US Army Corps of Engineers

Inner Harbor Navigation Canal (IHNC) - Lock Replacement, Orleans Parish, Louisiana, General Reevaluation Report

APPENDIX D ECONOMICS

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Acknowledgement

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EXECUTIVE SUMMARY

The Inner Harbor Navigational Canal (IHNC) lock experiences greater transit times than anywhere else in the Nation. When comparing processing times, the IHNC lock ranks 74th, but a comparison of the transit times (delay time plus processing times) shows the IHNC Lock as having the longest average transit times in the Nation, averaging more than 16 hours per tow. Many times these delays are between 24 and 36 hours during high Mississippi River stages.

The Inner Harbor Navigation Canal (IHNC) Lock Replacement General Reevaluation Report (GRR) assess the feasibility of improving navigation efficiencies for traffic on the GIWW and the Mississippi River via the IHNC lock in New Orleans, Louisiana. While replacing the lock to improve navigation inefficiency at IHNC has been studied previously, a GRR is required due to changes in the scope of the project which require reanalysis of the recommended plan. After initial filtering, the following plans were identified for further analysis

1. Plan 1 – No Action
2. Plan 2 - 75' x 900' x 22'
3. Plan 3 - 110' x 900' x 22'
4. Plan 4 - 75' x 1200' x 22'
5. Plan 5 - 110' x 1200' x 22'

To generate the metrics to analyze these plans, the USACE Planning Center of Expertise for Inland Navigation Risk-Informed Economics Division (PCXIN-RED) employed the Waterway Analysis Model (WAM) and the Navigation Investment Model (NIM). The WAM and NIM work together to model how the different plans will impact lock capacity, waterway demand, waterway costs, waterway benefits, and other variables.

As shown in the table below, the results of the PCXIN-RED analysis show the metrics for all plans are relatively close. For example, the difference in total costs between Plan 2 and Plan 5 is less than $3.2 million and difference in net benefits is less than $3.5 million for the mid traffic scenarios. Despite the small difference, the results do show that Plan 2 and Plan 3 have lower costs and greater benefits than Plan 4 and Plan 5. When comparing Plan 2 and Plan 3, Plan 3 becomes the Tentatively Selected Plan (TSP) because it has the best BCRs and greatest net benefits for the mid traffic forecast scenario which is the most likely scenario.

Inner Harbor Navigation Canal

Lock Replacement GRR

Average Annual Benefit - Cost Summary[1]

Elastic Movement-Level Demand[2]

(Dollars, Average annual 2.875% discount/amortization rate, 2019-2082 with 2032 base year)

Lock Alternative	Plan 2: 75' x 900'	Plan 3: 110' x 900'	Plan 4: 75' x 1,200'	Plan 5: 110' x 1,200'
First Cost of Construction	$937,730,713	$952,108,468	$972,850,987	$1,002,530,370
Interest During Construction	$210,122,700	$213,913,418	$218,607,128	$225,849,983
Total Investment	$1,147,853,413	$1,166,021,887	$1,191,458,115	$1,228,380,353
Average Annual Const. Cost	$43,558,840	$44,248,299	$45,213,555	$46,614,683
Average Annual Increm. O&M	$1,366,399	$1,353,464	$1,435,237	$1,435,237
Total Average Annual Cost	$44,925,239	$45,601,762	$46,648,792	$48,049,920
Total Average Annual Benefits	$214,683,201	$217,916,647	$216,793,536	$218,269,611
Net Excess Benefits	$169,757,963	$172,314,885	$170,144,745	$170,219,691
B/C Ratio	4.78	4.78	4.65	4.54

[1]PCXIN-RED Results 27-OCT-2016

[2]GEC Reference Traffic Demand Forecasts and Wilson Calcasieu study commodity group elasticities.

(yellow)	Worst performing plan according to the metric
(green)	Best performing plan according to metric

1. INTRODUCTION

The Inner Harbor Navigation Canal (IHNC) Lock, completed by the Port of New Orleans in 1923, is 75 feet wide and 640 feet long and has a depth over the sill of 31.5 and is located at Mississippi River Mile 92.6 Above Head of Passes (AHP). Since the lock's location is in the middle of an urban area, lock operations are influenced by the three bridges: the St. Claude Ave. vehicular bridge, the Claiborne Ave. vehicular bridge, and the Florida Ave. vehicular/railroad Bridge. As shown in **FIGURE 1-1**, the Florida Avenue Bridge and Claiborne Avenue Bridge are some distance away from the lock, so coordination of these bridge openings with lock operations is more easily done thereby making interference to navigation from these bridges less significant. However, the St. Claude Ave. Bridge is located between the approach point (waiting point) for vessels ready for lock service entering from the Mississippi River and the lock chamber.

FIGURE 1-1: Inner Harbor Navigation Canal Lock and Related Bridges

Between 2009 and 2013, the tons transiting IHNC Lock fluctuated between 14.7 million tons and 16.4 million tons. During this time, the delays to navigation at IHNC Lock increased from approximately 10 to 13 hours per tow. These delays, caused by the inadequate lock size and the effects of the three existing vehicular bridges crossing the IHNC in the vicinity of the lock reduced the overall efficiency of the IHNC, the Gulf Intracoastal Waterway (GIWW), and the U.S. inland navigation system.

With the problem of IHNC Lock inefficiencies in mind, the USACE New Orleans District began the IHNC Lock Replacement General Reevaluation Report (IHNCLR-GRR). The goal of the IHNCLR-GRR is to identify the National Economic Development (NED) plan to improve navigation efficiencies at the IHNC lock. Specifically the study aims to identify ways to reduce navigation transit times between the Mississippi River and waterways to the east of the river over a 50 year planning horizon.

To meet this objective, the IHNCLR-GRR Project Delivery Team (PDT) reviewed numerous studies and reports to develop a list of various locations and potential solutions. After screening the measures based on effectiveness, efficiency, and negative effects, the PDT established that building a larger concrete U-frame lock in an area north of Claiborne Avenue was the best possible option. To determine the optimal size for the new lock chamber, the following four chamber sizes were evaluated in the IHNC Lock GRR:

Plan 2 - 75' x 900' x 22'

Plan 3 - 110' x 900' x 22'

Plan 4 - 75' x 1200' x 22'

Plan 5 - 110' x 1200' x 22'

This economic appendix is divided into three sections. The first section provides background information such as project details, statistics on GIWW traffic, and statistics on IHNC traffic. Next, the second section discusses the analysis methods by outlining the general analysis framework, by detailing the Future Without Project (FWOP) assumptions, by discussing the Future With Project (FWP) analysis techniques, and by describing the models and inputs used to analyze the alternatives including how the Navigation Investment Model (NIM) estimates the Benefit-Cost Ratio (BCR) for each alternative. Finally, the last section of the economic appendix presents the results for each alternative.

2. BACKGROUND INFORMATION

2.1 Project Description

The Inner Harbor Navigation Canal (IHNC) and the IHNC Lock were built during the early 1920's. The canal and lock, which are also known as the Industrial Canal and Lock, intersect the Mississippi River at mile 93 above Head of Passes (AHP). They originally connected only Lake Pontchartrain and the river, and were built by the Board of Port Commissioners of Louisiana (now known as the Board of Commissioners of the Port of New Orleans or Dock Board) in response to a need for more port areas to handle increased water traffic in the port. The canal was initially built 200 feet wide and 20 feet deep with approximately 1,000 feet of land on each side of the canal to be used for port and industrial development. The lock was built to dimensions of 640 by 75 by 31.5 feet. Currently, the land on both sides of the canal is fully developed and devoted to industrial use. During World War II, the Federal Government rerouted the Gulf Intracoastal Waterway (GIWW) so that the IHNC lock connected the eastern and western sections of the GIWW, creating a more direct route to locations on the eastern gulf coast. Concurrent with the relocation of the GIWW-East, the Federal Government leased the IHNC lock and assumed its maintenance and operation. The lock was subsequently purchased by the Federal Government in 1986.

During three decades following construction of the IHNC, the Port of New Orleans continued to experience growth and ultimately congestion in the existing port area and entrances to the port. In 1956 Congress authorized construction of the Mississippi River-Gulf Outlet (MR-GO) to provide a tidewater channel to new harbor facilities that would supplement the existing port facilities as well as an alternate route to the Gulf of Mexico for oceangoing vessels. Intersecting the IHNC about 2.1 miles north of its intersection with the Mississippi River, the MR-GO was completed in 1967 with project dimensions of 500 feet wide by 36 feet deep. The distance to the Gulf of Mexico from the IHNC lock is about 70 miles, or about 50 miles shorter than the 45-foot depth route to the gulf via the Mississippi River. The provision of direct deep water access to the "Tidewater Port", as it came to be called, allowed the port to enter the era of containerization with competitive strengths that would not have been attainable if only the Mississippi River had been available. However, in the aftermath of Hurricane Katrina in 2005, there was strong belief by many local officials that the MR-GO channeled the hurricane's storm surge into the heart of Greater New Orleans, contributing significantly to the subsequent multiple engineering failures experienced by the region's hurricane protection network. In addition environmentalists also blamed it for killing off thousands of acres of cypress wetlands and marsh, vital to helping the area absorb the pounding of hurricanes. Consequently, in May 2007 the Corps of Engineers announced it would close the MR-GO to all traffic which was achieved in 2009 by constructing a closure dike across the waterway near its entrance to the Gulf of Mexico.

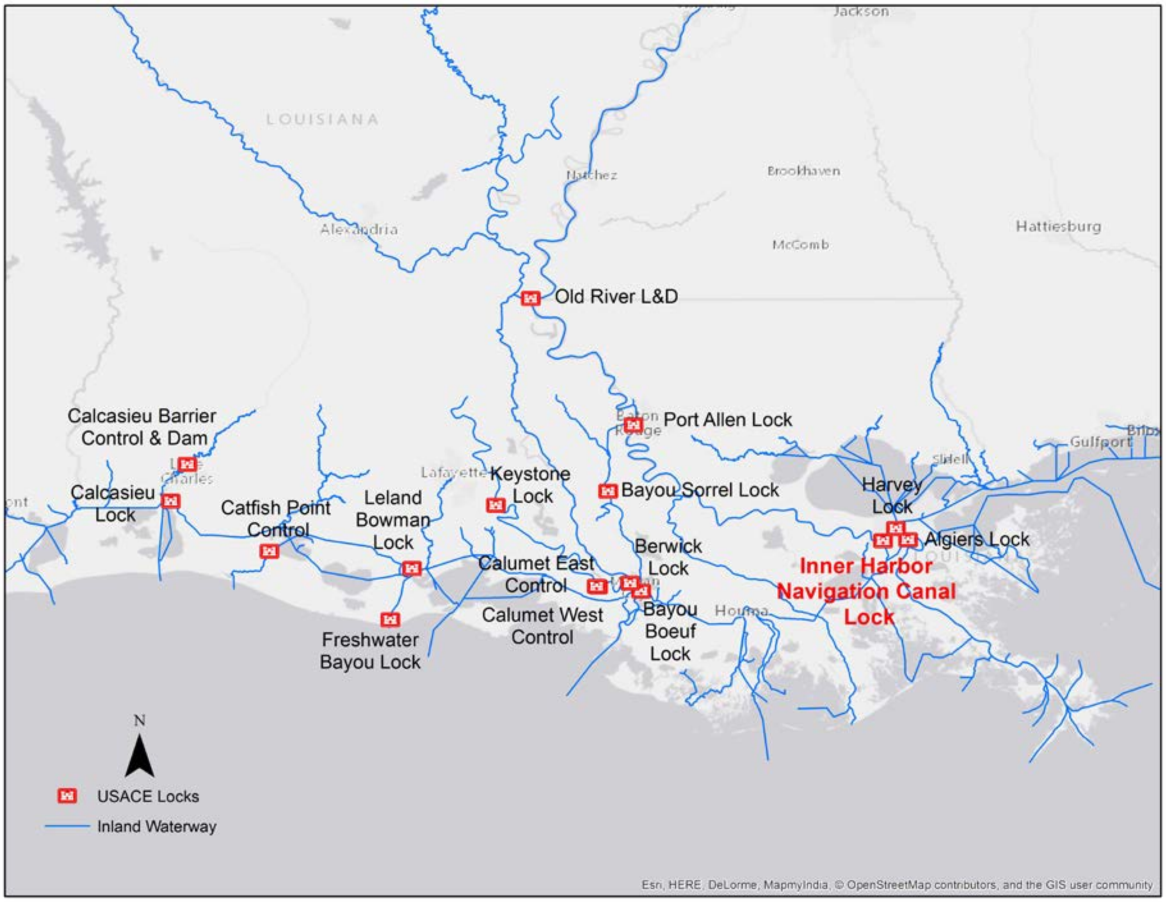
The GIWW, of which the IHNC is a crucial link, also grew rapidly during this period. The GIWW traces the U.S. coast along the Gulf of Mexico from Apalachee Bay near St. Marks, Florida, to the Mexican border at Brownsville, Texas. Mile 0.0 of the GIWW intersects the Mississippi River at mile 98.2 (AHP), the location of Harvey Lock, and extends eastwardly for approximately 376 miles and westward for approximately 690 miles. In addition to the mainstem, the GIWW includes a major alternate channel, 64 miles long, which connects Morgan City, Louisiana to Port Allen, Louisiana at Mississippi River mile 227.6 AHP, and a parallel mainstem channel, 9.0 miles long, which joins the Mississippi River at mile 88.0 AHP, the location of Algiers Lock, to the mainstem at GIWW West mile 6.2. Project dimensions for the mainstem channel and the alternate route are 12 feet deep and 125 feet wide, except for the 150 foot width between the Mississippi River and Mobile Bay portion of the GIWW East. Numerous side channels and tributaries intersect both the eastern and western mainstem channels providing access to inland areas and coastal harbors.

There are five primary GIWW navigation locks on the mainstem west: Algiers, Harvey, Bayou Boeuf, Leland Bowman, and Calcasieu, with Port Allen and Bayou Sorrel on the GIWW Morgan City-Port Allen Alternate Route. West of Calcasieu lock, the westernmost lock identified above, there are four additional navigation structures. These include the East and West Brazos River Floodgates located at GIWW West mile 404.1, and the East and West Colorado River Locks located at GIWW West mile 444.8. There are no navigation structures on the GIWW east of the IHNC lock. **TABLE 2-1** describes the physical characteristics and locations of the primary GIWW locks and **FIGURE 2-** maps the area that includes these locks.

TABLE 2- 1: System Physical Description of Locks

Waterway/Lock	GIWW Mile	Miss. River Mile	Length (Feet)	Width (Feet)	Sill Depth (Feet)	Lift (Feet)	Year Opened
GIWW East							
IHNC	0	92.6	640	75	31.5	17	1923
GIWW West							
Algiers	0	88	760	75	13	18	1956
Harvey	0	98.2	425	75	12	20	1935
Bayou Boeuf	93.3	n.a.	1156	75	13	11	1954
Leland Bowman	162.7	n.a.	1200	110	15	5	1985
Calcasieu	238.9	n.a.	1206	75	13	4	1950
GIWW Alt. Route M.C. - P.A.							
Port Allen	64.1	227.6	1202	84	14	45	1961
Bayou Sorrel	36.7	n.a.	797	56	14	21	1952
Atchafalaya-Mississippi River Link (Old River)							
Old River	n.a.	304	1200	75	11	35	1963

FIGURE 2-0: Inner Harbor Navigation Canal Lock Along With Other Gulf Intercoastal Waterway Locks



2.2 Historical and Current Statistics

This section discusses the amount and types of commodities moving on the Gulf Intracoastal Waterway (GIWW) and through the Inner Harbor Navigational Canal (IHNC). The final year in the following tables and figures is 2012 because this was latest year of available data at the time of report generation.

