga=2.267615628.343761565.1573666805-336782386.1549068769 (accessed on November 13, 2019)

Louisiana Trustee Implementation Group (TIG), 2019. Draft Phase II Restoration Plan: Mid-Barataria Sediment Diversion.

Lowe, M.R., T. Sehlinger, T.M. Soniat, and M.K. La Peyre. 2017. Interactive effects of water temperature and salinity on growth and mortality of eastern oyster, *Crassostrea virginica*: A meta-analysis using 40 years of monitoring data. Journal of Shellfish Research 36: 683–697.

Melancon, E., T.M. Soniat, V. Cheramie, R.J. Dugas, J. Barras, and M. Lagarde. 1998. Oyster resource zones of the Barataria and Terrebonne estuaries of Louisiana. Journal of Shellfish Research 17:1143–1148.

Murray, J., H. Roman, and J.J. Westerink. 2015. Technical Memorandum: Development of oyster larval transport analysis (ADCIRC). DWH Oyster NRDA Technical Working Group Report.

Oyster Technical Task Force. 2012. The oyster fishery of the Gulf of Mexico, United States: A fisheries management plan. (S. J. Vanderkooy, Ed.). Ocean Springs, MS: Gulf States Marine Fisheries Commission.

Pattillo, M., L.P. Rozas, and R.J. Zimmerman. 1995. A review of salinity requirements for selected invertebrates and fishes of U.S. Gulf of Mexico estuaries (Final report to the Environmental Protection Agency, Gulf of Mexico Program). U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southeast Fisheries Science Center, Galveston Laboratory.

Pattillo, M.E., T.E. Czapla, D.M. Nelson, and M.E. Monaco. 1997. Distribution and abundance of fishes and invertebrates in Gulf of Mexico estuaries, Vol. II: Species life history summaries (No. 11, p. 377). Silver Spring, Md.: U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service. Retrieved from: https://archive.org/details/distributionabun02nels

Plunket, J. and M. La Peyre. 2005. Oyster beds as fish and macroinvertebrate habitat in Barataria Bay, Louisiana. Bulletin of Marine Science 77(1):155–164.

Powers, S. P., and S.B. Scyphers. 2015. Estimating injury to nearshore fauna resulting from the Deepwater Horizon oil spill (NS_TR.17). DWH Shoreline Technical Working Group Report.

Powell, E. N. 2017. What is going on with *Perkinsus marinus* in the Gulf of Mexico? Estuar. Coasts 40:105–120.

Roman, H. 2015. Development of oyster nearshore injury quantification (NS_TR.04). DWH Oyster NRDA Technical Working Group Report.

Rose, K., C. Ainsworth, D. Brady, K. de Mutsert, K. Lewis, and S. Sable. 2019. Description of the Barataria Bay Food Web Structure and Energetics from the EwE and CASM Ecosystem Models. Report prepared by the Expert Panel for the Louisiana Trustee Implementation Group for consideration in the Environmental Impact Statement (EIS). January 29.

Rybovich, M.M. 2014. Growth and mortality of spat, seed, and market-sized oysters (*Crassostrea virginica*) in low salinities and high temperatures. Louisiana State University, Master's Theses. 3690. Available at: https://digitalcommons.lsu.edu/gradschool_theses/3690

Sellers M.A. and J.G. Stanley. 1984. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (North Atlantic) – American oyster. U.S. Fish Wildl. Serv. FWS/OBS-82/11.23. U.S. Army Corps of Engineers, TR EL-82-4. 15 pp. Available at: http://www.nwrc.usgs.gov/publications/specprof.htm

Shumway, S. 1996. Natural environmental factors. Chapter 13 in Kennedy, V.S., R.I.E. Newell, and A.F. Eble (eds.) The Eastern Oyster: *Crassostrea virginica*. Pp. 467-513.

Soniat, T.M. 2012. Eastern Oyster Habitat Suitability Index Technical Report. In: Louisiana's Comprehensive Master Plan for a Sustainable Coast, Appendix D-13.