2.2.1 GIWW

2.2.1.1 Tons and Commodity Types

TABLE 2-2 presents the annual vessel trips and tons for the major commodity groups' traveling on the GIWW for the period 2003 through 2012. The Total annual commodity tons was 85.343 million in 2003, rising to a 10-year maximum of 89.637 million in 2006 (very close to 89.244 million tons in 2004) and then declining to a 10-year minimum of 78.868 million in 2009. Total annual commodity tons was relatively stable in 2011 and 2012 at 79.686 and 80.537 million, respectively. However, annual coal tonnage has declined from a high value of 1.621 million tons in 2004 to 0.696 million tons in 2012. Coal tonnages in 2007, 2009, 2011 and 2012 were similar at 0.780 million, 0.846 million, 0.825 million and 0.696 million, respectively.

TABLE 2-3 contains the percentages of commodity vessel trips and tons of total waterborne commerce transiting the GIWW as per **TABLE 2-2**. **TABLE 2-3** reflects petroleum increasing to a larger share of GIWW total annual commodity tons, increasing from a share of about 44 percent in 2003 to about 50 percent near the end of the time series, including years 2009 (51.17 percent), 2010 (49.90 percent), 2011 (49.65 percent) and 2012 (50.765 percent). The share of chemical tonnage of total GIWW tonnage has fluctuated in line with the fluctuations in chemical traffic which has declined unlike total petroleum tons. Chemical tonnage was nearly 19 percent of total GIWW commodity tons in 2003 and declined subsequently to 14.33 percent in 2009 and then rose to about 16 percent in 2011 and 2012. Crude materials share of total commodity tons was relatively constant across the time series, about 25 percent, declining slightly in 2011 and 2012 to 23.21 percent and 22.07 percent, respectively. Primary manufactured goods share of total commodity tons has been relatively stable, about 5 percent to 6 percent of total annual tons. The three major commodity groups, petroleum, chemicals, and crude materials, collectively account for nearly 90 percent of total annual GIWW tons. Their total share ranges from 86.70 percent (2003) to 88.66 percent (2012).

Other declining commodity tons during the time series are reflected by manufactured equipment, machinery and products, and chemicals. These groups represented totals of 2.174 and 16.142 million tons in 2003, respectively, but by 2013 the annual tons had declined to 0.608 and 12.834 million tons, respectively. Chemical tonnages declined to 11.303 million in 2009 and since then have ranged in the vicinity of 13 million tons (13.070 million in 2010, 12.796 million in 2011 and 12.834 million in 2012). To the contrary the manufactured equipment group tons have continued to decline after stabilizing at about 1.300 million in 2007, 2008, 2009 and 2012 to 0.700 and 0.608 million in 2011 and 2012.

The largest commodity group using the GIWW, petroleum and petroleum products, has been relatively stable during the time series 2003 through 2012 with some growth in recent years after 2008. Total petroleum annual tons was 37.757 million in 2003 and 40.791million in 2012. The maximum and minimum petroleum tons between 2003 and 2012 were 42.852 million in 2007 (about the same for 2006, 42.691 million) and 37.757 in 2003.

The second largest commodity group using the GIWW, chemicals and related products, displayed a cyclical decline over the time series with respect to the total annual tons transiting the GIWW. Total chemical tonnage was 16.142 million in 2003, a maximum for the time series that declined to 11.303 million in 2009 and then rose to nearly 13 million in the following years 2010, 2011 and 2012. Total annual chemical tons have been essentially flat between 2008 and 2012 about 12.8 million tons.

The third largest commodity group using the GIWW, crude materials inedible except fuels, has been relatively stable with respect to total annual tons during the period 2003 through 2008. Total tons was 2.589 million in 2003, increasing to 3.271 million in 2004 and remaining relatively stable until a small decline to 2.947 million in 2011 followed by 3.671 million and 3.847 million in 2012 and 2013, respectively.

The fourth largest commodity group using the GIWW, primary manufactured products, was relatively stable over the time series beginning with 4.383 million tons in 2003 and ending with 4.921 million tons in 2012. Between 2003 and 2012 primary manufactured products had a maximum tonnage of 5.941 million (2008) and a minimum tonnage of 3.726 million (2009). For the last three recorded years, 2010, 2011 and 2012, the tonnage has been in the range of 4.4 million (2011) to 4.9 million (2012).

FIGURE 2-1, FIGURE 2-2, FIGURE 2-3, and **FIGURE 2-4** display the annual tons of four largest commodity groups using the GIWW for the period 2003 through 2012 from **TABLE 2-2** with respect to petroleum and petroleum products (**FIGURE 2-1**), chemicals and related products (**FIGURE 2-2**), crude materials inedible except fuels (**FIGURE 2-3**) and primary manufactured products (**FIGURE 2-4**). **FIGURE 2-5** displays the total annual commodity tons using the GIWW for the period 2003-2012.

TABLE 2-2: GIWW Annual Vessel Trips and Major Commodity Group Tons, 2003-2012

PUB_NAME	2003		2004		2005		2006		2007	
	TRIPS	TONS	TRIPS	TONS	TRIPS	TONS	TRIPS	TONS	TRIPS	TONS
Total, all commoditiues	**57,994**	**85,343,864**	**66,376**	**89,244,144**	**62,481**	**84,467,558**	**60,885**	**89,637,347**	**60,782**	**87,348,400**
Total Coal	889	1,429,327	1,021	1,621,759	787	1,252,493	923	1,500,305	482	780,588
Total petroleum and petroleum products	17,204	37,757,696	19,417	39,954,020	17,928	38,958,488	18,955	42,691,881	19,226	42,852,987
Total chemicals and related products	7,815	16,142,530	8,095	16,073,125	7,038	15,000,580	7,500	14,892,831	7,440	14,950,271
Total crude materials inedible except fuels	16,816	20,091,809	18,224	21,987,263	16,895	20,414,409	17,295	21,557,512	16,224	19,627,623
Total primary manufactured goods	3,439	4,383,998	3,509	4,410,925	3,743	4,391,319	3,623	4,927,584	4,189	5,347,224
Total food and farm products	1,774	2,601,216	1,484	2,350,308	1,041	1,689,716	1,177	1,706,736	1,109	1,668,078
Total all manufactured equipment, machinery and products	9,563	2,174,864	14,112	2,081,276	14,342	1,766,059	10,764	1,440,112	11,573	1,347,436
Waste and Scrap NEC	494	692,205	514	728,614	707	982,317	648	920,026	539	771,247
Total unknown or not elsewhere classified	0	70,219	0	36,854	0	12,177	0	360	0	2,946

PUB_NAME	2008		2009		2010		2011		2012	
	TRIPS	TONS	TRIPS	TONS	TRIPS	TONS	TRIPS	TONS	TRIPS	TONS
Total, all commoditiues	**60,704**	**83,124,163**	**59,721**	**78,868,106**	**55,195**	**82,896,351**	**50,262**	**79,686,171**	**50,651**	**80,536,159**
Total Coal	653	1,055,274	321	846,038	479	1,125,850	519	825,140	440	696,414
Total petroleum and petroleum products	17,205	38,582,400	17,559	40,356,309	17,870	41,364,257	15,743	39,563,361	16,186	40,791,002
Total chemicals and related products	6,235	12,607,455	5,512	11,303,081	6,356	13,070,968	6,180	12,796,593	6,322	12,834,263
Total crude materials inedible except fuels	17,157	21,303,192	14,729	18,728,576	14,679	18,961,355	14,524	18,495,284	14,182	17,777,873
Total primary manufactured goods	4,229	5,941,577	2,508	3,716,898	3,153	4,500,561	2,996	4,399,760	3,208	4,921,775
Total food and farm products	970	1,485,822	1,048	1,777,761	1,065	1,861,189	1,220	2,185,620	1,302	2,218,535
Total all manufactured equipment, machinery and products	13,682	1,300,770	17,346	1,396,206	11,036	1,201,240	8,626	700,069	8,604	608,854
Waste and Scrap NEC	573	836,977	698	725,585	557	736,719	454	679,945	407	591,397
Total unknown or not elsewhere classified	0	10,696	0	17,652	0	74,212	0	40,399	0	96,046

Source: WCSC

TABLE 2-3: GIWW Annual Vessel Trips and Major Commodity Group Tons Percentage Distributions, 2003-2012

	2003		2004		2005		2006		2007	
PUB_NAME	TRIPS	TONS	TRIPS	TONS	TRIPS	TONS	TRIPS	TONS	TRIPS	TONS
Total, all commoditiues	**57,994**	**85,343,864**	**66,376**	**89,244,144**	**62,481**	**84,467,558**	**60,885**	**89,637,347**	**60,782**	**87,348,400**
Total Coal	2%	2%	2%	2%	1%	1%	2%	2%	1%	1%
Total petroleum and petroleum products	30%	44%	29%	45%	29%	46%	31%	48%	32%	49%
Total chemicals and related products	13%	19%	12%	18%	11%	18%	12%	17%	12%	17%
Total crude materials inedible except fuels	29%	24%	27%	25%	27%	24%	28%	24%	27%	22%
Total primary manufactured goods	6%	5%	5%	5%	6%	5%	6%	5%	7%	6%
Total food and farm products	3%	3%	2%	3%	2%	2%	2%	2%	2%	2%
Total all manufactured equipment, machinery and products	16%	3%	21%	2%	23%	2%	18%	2%	19%	2%
Waste and Scrap NEC	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
Total unknown or not elsewhere classified	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

	2008		2009		2010		2011		2012	
PUB_NAME	TRIPS	TONS	TRIPS	TONS	TRIPS	TONS	TRIPS	TONS	TRIPS	TONS
Total, all commoditiues	**60,704**	**83,124,163**	**59,721**	**78,868,106**	**55,195**	**82,896,351**	**50,262**	**79,686,171**	**50,651**	**80,536,159**
Total Coal	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
Total petroleum and petroleum products	28%	46%	29%	51%	32%	50%	31%	50%	32%	51%
Total chemicals and related products	10%	15%	9%	14%	12%	16%	12%	16%	12%	16%
Total crude materials inedible except fuels	28%	26%	25%	24%	27%	23%	29%	23%	28%	22%
Total primary manufactured goods	7%	7%	4%	5%	6%	5%	6%	6%	6%	6%
Total food and farm products	2%	2%	2%	2%	2%	2%	2%	3%	3%	3%
Total all manufactured equipment, machinery and products	23%	2%	29%	2%	20%	1%	17%	1%	17%	1%
Waste and Scrap NEC	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
Total unknown or not elsewhere classified	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Source: WCSC

FIGURE 2-1: GIWW: Annual Tonnages of Petroleum and Petroleum Products, 2003-2012

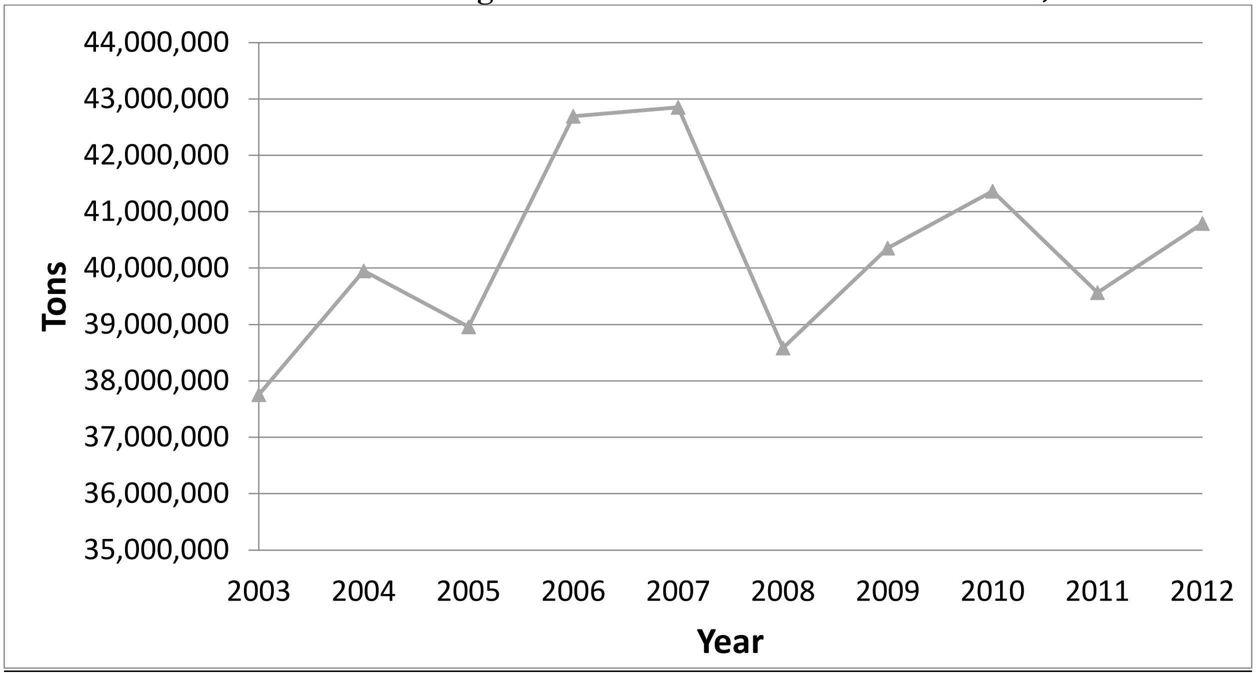


FIGURE 2-2: GIWW: Annual Tonnages of Chemicals and Related Products, 2003-2012

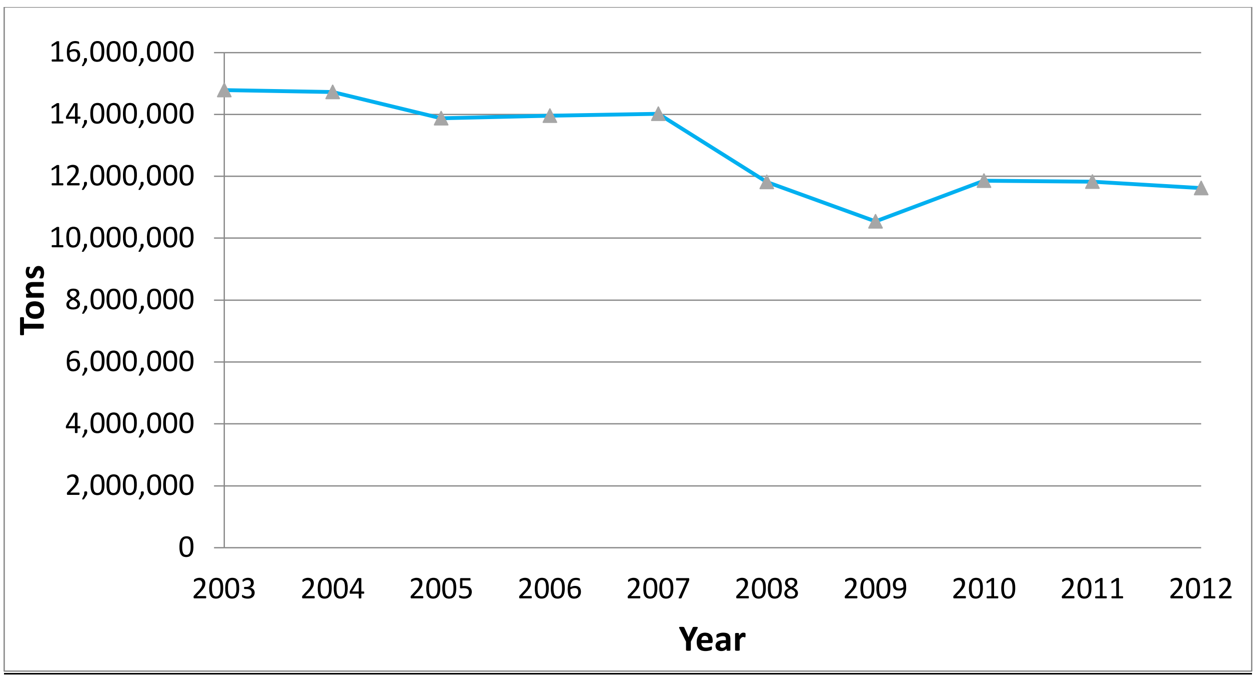


FIGURE 2-3: GIWW: Annual Tonnages of Crude Materials Inedible Except Fuels, 2003-2012

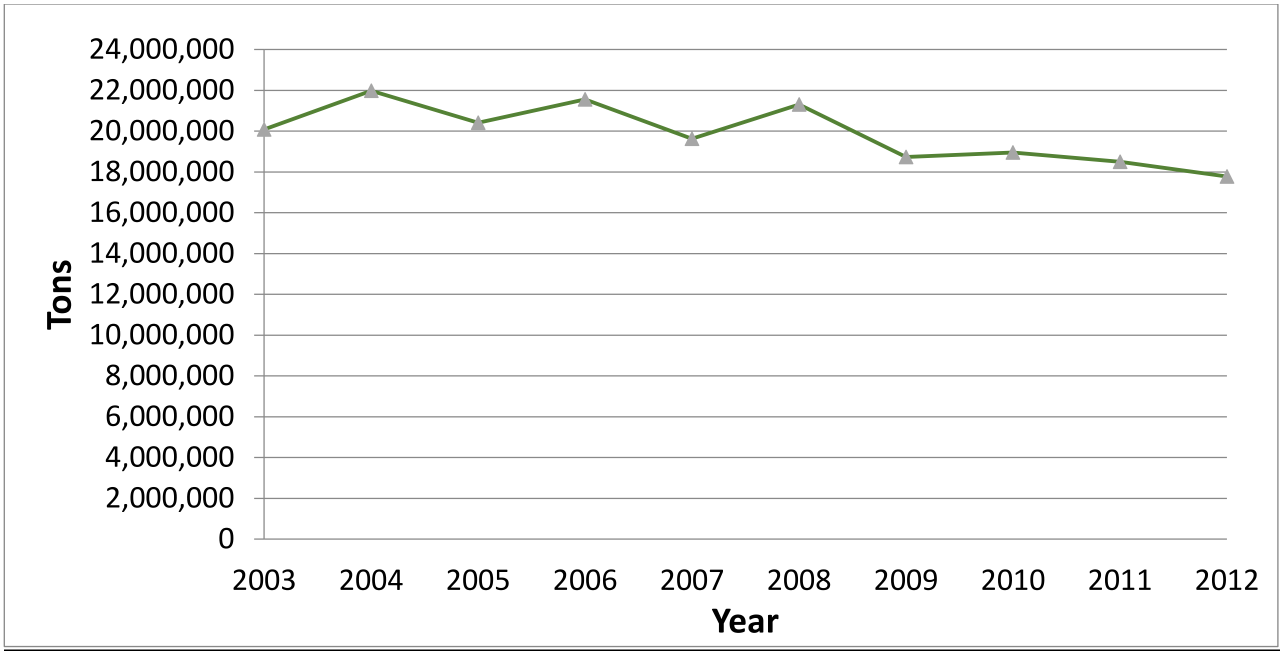


FIGURE 2-4: GIWW: Annual Tonnages of Primary Manufactured Goods, 2003-2012

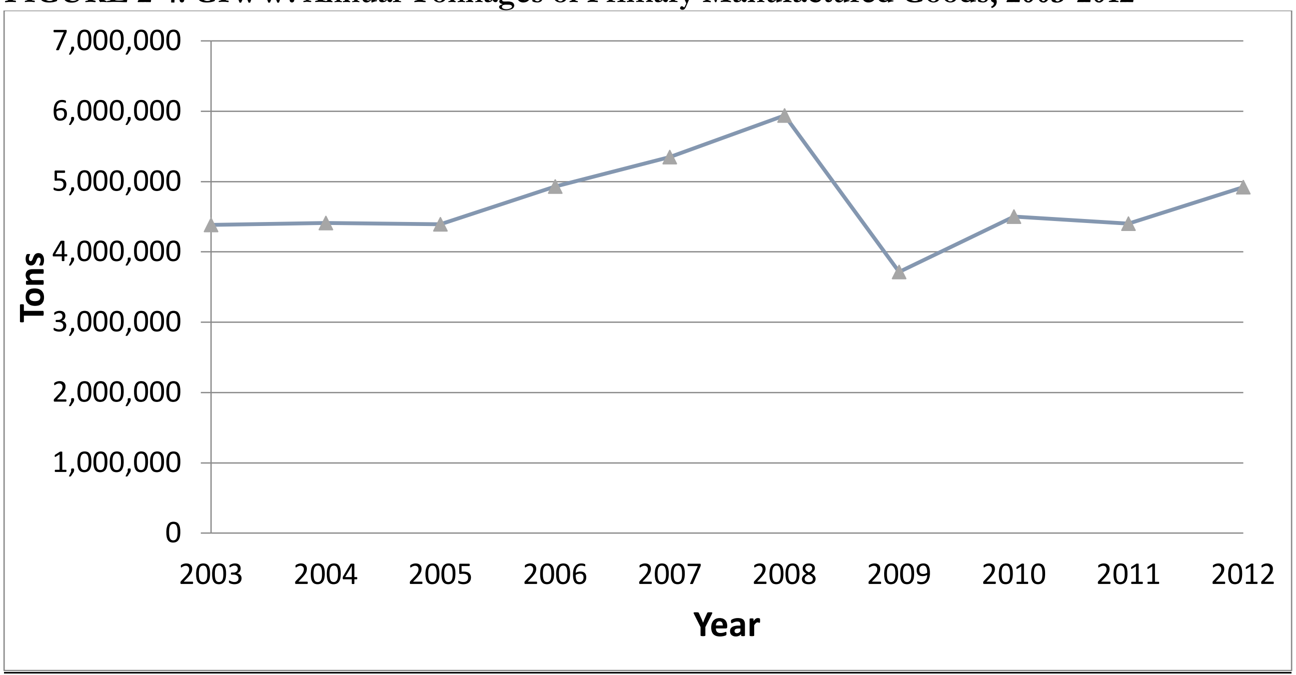
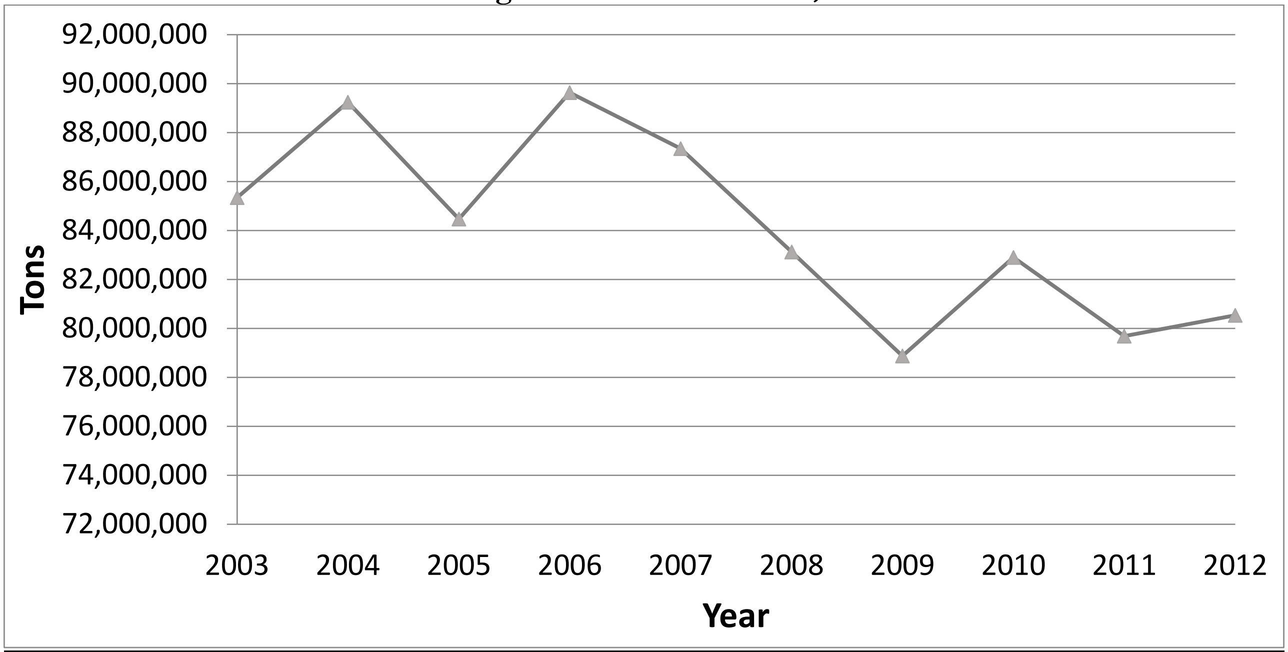


FIGURE 2-5: GIWW: Annual Tonnages of All Commodities, 2003-2012



2.2.2 IHNC

2.2.2.1 Tons and Commodity Types

TABLE 2-4 represents a compilation of the major commodity groups annual tons and vessel trips for the period 2003 through 2013 for the IHNC. Total annual commodity tons was 18.177 million in 2003, rising to a 10-year maximum of 18.774 million tons in 2004 and then declining to a 10-year minimum of 14.771 million tons in 2008. Recently, total annual commodity tons was relatively stable in 2012 and 2013 at 16.378 and 16.379 million tons, respectively. However, annual coal tonnage has declined from a high value of 1.236 million tons in 2004 to 0.313 million tons in 2013. Coal tonnages in 2011 and 2012 were similar to 2013 at 0.329 and 0.219 million tons, respectively.

TABLE 2-5 contains the percentages of commodity vessel trips and tons of total waterborne commerce transiting the IHNC as per **TABLE 2-4**. The distribution of total tons among the big four groups, petroleum, chemicals, crude materials and manufactured goods, was 36.1 percent, 26.8 percent, 14.2 percent and 9.9 percent in 2003,respectively, while in 2013 the percentage distribution for these four groups was 38.6 percent, 22.9 percent, 23.5 percent and 11.6 percent, respectively. There is a slight increase in the share of total tons in 2013 compared to 2003 for petroleum and manufactured goods and a slight decrease for chemicals. The group that represents crude materials has a much larger share of total tonnage transiting the IHNC in 2013 compared to 2003.

Other declining commodity tons during the time series are reflected by two groups, manufactured equipment, machinery and products, and food and farm products. These groups represented a total of 0.737 and 0.503 million tons in 2003, respectively, but by 2013 the annual tons had declined to 0.006 and 0.241 million tons, respectively. Food and farm products have been more stable in recent years ranging from 0.268 million tons in 2009 to 0.325 million tons in 2010, 0.359 million tons in 2011 and 0.363 million tons in 2012. To the contrary the manufactured equipment group tons have all but disappeared relative to the level recorded in 2003.

The largest commodity group using the IHNC, petroleum and petroleum products, has been relatively stable during the time series 2003 through 2013. Total petroleum annual tons were 6.567 million in 2003 and 6.323 million in 2013. The maximum and minimum petroleum tons between 2003 and 2013 were 7.096 million in 2010 and 5.834 million in 2008, respectively.

The second largest commodity group using the IHNC, chemicals and related products, displayed more fluctuation than the petroleum group with respect to the total annual tons transiting the IHNC. Total chemical tonnage was 4.880 million in 2003, a maximum for the time series that declined to 2.877 million in 2009 and then rose to 3.747 million in 2013. In the last four years the total annual tons of chemicals transiting the IHNC have been relatively stable albeit depressed compared to 2003. Annual total tons were 3.394 million in 2010, 3.389 million in 2011 and 3.312 million in 2012 before increasing to 3.747 million in 2013.

The third largest commodity group using the IHNC, crude materials inedible except fuels, has been relatively stable with respect to total annual tons during the period 2003 through 2013. Total tons was 2.589 million in 2003, increasing to 3.271 million in 2004 and remaining relatively stable until a small decline to 2.947 million in 2011 followed by 3.671 million and 3.847 million in 2012 and 2013, respectively.

The fourth largest commodity group using the IHNC, primary manufactured products, displayed more year to year fluctuations than the previous three large groups. Total annual tons was 1.792 million in 2003, declining to 1.593 million in 2005 and then rising to 2.266 million in 2008, then declining to 1.312 million in 2009 and then rising to 2.076 million tons in 2012 and 1.894 million tons in 2013.

FIGURE 2-6, **FIGURE 2-7**, ***FIGURE 2-8***, and ***FIGURE 2-9*** display the annual tons of the four largest commodity groups using the IHNC for the period 2003 through 2013 from **TABLE 2-4** with respect to petroleum and petroleum products (**FIGURE 2-6**), chemicals and related products (**FIGURE 2-7**), crude materials inedible except fuels (***FIGURE 2-8***) and primary manufactured products (***FIGURE 2-9***). ***FIGURE 2-10*** displays the total annual commodity tons using the IHNC for the period 2003-2013.