Soniat, T.M., C.P. Conzelmann, J.D. Byrd, D.P. Roszell, J.L. Bridevaux, K.J. Suir, and S.B. Colley. 2013. Predicting the effects of proposed Mississippi River diversions on oyster habitat quality; application of an oyster habitat suitability index model. Journal of Shellfish Research 32(3):629–638.

Soniat, T. M., J. M. Klinck, E. N. Powell, N. Cooper, M. Abdelguerfi, E. E. Hofmann, J. Dahl, S. Tu, J. Finigan, B. Eberline, J. F. La Peyre, M. K. La Peyre, and F. Qaddoura. 2012. A shell-neutral modeling approach yields sustainable oyster harvest estimates: A retrospective analysis of the Louisiana state primary seed grounds. Journal of Shellfish Research 31(4):1103-1112.

Soniat, T. M., Cooper, N. A., & Powell, E. N. (2019). Prospects for the Sustainable Management of Public Oyster Resources. Journal of Shellfish Research, 38(2), 337-349.

Southworth, M., M.C. Long, R. Mann. 2017. Oyster (Crassostrea Virginica [Gmelin, 1791]) Mortality at Prolonged Exposures to High Temperature and Low Salinity. VIMS Articles 303.

Stanley, J.G. and M.A. Sellers. 1986. Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Gulf of Mexico)--American oyster (No. TR EL-82-4) (p. 25). U.S. Army Corps of Engineers.

Stokes, S., S. Wunderink, M. Lowe, and G. Gereffi. 2012. Restoring Gulf oyster reefs: Opportunities for innovation [online report]. Duke Center on Globalization, Governance & Competitiveness. Available at: http://www.mississippiriverdelta.org/files/2012/07/CGGC_Oyster-Reef-Restoration.pdf

Turner, R. E. 1997. Wetland loss in the northern Gulf of Mexico: Multiple working hypotheses. Estuaries 20(1):1-13.

TWI (The Water Institute of the Gulf). 2019. Technical Memorandum: Hysteresis – detailed oyster habitat suitability index results for Mid-Barataria EIS, May 17, 2019. Prepared for Joseph Wes Leblanc, Coastal Protection and Restoration Authority. Prepared by TWI.

USGS and Louisiana DNR. 2019. Oyster Ground GIS Data provided by Blair Hutchison, USGS Wetland Aquatic Center in Baton Rouge, Louisiana on October 11, 2019.

Van Sickle, V., B. Barrett, T. Ford and L. Gulick. 1976. Barataria Basin: Salinity changes and oyster distribution. Louisiana Sea Grant Publication No. LSU-T-76-02.

Wallace, R.K., P. Waters, and F.S. Rikard. 2008. Southern Regional Aquaculture Center: Oyster hatchery techniques [online resource]. SRAC Publication No. 4302. Available at: https://agrilifecdn.tamu.edu/fisheries/files/2013/09/SRAC-Publication-No.-4302-Oyster-Hatchery-Techniques.pdf (accessed on November 13, 2019).

Wicker, K.M. 1979. The Development of the Louisiana Oyster Industry in the 19th Century. Louisiana State University, Historical Dissertations and Theses. 3362. Available at: https://digitalcommons.lsu.edu/gradschool_disstheses/3362

Wilber, D. and D. Clarke. 2010. Dredging activities and the potential impacts of sediment resuspension and sedimentation on oyster reefs. Conference Presentation, Western Dredging Association, San Juan, Puerto Rico. Available at: https://www.westerndredging.org/phocadownload/ConferencePresentations/2010_SanJuanPR/Session2A-EnvironmentalAspectsOfDredging/1%20-%20Wilber%20-%20Dredging%20Activities%20and%20Potential%20Impacts%20of%20Sedimentation%20and%20Resuspension%20on%20Oyster%20Reefs.pdf (accessed on October 30, 2019).

Zivkovik, B. 2010. Ecology, conservation, and restoration of oyster reefs in North Carolina [online article]. Science in the Triangle. Available at: http://scienceinthetriangle.org/2010/01/ecology-conservation-and-restoration-of-oyster-reefsin-north-carolina/

N3: Essential Fish Habitat Correspondence
(to be provided in the FEIS)