TABLE 2-4: IHNC Annual Vessel Trips and Major Commodity Group Tons, 2003 - 2013

	2003		2004		2005		2006		2007		2008	
PUB_NAME	TRIPS	TONS	TRIPS	TONS	TRIPS	TONS	TRIPS	TONS	TRIPS	TONS	TRIPS	TONS
Total, all commoditiues	**12,110**	**18,177,788**	**12,802**	**18,774,232**	**11,568**	**16,764,794**	**11,852**	**17,228,373**	**11,661**	**16,771,812**	**11,609**	**15,409,037**
Total Coal	663	1,058,929	781	1,236,277	498	784,339	546	884,870	213	342,148	353	569,738
Total petroleum and petroleum products	2,310	6,567,472	2,319	6,540,301	2,064	6,424,778	2,195	6,957,353	2,256	6,988,979	1,961	5,834,832
Total chemicals and related products	1,937	4,880,622	2,032	4,787,711	1,817	4,432,052	1,731	4,116,364	1,784	4,312,344	1,431	3,298,903
Total crude materials inedible except fuels	3,555	2,589,459	4,151	3,271,323	3,933	2,963,955	4,142	3,375,984	3,998	3,083,980	4,180	3,316,451
Total primary manufactured goods	1,117	1,792,930	1,151	1,940,322	1,057	1,593,112	1,121	1,767,994	1,268	1,866,052	1,582	2,266,006
Total food and farm products	2,177	503,283	2,210	524,762	2,118	390,110	2,073	99,075	2,100	136,894	2,081	102,584
Total all manufactured equipment, machinery and products	351	737,506	158	456,265	81	169,475	44	26,673	42	41,325	21	20,523
Waste and Scrap NEC	0	0	0	0	0	0	0	0	0	0	0	0
Total unknown or not elsewhere classified	0	47,587	0	17,271	0	6,973	0	60	0	90	0	0

	2009		2010		2011		2012		2013	
PUB_NAME	TRIPS	TONS	TRIPS	TONS	TRIPS	TONS	TRIPS	TONS	TRIPS	TONS
Total, all commoditiues	**10,523**	**14,771,324**	**12,017**	**16,967,667**	**11,008**	**15,236,538**	**11,693**	**16,378,596**	**11,432**	**16,379,077**
Total Coal	211	666,951	382	968,706	207	329,987	138	219,918	192	313,781
Total petroleum and petroleum products	2,053	6,411,643	2,661	7,096,598	2,010	6,368,206	2,095	6,704,578	1,812	6,323,369
Total chemicals and related products	1,306	2,877,078	1,526	3,394,757	1,468	3,389,560	1,459	3,312,626	1,662	3,747,612
Total crude materials inedible except fuels	3,967	3,204,196	4,115	3,368,790	3,931	2,947,521	4,466	3,671,868	4,430	3,847,461
Total primary manufactured goods	882	1,312,047	1,207	1,785,798	1,276	1,828,653	1,372	2,076,864	1,215	1,894,204
Total food and farm products	2,090	268,260	2,085	325,383	2,102	359,970	2,144	363,167	2,117	241,607
Total all manufactured equipment, machinery and products	14	31,149	41	27,634	14	12,641	19	28,975	4	6,105
Waste and Scrap NEC	0	0	0	0	0	0	0	600	0	0
Total unknown or not elsewhere classified	0	0	0	1	0	0	0	0	0	4,938

Source: WCSC and LPMS Data

TABLE 2-5: IHNC Annual Vessel Trips and Major Commodity Group Tons Percentage Distributions, 2003 - 2013

PUB_NAME	2003		2004		2005		2006		2007		2008	
	TRIPS	TONS	TRIPS	TONS	TRIPS	TONS	TRIPS	TONS	TRIPS	TONS	TRIPS	TONS
Total, all commoditiues	**12,110**	**18,177,788**	**12,802**	**18,774,232**	**11,568**	**16,764,794**	**11,852**	**17,228,373**	**11,661**	**16,771,812**	**11,609**	**15,409,037**
Total Coal	5%	6%	6%	7%	4%	5%	5%	5%	2%	2%	3%	4%
Total petroleum and petroleum products	19%	36%	18%	35%	18%	38%	19%	40%	19%	42%	17%	38%
Total chemicals and related products	16%	27%	16%	26%	16%	26%	15%	24%	15%	26%	12%	21%
Total crude materials inedible except fuels	29%	14%	32%	17%	34%	18%	35%	20%	34%	18%	36%	22%
Total primary manufactured goods	9%	10%	9%	10%	9%	10%	9%	10%	11%	11%	14%	15%
Total food and farm products	18%	3%	17%	3%	18%	2%	17%	1%	18%	1%	18%	1%
Total all manufactured equipment, machinery and products	3%	4%	1%	2%	1%	1%	0%	0%	0%	0%	0%	0%
Waste and Scrap NEC	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Total unknown or not elsewhere classified	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

PUB_NAME	2009		2010		2011		2012		2013	
	TRIPS	TONS	TRIPS	TONS	TRIPS	TONS	TRIPS	TONS	TRIPS	TONS
Total, all commoditiues	**10,523**	**14,771,324**	**12,017**	**16,967,667**	**11,008**	**15,236,538**	**11,693**	**16,378,596**	**11,432**	**16,379,077**
Total Coal	2%	5%	3%	6%	2%	2%	1%	1%	2%	2%
Total petroleum and petroleum products	20%	43%	22%	42%	18%	42%	18%	41%	16%	39%
Total chemicals and related products	12%	19%	13%	20%	13%	22%	12%	20%	15%	23%
Total crude materials inedible except fuels	38%	22%	34%	20%	36%	19%	38%	22%	39%	23%
Total primary manufactured goods	8%	9%	10%	11%	12%	12%	12%	13%	11%	12%
Total food and farm products	20%	2%	17%	2%	19%	2%	18%	2%	19%	1%
Total all manufactured equipment, machinery and products	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Waste and Scrap NEC	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Total unknown or not elsewhere classified	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Source: WCSC and LPMS Data

FIGURE 2-6: IHNC Annual Tonnages of Petroleum and Petroleum Products, 2003-2013

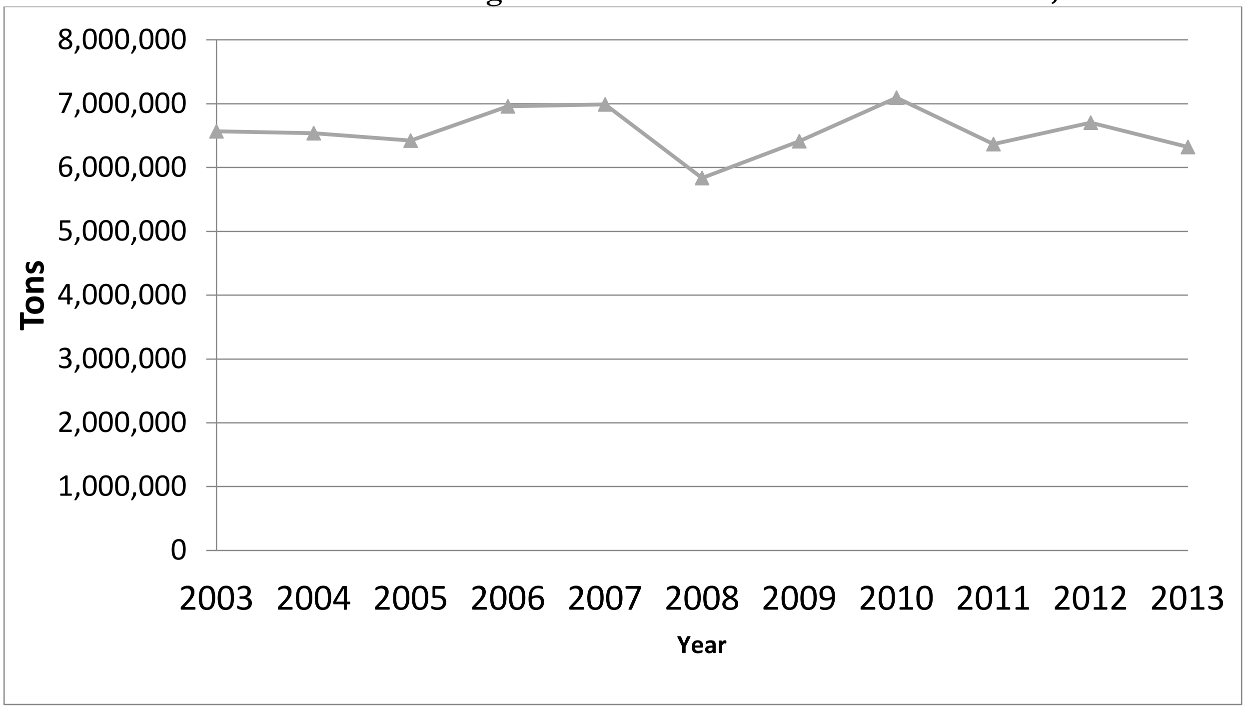


FIGURE 2-7: IHNC Annual Tonnages of Chemicals and Related Products, 2003-2013

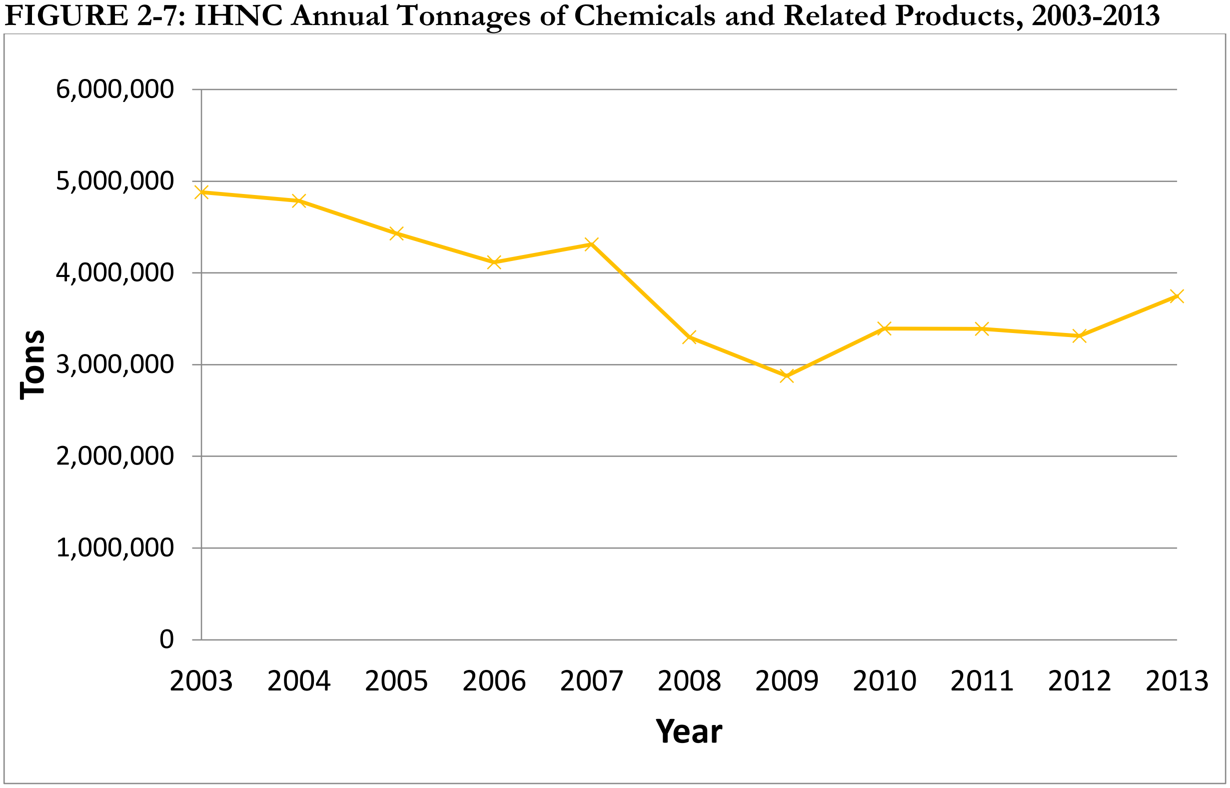


FIGURE 2-8: IHNC Annual Tonnages of Crude Materials Inedible Except Fuels, 2003-2013

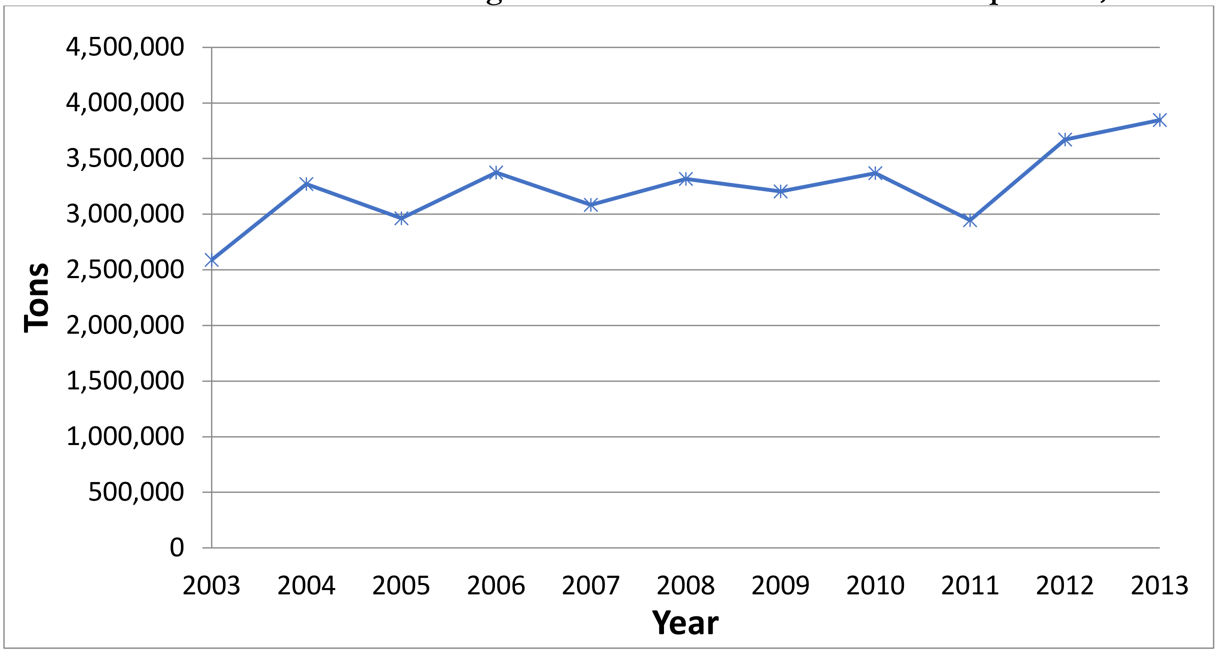
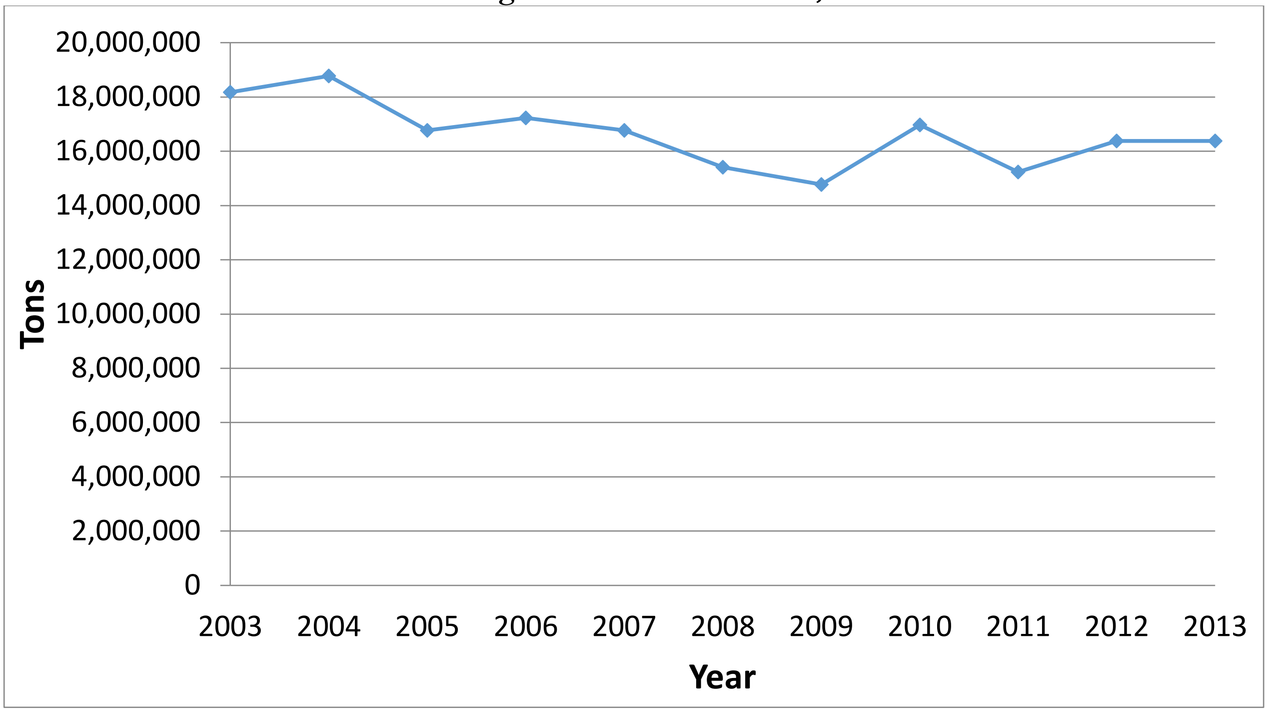


FIGURE 2-9: IHNC Annual Tonnages of Primary Manufactured Goods, 2003-2013

FIGURE 2-10: IHNC Annual Tonnages of All Commodities, 2003-2013



2.2.2.2 Origin and Destination Patterns

TABLE 2-6 contains the total numbers of annual vessel trips and tons of all commodities transiting the IHNC for the period 2003 to 2013 for state to state movements. The largest state to state commodity tons in 2013 included: (1) Louisiana to Alabama - 3.036 million; (2) Alabama to Louisiana - 2.319 million; (3) Louisiana to Mississippi - 1.235 million; (4) Texas to Alabama - 1.178 million; (5) Mississippi to Louisiana - 0.924 million; (6) Alabama to Texas - 0.924 million; (7) Kentucky to Mississippi - 0.741 million; (8) Mississippi to Texas - 0.560 million tons; (9) Kentucky to Louisiana - 0.552 million; and (10) Louisiana to Louisiana - 0.544 million. Collectively the 10 largest state to state pairs with respect to total matched commodity tons in 2013 account for 12.016 million or 80 percent of the total matched tons in 2013 (14.969 million).

TABLE 2-6: IHNC State to State Total Trips and Tons, 2003 to 2013

		2003		2004		2005		2006		2007		2008		2009		2010		2011		2012		2013	
STATE_S	STATE_R	Trips	Tons	Trips	Tons	Trips	Tons	Trips	Tons	Trips	Tons	Trips	Tons	Trips	Tons	Trips	Tons	Trips	Tons	Trips	Tons	Trips	Tons
AL	AR	91	127,512	125	183,030	147	216,011	89	131,286	89	135,099	45	67,784	22	31,774	77	118,163	105	161,272	56	81,296	99	145,519
AL	IA	1	1,474	5	7,129	3	4,625	11	16,391	5	7,480	4	5,600	1	1,515	1	1,613	7	10,929	4	6,394	10	15,357
AL	IL	33	47,982	100	160,391	21	33,911	61	90,502	23	38,127	39	60,429	5	7,618	15	23,473	22	28,930	86	115,199	41	57,894
AL	IN	28	42,052	38	53,566	25	37,414	24	35,315	24	34,780	43	65,051	12	18,000	7	9,961	48	61,030	86	118,085	11	13,928
AL	KY	33	45,069	55	74,274	57	80,067	51	71,988	32	38,095	35	48,213	22	29,789	54	107,797	44	55,813	46	75,497	23	35,968
AL	LA	1,057	2,751,674	974	2,433,235	846	2,243,650	884	2,418,744	919	2,383,919	1,222	2,877,297	781	2,033,960	1,055	2,349,402	917	2,187,632	855	2,093,462	920	2,319,853
AL	MN	2	1,393	2	2,379	2	2,195	3	4,357	1	1,433	2	2,900	6	8,282	7	9,687	6	8,798	19	25,513	11	14,946
AL	MO	12	17,186	10	16,468	22	26,802	36	50,762	54	77,298	41	59,648	33	48,350	58	87,373	26	37,118	30	43,784	12	17,532
AL	MS	29	50,443	59	95,188	25	44,133	83	137,209	215	349,224	301	459,868	248	382,144	270	374,091	1	1,605	1	1,590	14	18,472
AL	OK	9	13,280	10	14,900	8	14,515	18	28,084	15	22,360	15	22,700	11	16,500	26	38,433	54	62,384	43	58,266	9	12,204
AL	TN	78	117,362	97	155,020	87	134,963	99	148,366	78	132,016	105	175,736	104	169,590	51	83,881	16	22,073	48	66,059	45	62,059
AL	TX	438	988,360	540	1,267,509	463	1,087,844	518	1,185,418	517	1,172,371	620	1,392,864	399	1,254,769	271	689,282	505	1,003,503	557	1,197,816	434	924,030
AR	AL	40	61,241	52	78,965	51	79,628	35	54,727	48	68,117	39	55,108	23	34,993	49	78,184	58	102,290	77	120,787	72	112,233
AR	LA	1	1,512	8	11,600	26	38,089	63	91,353	117	172,350	58	84,100	260	376,500	71	66,499	17	24,641	1	1,450	2	3,003
FL	LA	47	68,038	50	80,988	30	13,192	12	5,455	11	25,729	0	780	35	50,261	6	10,524	1	1,411	56	50,122	75	115,824
FO	LA		533,141		206,837		120,339		752		2,805		1,440		52,856		19,722		909		8,600		24
IL	AL	100	188,676	244	414,591	260	423,493	139	224,911	81	177,283	71	169,202	118	223,931	117	323,985	238	646,003	130	284,764	133	253,669
IL	FL	236	379,698	191	353,817	223	351,577	285	464,973	30	49,959	64	104,921	4	14,085	18	52,367	15	49,275	14	40,164	31	45,628
IL	LA	286	485,835	117	196,823	195	339,422	191	330,727	54	85,087	34	56,187	93	142,383	285	470,378	114	188,581	104	171,358	84	132,002
IL	MS	370	609,536	299	497,770	99	183,099	65	112,801	80	136,554	103	164,431	67	110,620	92	168,452	28	85,570	59	122,477	62	110,303
IN	AL	14	19,303	13	18,921	11	16,423	18	28,031	9	13,658	15	28,640	7	13,212	18	27,032	50	138,246	41	115,946	10	15,898
KY	AL	77	139,163	201	340,280	203	336,151	127	221,989	83	126,503	140	194,168	72	111,445	113	162,317	19	35,181	21	62,147	15	24,948
KY	LA	169	280,487	249	416,610	204	340,971	596	987,375	389	646,069	346	598,593	408	732,005	414	736,434	935	1,402,730	699	1,021,429	322	552,739
KY	MS	40	62,113	34	58,223	199	313,380	358	581,925	184	288,355	427	614,989	314	506,003	267	432,574	236	382,471	168	274,829	461	741,445
LA	AL	949	2,109,734	1,042	2,381,739	921	2,232,807	1,067	2,675,786	1,134	3,038,163	744	1,900,016	759	2,245,381	793	2,168,638	862	2,396,645	959	2,644,936	1,096	3,036,182
LA	FL	482	1,217,561	710	1,530,129	428	1,318,866	302	941,189	263	693,034	178	501,455	176	442,187	243	686,290	189	581,370	209	488,050	124	385,602
LA	IL	41	62,771	46	71,119	27	39,588	2	2,832	22	32,672	11	16,143	10	16,411	15	21,711	27	39,535	6	7,841	34	56,165
LA	KY	6	8,906	19	28,403	18	32,166	2	2,963	1	1,496	3	18,010	5	12,199	9	12,515	15	23,036	14	21,531	21	37,262
LA	LA	313	400,020	380	407,736	320	459,865	323	558,374	242	323,639	196	240,653	291	445,681	237	384,580	107	180,443	136	182,003	291	544,547
LA	MS	407	782,424	450	831,471	485	919,696	415	821,373	492	988,031	346	667,485	307	659,300	477	1,040,029	475	883,350	568	1,166,046	536	1,235,085
LA	TX	59	177,058	57	120,000	16	25,339	2	2,984	24	35,442	4	5,848	15	22,329	7	14,496	10	18,496	3	6,925	18	33,477
MO	AL	36	55,197	20	33,706	15	25,841	7	11,076	5	7,916	10	16,370	78	126,397	74	127,477	15	28,014	29	50,874	54	108,457
MO	LA	56	94,048	15	28,888	6	10,899	27	42,651	5	7,500	50	83,181	10	14,000	125	202,305	71	125,665	548	819,839	86	140,717
MS	AR	12	18,675	20	31,346	20	31,660	5	8,075	17	27,625	9	14,321	4	6,302	25	39,719	13	20,774	18	29,408	16	26,530
MS	IA	8	12,849	16	25,584	13	20,823	10	16,032	3	4,936	3	4,871	5	7,869	21	33,584	12	17,558	21	30,835	10	15,153
MS	IL	55	86,432	64	100,734	62	110,826	30	57,768	42	81,644	19	29,880	14	21,672	69	121,245	49	85,371	53	77,084	37	61,410
MS	IN	1	1,642	4	6,540	7	11,272	7	10,422	3	4,598	7	13,634	3	4,677	6	9,240	11	17,970	12	18,479	15	20,365
MS	KY	24	36,615	17	25,275	31	64,876	21	32,378	31	53,851	8	16,822	3	4,679	11	20,947	11	20,495	13	20,828	16	26,323
MS	LA	402	1,303,592	461	1,512,326	310	1,019,114	441	1,364,268	535	1,275,256	537	964,029	487	1,088,158	513	1,378,601	322	783,715	377	1,012,517	331	924,347
MS	MN	6	9,715	17	27,887	14	22,457	5	7,786	3	4,754	4	6,404	5	7,825	22	34,528	8	13,089	4	6,369	3	4,536
MS	MO	22	34,501	13	21,076	33	52,974	13	19,708	14	22,575	4	6,461	6	9,435	40	64,032	23	35,443	17	24,873	16	21,929
MS	MS	11	23,891	10	16,279	18	29,544	5	9,489	17	19,061	4	12,171	15	36,460	1	1,128	5	8,880	10	17,972	45	78,543
MS	OK	32	50,986	34	54,438	29	44,290	10	15,931	8	12,802	4	6,331	18	28,463	39	61,789	29	45,072	28	44,872	22	33,926
MS	TN	39	68,863	57	95,497	36	64,918	41	61,219	36	56,538	27	42,192	16	39,247	5	9,783	5	15,624	2	3,138	1	1,694
MS	TX	375	590,964	368	734,381	273	595,994	319	697,352	408	890,185	345	730,893	417	731,084	837	798,196	323	737,170	339	811,472	260	560,499
OK	LA	4	6,017	46	69,488	37	56,514	3	4,525	51	77,130	15	22,673	20	31,753	2	3,014	13	20,022	19	30,447	26	40,972
TN	AL	8	11,250	20	33,534	8	10,986	22	34,161	32	53,628	11	17,706	8	10,565	9	13,669	1	1,400	7	10,827	34	55,143
TN	FL	72	98,163	70	96,305	47	67,071	17	23,916	47	65,896	32	45,079	33	46,665	25	35,014	27	37,825	42	54,955	12	16,582
TX	AL	284	787,378	378	923,288	444	1,217,853	433	1,122,955	489	1,301,660	541	1,348,488	263	767,341	348	981,655	403	1,174,059	391	1,144,030	433	1,178,097
TX	FL	99	325,659	116	328,865	96	327,488	99	309,507	74	245,743	67	195,074	65	218,262	86	250,053	70	238,111	56	180,545	59	191,269
TX	MS	130	300,416	121	332,193	110	333,418	115	381,809	153	466,373	114	311,898	137	304,787	146	344,656	98	183,876	148	304,931	137	389,267
Total Matched		7,124	15,707,857	8,044	17,006,741	7,031	15,629,039	7,509	16,659,970	7,209	15,976,819	7,062	14,548,737	6,215	13,719,714	7,527	15,300,518	6,656	14,431,403	7,230	15,368,661	6,629	14,969,557
Total		8,104	18,177,788	8,794	18,774,232	7,558	16,764,794	7,840	17,228,373	7,647	16,771,812	7,593	15,409,037	6,505	14,771,324	7,997	16,967,667	6,986	15,236,538	7,669	16,378,596	7,406	16,379,077
Percent of Total		87.91%	86.41%	91.47%	90.59%	93.03%	93.23%	95.78%	96.70%	94.27%	95.26%	93.01%	94.42%	95.54%	92.88%	94.12%	90.17%	95.28%	94.72%	94.28%	93.83%	89.51%	91.39%

Sources: Waterborne Commerce Statistics and G.E.C., Inc.

2.2.2.3 Vessel and Lock Statistics

TABLE 2-7 presents the average delay per tow, the total tons, number of vessels, number of barges, and number of lockages that passed through IHNC Lock. Trends of increasing tonnage, decreasing number of barges, and decreasing number of lockages point to increases in the size of barges transiting IHNC Lock. Another perceptible trend is the increase in IHNC Lock navigation delays since 2009 while the tons have remained relatively constant.

TABLE 2-7: Average Delay, Tons, Number of Vessels, Number of Barges, and Number of Lockages for IHNC Lock

Year	Average Delay Per Tow (Hours)	Total Tons (Millions)	# of Vessels	# of Barges	# of Lockages
2004	8.25	18.7	15,926	18,928	11,695
2005	8.01	16.3	13,252	15,756	10,088
2006	8.17	16.7	8,089	16,129	9,366
2007	7.13	17.4	13,058	16,766	11,349
2008	8.44	12.8	9,486	12,512	8,190
2009	7.78	14.2	11,453	14,207	10,237
2010	10.80	16.4	12,094	16,810	10,590
2011	11.93	15.1	9,607	14,873	9,212
2012	13.62	15.5	10,121	15,588	9,664
2013	12.42	15.7	8,441	14,329	8,365
2014	24.41	15.8	8,500	14,540	8,431
2015	17.04	15.3	7,733	13,262	8,184

SOURCE: Lock Performance Monitoring System (LPMS), 2016

Another useful statistics to understand is how operations at IHNC Lock compare to the operations at other locks across the country. As shown in

TABLE 2-8, IHNC experiences greater transit times than anywhere else in the nation. When comparing only processing times, IHNC lock ranks 74th, but a comparison of the transit times (delay time plus processing times) causes IHNC Lock to rise to number 1.

TABLE 2-8: Comparison of Transit Times Between Locks on U.S. Waterways

	Processing Time (Hours Per Tow)		Delay Time (Hours Per Tow)		Transit Time (Hours Per Tow)	
Lock	Five Year Average	Rank	Five Year Average	Rank	Five Year Average	**Rank**
IHNC	0.616	74	15.884	1	16.50	**1**
Kentucky	1.386	1	8.74	3	10.13	**2**
St. Lucie	0.012	165	9.224	2	9.24	**3**
Fort Loudon	0.476	108	6.67	4	7.15	**4**
Bayou Sorrel	0.638	71	6.468	5	7.11	**5**
Algiers	0.53	91	6.31	6	6.84	**6**
Harvey	0.334	125	6.274	7	6.61	**7**
52 Ohio	0.438	112	5.64	8	6.08	**8**
Chickamauga	0.314	128	4.878	9	5.19	**9**
Markland	0.93	19	4.148	12	5.08	**10**

SOURCE: Lock Performance Monitoring System (LPMS), 2016

3. METHODS

3.1 Introduction

3.1.1 Objective and National Economic Development (NED) benefit

The purpose of a U. S. Army Corps of Engineers planning analysis "… is to estimate changes in national economic development that occur as a result of differences in project outputs with a plan, as opposed to national economic development without a plan". This is accomplished through a federally mandated National Economic Development (NED) analysis which is "… generally defined as an economic cost-benefit analysis for plan formulation, evaluation, and selection that is used to evaluate the federal interest in pursuing a prospective project plan." NED benefits are defined as "… increases in the net value of the national output of goods and services, expressed in monetary units …"

For a navigation project investment, NED benefits are composed primarily of the reductions in transportation costs attributable to the improved waterway system. The reduction in transportation costs is achieved through increased efficiency of existing waterway movements, shifts of waterway and overland traffic to more efficient modes and routes, and shifts to more efficient origin destination combinations. Further benefits accrue from induced (new output / production) traffic that is transported only because of the lower transportation cost deriving from an improved project, and from creating or enhancing the potential for other productive uses of the waterway, such as the generation of hydropower. National defense benefits can also be realized from regional and national growth, and from diversity in transportation modes. In many situations, lower emissions can be achieved by transporting goods on the waterway. The "… basic economic benefit of a navigation project is the reduction in the value of resources required to transport commodities" remains the conceptual basis of NED benefits for inland navigation.

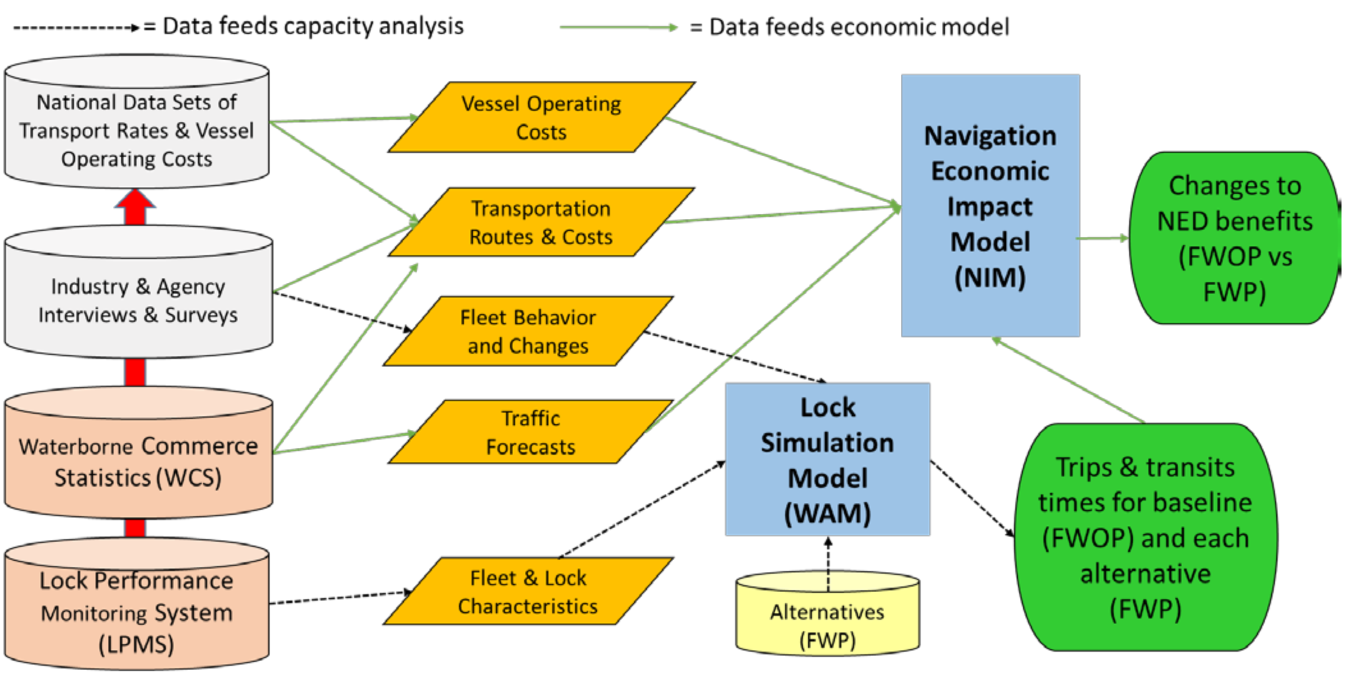
Traditionally, this primary benefit for barge transportation is calculated as the cost savings for barge shipment over the long-run least costly all-overland alternative routing. This benefit estimation is referred to as the waterway transportation rate-savings which also accounts for any difference in transportation costs arising from loading, unloading, trans-loading, demurrage, and other activities involved in the ultimate point to point transportation of goods. A newer way to estimate this primary benefit is to define the movement willingness-to-pay for water transportation with a demand curve (instead of the long-run least-costly all-overland rate) and then calculate a transportation surplus (consumer surplus). Either way, the primary benefit for federal investment in commercially-navigable waterways (benefits with a plan as opposed to benefits without a plan) ends up as a transportation cost reduction.

The primary guidance document that sets out principals and procedures for evaluating federal interest is the Principles and Guidelines (P&G). Corps guidance for implementing P&G is found in the Planning Guidance Notebook with additional discussions of NED analysis documented in the National Economic Development Procedures Overview Manual. For inland navigation analysis, the focus is on the evaluation and comparison of the existing waterway system with three basic alternative measures: 1) increase capacity (decrease transit times and thereby reduce delay costs); 2) increase reliability (replace or rehabilitate aging structures, thereby reduce the probability of structural failure and its consequences); and / or 3) reduce demand (e.g. congestion fees). The P&G provides general guidance for doing the benefit assessment, but leaves open opportunities to improve the analytical tools used as new data and computational capabilities are developed.

3.1.2 Inner Harbor Navigation Canal Analysis Procedures

While the previous section discussed the objective of an inland navigation analysis and the role of the NED benefit, this section outlines the steps to estimate the changes in NED for each of the alternatives. **FIGURE 3-** shows how the analysis flows from raw data to model inputs to models to results. The cylinders, on the left side of **FIGURE 3-**, represent the raw data which are the foundation of any analysis. Sources of raw data include the Lock Performance Monitoring System (LPMS) database which provides lock statistics, the Waterborne Commerce Statistics Center (WCSC) database which contains commodity movement information, industry surveys and interviews which help understand industry responses, and national dataset of transportation rates and vessel operating costs which assist in calculating when movements will switch modes. The raw data is transformed into the following five model inputs: vessel operating costs (VOCs) for the vessels in GIWW region, transportation routes and costs for waterway movements through IHNC, changes in the way the fleet operates for each alternative, forecasts for traffic transiting GIWW and IHNC, and current fleet and lock operational characteristics of vessels using IHNC. To identify the NED plan for the IHNC Lock Analysis, the Planning Center of Expertise for Inland Navigation Risk-Informed Economist Division (PCXIN-RED) relied on two certified models, the Waterway Analysis Model (WAM) and the Navigation Investment Model (NIM). The WAM is a lock simulation model which estimates how lock processing and delay times will change under the alternatives. The output of the WAM is one of the inputs for the NIM which estimates the benefits and costs for the baseline and alternatives. In **FIGURE 3-**, the black dashed lines show which pieces of information feed the Lock Simulation Model (WAM) and the solid green lines trace the inputs to the Navigation Economic Impact Model (NIM).

FIGURE 3-0: Flowchart of Navigation Impact Analysis



With the objectives established and the general process described, the rest of this chapter focuses on three areas. First the chapter outlines the assumptions made for the Future Without Project (FWOP) Condition including what construction and maintenance would occur without any changes and how traffic will change over time. Next, this chapter provides additional detail on analysis of the Future With Project (FWP) Conditions by offering additional detail on the NED benefit for WPC, by discussing the theoretical equilibrium for supply and demand of waterway traffic, and by explaining the role of life-cycle analysis. Finally, this chapter delves in-depth into the WAM and NIM models to help understand how these models produce the NED benefit results.

3.2 Future Without Project Condition

Identification of the most likely condition expected to exist in the future in the absence of any improvements to the existing navigation system is a fundamental first step in the evaluation of potential improvements. The Future Without Project (FWOP) Condition serves as a baseline against which plan improvements are evaluated. The increment of change between a plan and the future without project condition provides the basis for evaluating the beneficial or adverse economic, environmental, and social effects of the considered plan. Definition of the future without project condition is presented below. The forecast of the FWOP Condition reflects the conditions expected during the period of analysis.

The FWOP Condition identified for use in this study includes the following analytical assumptions:

1. Operation and maintenance of all system locks will be continued through the period of economic analysis to ensure continued navigability.
2. All existing waterway projects or those under construction are to be considered in place and will be operated and maintained through the period of analysis.
3. All system locks are using the most efficient locking policies.
4. Alternative non-system transportation means (rail and non-system water) are assumed to have sufficient capacity to move diverted system traffic at current costs over the period of analysis.
5. The capacities of system locks are as presented in this appendix.
6. Traffic demands on the system will grow at the mid (most likely) growth rates.
7. All existing vehicular bridges that span the IHNC are to be considered in place and will be operated and maintained through the period of analysis.
8. Miter gate leaves and miter gate machinery will be replaced every 10 years. The gate bays will have to be dewatered for installation and adjustment of the gates. The lock will be closed to navigation for 90 days. However, during the closure period, in cooperation with the U.S. Coast Guard, a temporary alternate water route will be established. This water route will allow vessels that elect to do so, to travel through the Breton Sound area of the Gulf of Mexico via the Baptist Collette waterway on the Mississippi River to and from the Gulfport Ship Channel in Mississippi. ***FIGURE 3-1FIGURE 3-*** shows the location of the alternate route which will be approximately 82 miles longer than the normal GIWW route.
9. Lock closures associated with the dewatering periods will be announced in advance to allow navigation interests the opportunity to plan for the outage and to minimize the impacts of closure.

10. Alternative non-system transportation means (rail and truck) are assumed to have sufficient capacity to move diverted system traffic at current costs over the period of analysis.

FIGURE 3-1: Alternative Route for Navigation During IHNC Lock Closures

3.2.1 Construction and Maintenance

For an understanding of the construction and maintenance assumptions used to model the FWOP condition see **ATTACHMENT 1: CONSTRUCTION AND MAINTENANCE EVENT DATA** in this document.

3.2.2 Forecasted Demand

The forecast analysis was prepared by Gulf Engineers and Consultants (GEC) under contract with USACE. At the time GEC generated the report, the latest year for the available historical data was 2012, so the forecasts begin with 2013. The main source for the forecasts is the U.S. Department of Energy (DOE), Energy Information Administration (EIA) very long-term 25-year energy forecasts as presented in Annual Energy Outlook (AEO) 2015, spanning the period 2013 through 2040. The AEO energy forecasts are used to forecast the IHNC commodities between 2013 and 2040. The AEO forecasts are extrapolated to 2080 to cover the projected time span of with-project conditions (2031-2080). The extrapolated forecasts are used to forecast the IHNC commodities between 2041 and 2080.

This section summarizes the long-term forecasts of unconstrained commercial traffic expected to transit the IHNC Lock annually for the period 2013 through 2080. In this context, *unconstrained* means unconstrained by increases in future water congestion associated with increased levels of waterway traffic. Therefore, unconstrained traffic levels can also be viewed as levels of possible demand for waterway transportation on a particular waterway system, such as the GIWW. For a more thorough discussion, see **ATTACHMENT 3: GEC TRAFFIC DEMAND FORECASTS.**

3.2.2.1 Domestic Energy Forecasts Related to GIWW / IHNC Commodities

As shown previously, the majority of the commercial cargo tons transiting the IHNC Lock are related to the petrochemical industrial base that is contiguous to the lock and the adjacent waterway network. Petroleum products, chemicals, and crude oil constitute over 85 percent of the total annual lock tonnage. A wide array of other dry bulk commodities constitute the remainder of the lock cargo tonnages, primarily iron and steel products and aggregates. With that said, very long term domestic energy production and consumption forecasts can be used to describe and prescribe the long term trends for domestic shallow draft waterway commerce. Shallow draft waterborne commerce is often closely related to production and consumption of energy commodities such as crude oil and coal as well as refinements thereto such as refined petroleum products and chemicals.

The U.S. Department of Energy (DOE) through the Energy Information Administration (EIA) produces the Annual Energy Outlook (AEO) with very long-term energy projections for 25 years. The AEO covers all sectors of domestic energy production and consumption. The energy forecasts are for each year and in some sectors can be disaggregated to production and or consumption regions such as crude oil and coal production and electricity consumption. The EIA forecasts are also presented for high and low growth scenarios such as economy and or energy prices. An advantage of the EIA annual forecasts is that the general structure of each of the forecasts is similar for each year of publication. Consequently, it is possible to view EIA energy forecasts from a historical time series perspective to see how the forecasts have changed in response to changes in demand, supply and technology. For example, EIA forecasts with respect to production and prices of basic energy inputs, crude oil and natural gas, have fundamentally changed to reflect the technological shifts in exploration and extraction such as fracking.

Presented here is a historical comparison of AEO forecasts for the current period, 2015, with predecessors from 2012 and 2010, corresponding to AEO 2012 and AEO 2010, respectively. The AEO forecasts of production and prices for domestic crude oil and natural gas will be compared to demonstrate the paradigm shift that has taken place with respect to supply characteristics of two basic inputs to the U.S. chemical and refined petroleum products industries that compose a substantial portion of IHNC and GIWW waterborne commerce. Although the essence of the paradigm shift in domestic production and prices of crude oil and natural gas seems fully implemented, past AEO projections have lagged the full unfolding of these developments as with most if not all other energy forecasts. Consequently, it is not unlikely that forthcoming AEO forecasts might be further significantly adjusted for the unfolding production and price circumstances in the domestic crude oil and natural gas sectors.

3.2.2.1.1 Oil Prices and Production Forecasts

FIGURE 3-2 displays the AEO forecasts of crude oil prices for the period 2012 to 2035 from AEO 2010, AEO 2012 and AEO 2015. Both AEO 2010 and AEO 2012 forecasted crude prices for the period 2012 through 2035 are steadily increasing and break the $100 barrel threshold in 2019 (AEO 2010) and 2013 (AEO 2012). In comparison the AEO 2015 forecast shows domestic crude oil prices to remain below $100 per barrel until 2030.

FIGURE 3-3 displays the AEO forecasts (2010, 2012 and 2015) of domestic crude oil production for the period 2012 to 2035. For crude oil production the AEO 2010 forecast shows production increasing from 5.70 million barrels per day in 2013 to over 6.00 million barrels per day by 2019 and hovering around 6.20 million barrels per day between 2027 and 2035. The average annual compound growth rate (AACGR) for AEO 2010 daily domestic crude production between 2008 and 2035 is 0.9 percent (rounded from 0.8715 percent). The AEO 2012 forecast shows production increasing from 5.90 million barrels per day in 2013 to 6.00 in 2014. Production rises steadily to a peak of 6.70 million barrels per day by 2024 and then declines steadily to 5.99 million barrels per day by 2035. The AACGR for AEO 2012 daily domestic crude oil production between 2010 and 2035 is 0.40 percent.

The AEO 2015 crude oil production forecast is remarkably different than AEO 2010 and AEO 2012. AEO 2015 shows daily production to be 7.44 million barrels per day in 2013, rising to 10.00 million barrels per day by 2017, peaking at 10.60 million barrels per day in 2020, and then declining to 9.43 million barrels per day by 2040. The AACGR between 2013 and 2040 is 0.9 percent (rounded from 0.8804 percent).

FIGURE 3-2: Crude Oil Prices Forecasted by AEO 2010, AEO 2012, and AEO 2015

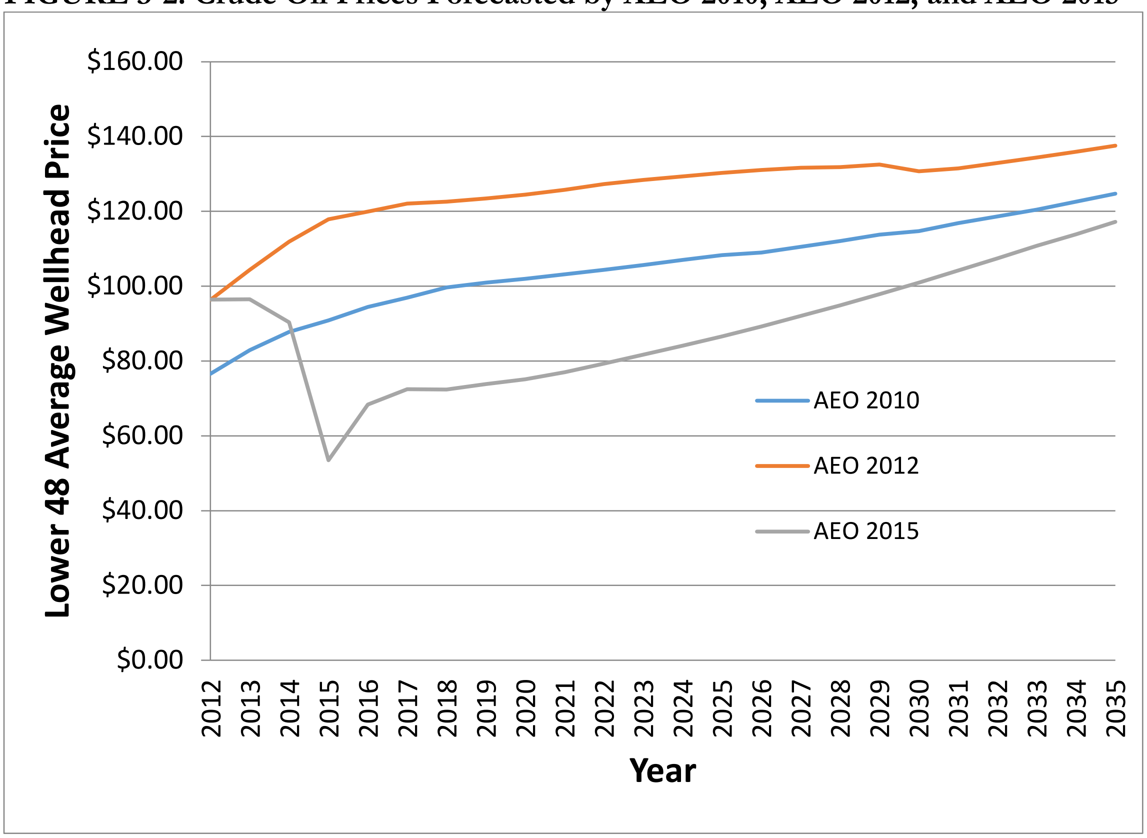
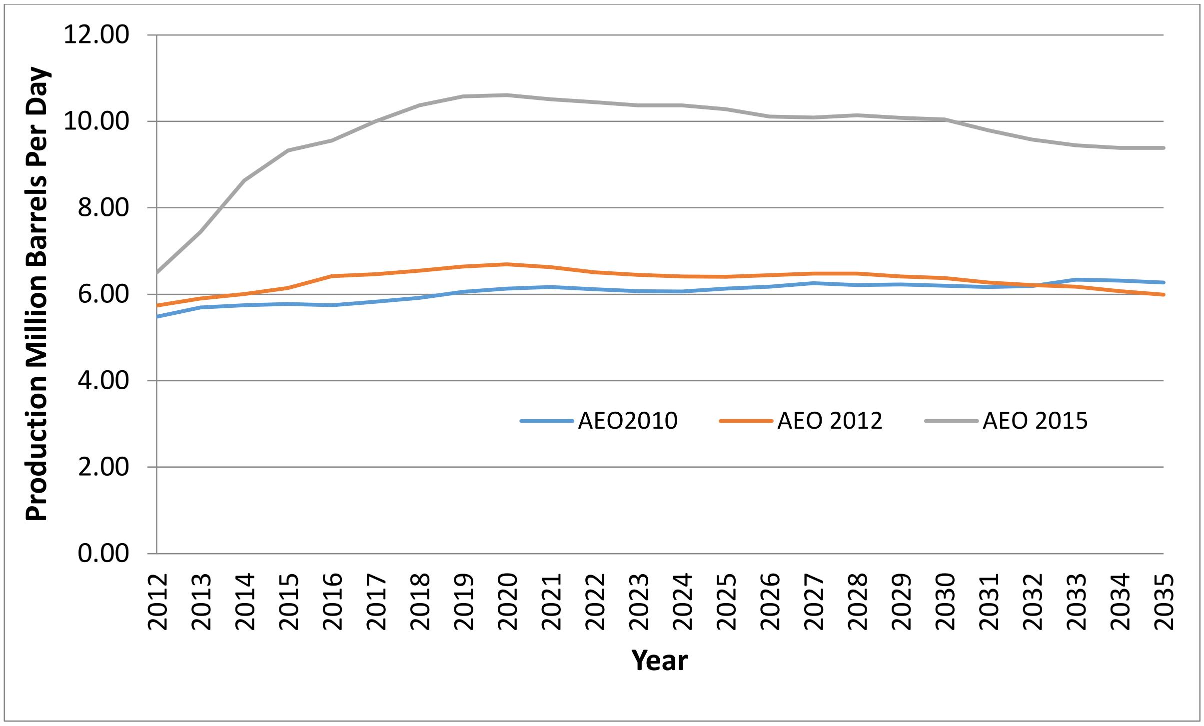


FIGURE 3-3: Domestic Crude Oil Price Forecasted by AEO 2010, AEO 2012, and AEO 2015



3.2.2.1.2 Natural Gas Prices and Production Forecasts

FIGURE 3-4 displays the AEO forecast natural gas prices for the period 2012 to 2035 for AEO 2010, AEO 2012 and AEO 2015. Both AEO 2010 and AEO 2012 forecasted natural gas prices for the period 2012 through 2035 are steadily increasing. AEO 2010 shows gas prices to rise continuously from $6.27 in 2015 to $8.88 by 2035. AEO 2012 shows gas prices to rise from $4.29 in 2015 to $7.37 by 2035. In comparison the AEO 2015 forecast shows gas prices to rise from $3.69 in 2015 to $6.76 by 2035.

FIGURE 3-5 displays the AEO forecasts (2010, 2012 and 2015) of domestic natural gas production for the period 2012 to 2035. For natural gas production the AEO 2010 forecast shows production increasing from 18.90 trillion cubic feet in 2013 to over 23.27 trillion cubic feet by 2035. The average annual compound growth rate (AACGR) for AEO 2010 natural gas production between 2008 and 2035 is 0.5 percent (rounded from 0.4597 percent). The AEO 2012 forecast shows production increasing from 22.76 trillion cubic feet in 2013 to 29.93 trillion cubic feet by 2035. The AACGR for AEO 2012 natural gas production between 2010 and 2035 is 1.00 percent.

The AEO 2015 natural gas production forecast is higher than AEO 2010 and AEO 2012. AEO 2015 shows natural gas production to be 24.40 trillion cubic feet in 2013 increasing to 34.14 trillion cubic feet by 2035. The AACGR between 2013 and 2040 is 1.4 percent (rounded from 1.393 percent).

FIGURE 3-4: AEO 2010, 2012, and 2015 Forecasted US Domestic Natural Gas Prices

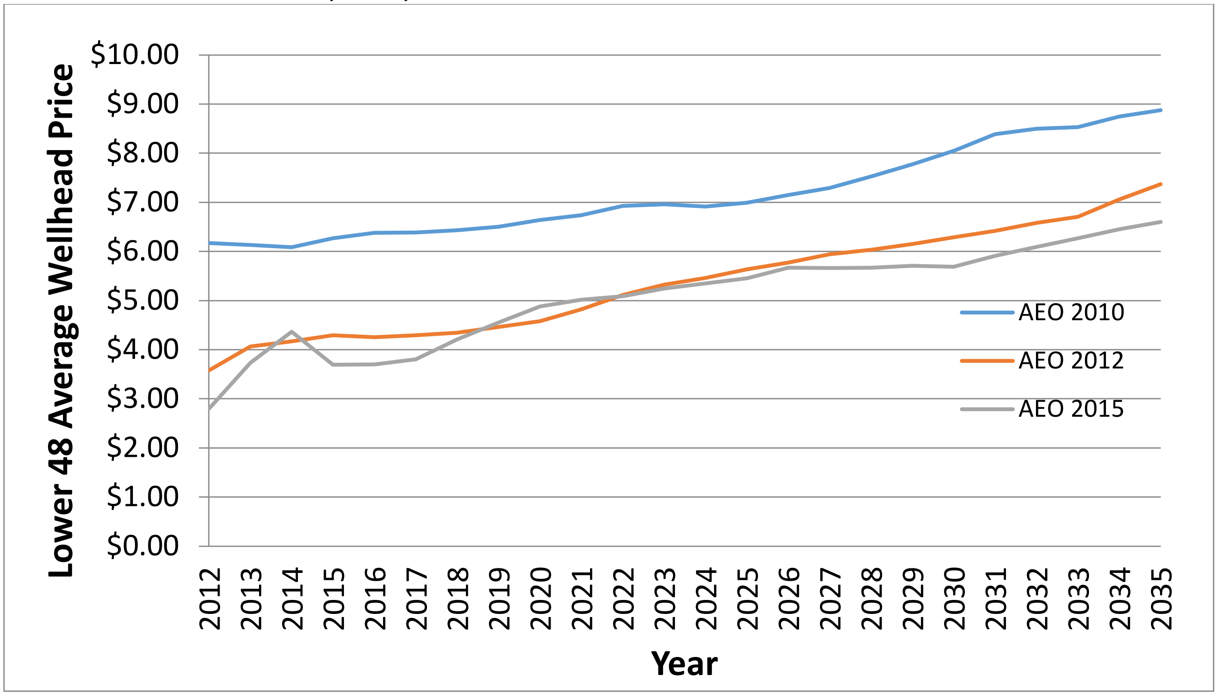
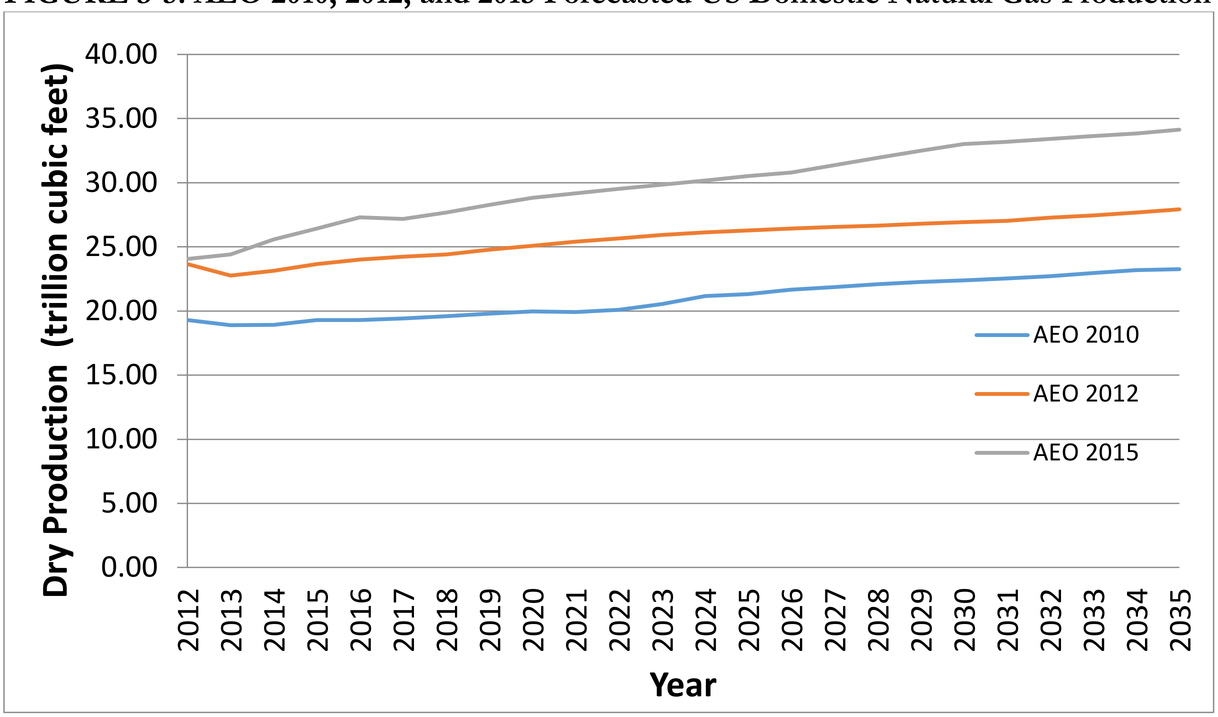


FIGURE 3-5: AEO 2010, 2012, and 2015 Forecasted US Domestic Natural Gas Production



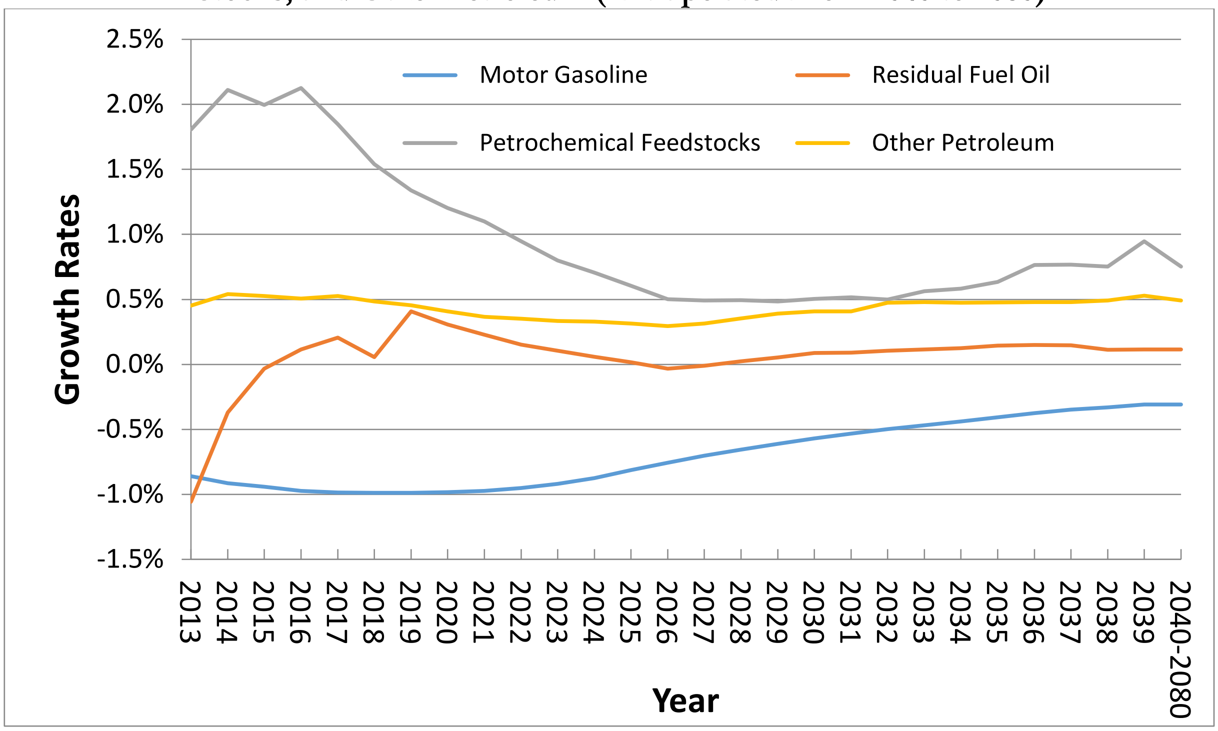
3.2.2.2 Average Annual Compound Growth Rates, 2013-2080

Beyond 2040, the AEO 2015 projections were extrapolated based on trends in the out years. The extrapolations expressed as Average Annual Compound Growth Rates (AACGR) will be noted for each of the sectors.

3.2.2.2.1 Petroleum Products

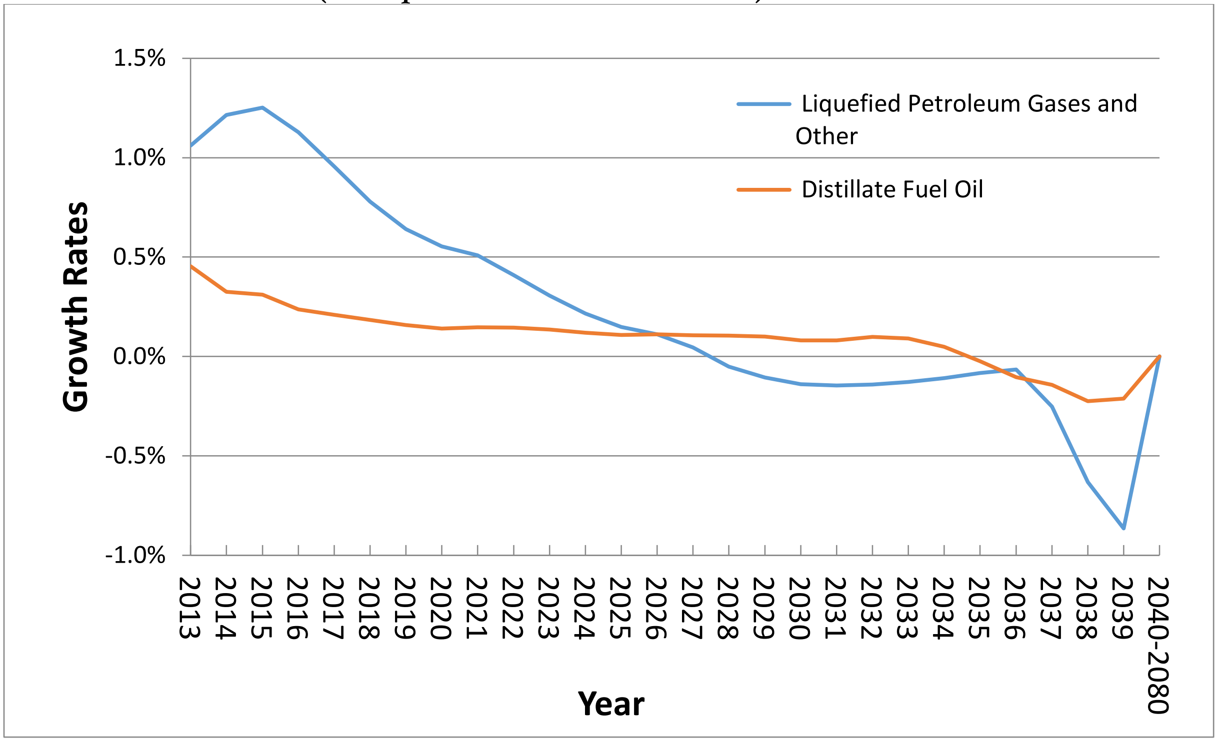
AEO 2015 forecasts were extrapolated from the last year or last years of the time series and the corresponding AACGR between the year chosen and 2040 for the following subsectors (parenthesis denotes negative growth): (1) gasoline - (0.309) percent; (2) jet fuel - 0.430 percent; (3) kerosene - (0.256) percent; (4) residual fuel oil - 0.116 percent; (5) petrochemical feed stocks - 0.752 percent; and other petroleum - 0.492 percent. No clear trend could be discerned for other sectors for which no growth, positive or negative, was presumed past 2040. The "no growth" sectors in total energy consumption include: (1) liquefied petroleum gases - 0.000 percent; and (2) distillate fuel oil - 0.000 percent. **FIGURE 3-6** depicts the AACGR, 2013-2040 and extrapolations thereof to 2080 for gasoline, residual fuel oil, petrochemical feed stocks and other petroleum. **FIGURE 3-7** depicts the AACGR, 2013-2040 and (no growth) extrapolations thereof to 2080 for liquefied petroleum gases and distillate fuel oil.

FIGURE 3-6: 2013 to 2040 Growth Rates of Gasoline, Residual Fuel Oil, Petroleum Feed Stocks, and Other Petroleum (Extrapolated From 2040 to 2080)



SOURCE: AEO 2015

FIGURE 3-7: 2013 to 2040 Growth Rates of Liquefied Petroleum Gases and Distillate Fuel Oil (Extrapolated From 2040 to 2080)

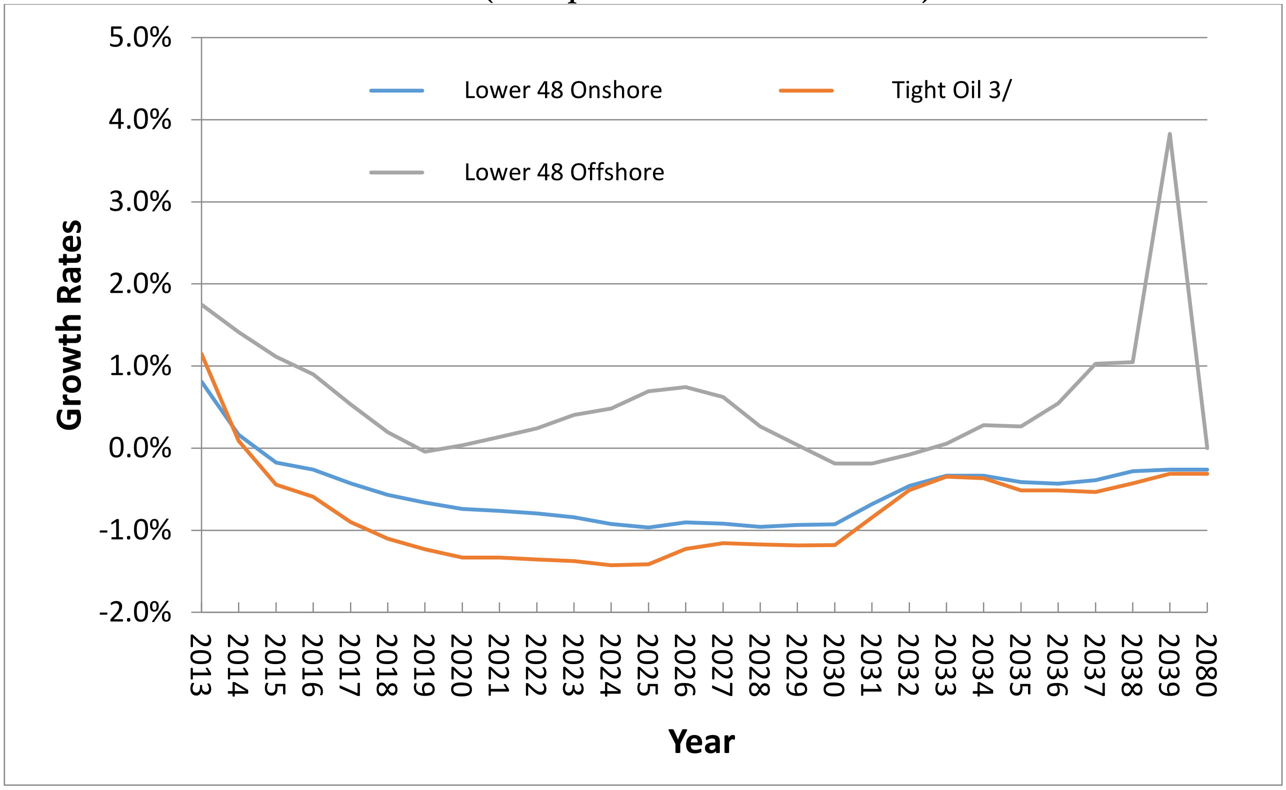


SOURCE: AEO 2015

3.2.2.2.2 Domestic Oil Supply

AEO 2015 extrapolations beyond 2040 for the period 2040-2080 included lower 48 onshore - (0.260) percent and tight oil - (0.313) percent. "No growth" was assumed for the category lower 48 offshore - 0.000 percent. **FIGURE 3-8** depicts the AACGR, 2013-2040 and extrapolations thereof to 2080 for lower 48 onshore, tight oil and lower 48 offshore sectors.

FIGURE 3-8: 2013 to 2040 Growth Rates of Lower 48 Onshore, Tight Oil and Lower 48 Offshore Production (Extrapolated From 2040 to 2080)

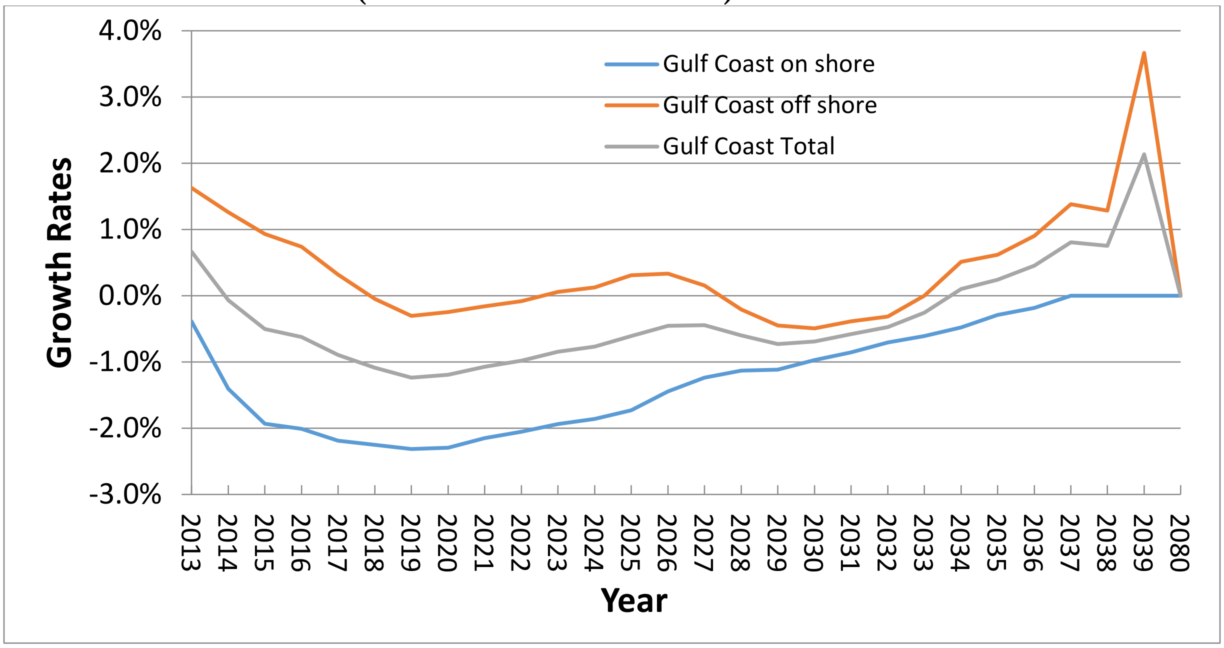


SOURCE: AEO 2015

3.2.2.2.3 Gulf Coast Oil Supply

No growth was assumed beyond 2040 to 2080 for the three sectors of Gulf Coast onshore, Gulf Coast offshore and Gulf Coast total. **FIGURE 3-9** depicts the AACGR, 2013-2040 and (no growth) extrapolations thereof to 2080 for Gulf Coast onshore, Gulf Coast offshore and Gulf Coast total.

FIGURE 3-9: 2013 to 2040 Growth Rates of Gulf Coast Onshore, Offshore, and Total Oil Production (Assumed Flat 2040 to 2080)

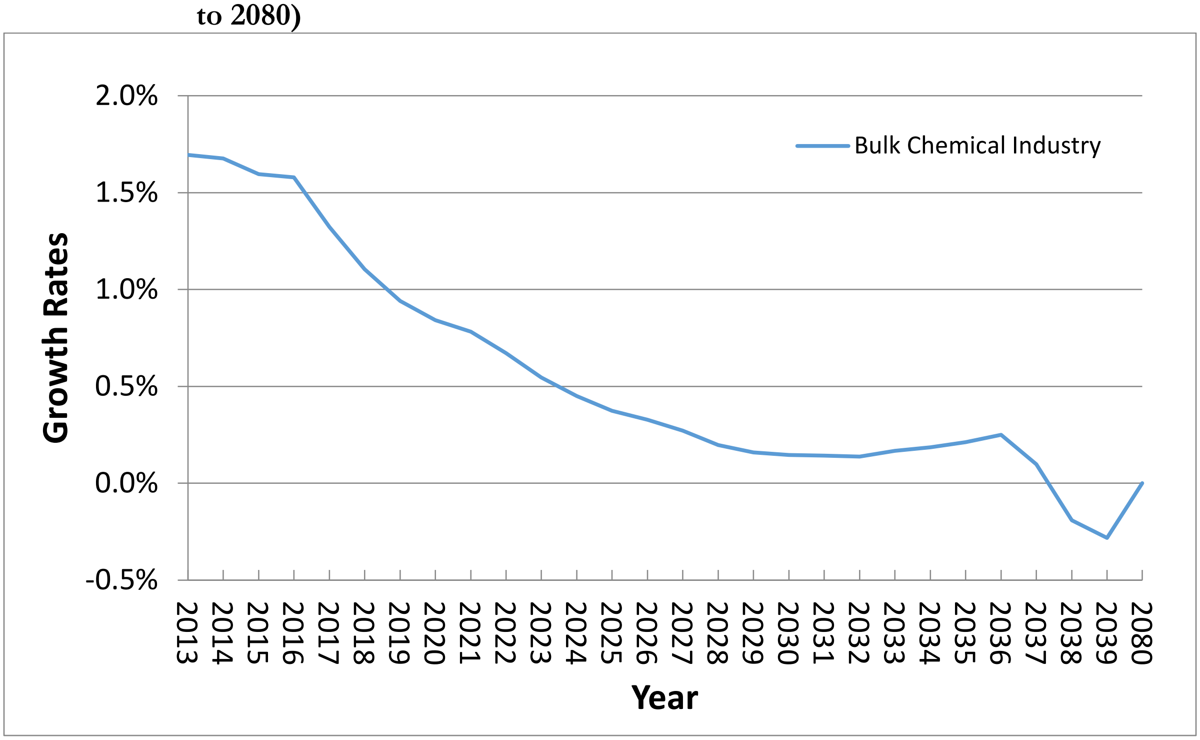


SOURCE: AEO 2015

3.2.2.2.4 Bulk Chemical Industry

No growth was assumed beyond 2040 to 2080. **FIGURE 3-10** depicts the AACGR, 2013-2040 and (no growth) extrapolation thereof to 2080 for bulk chemical industry.

FIGURE 3-10: 2013 to 2040 Growth Rates of Bulk Chemical Industry (Assumed Flat 2040 to 2080)

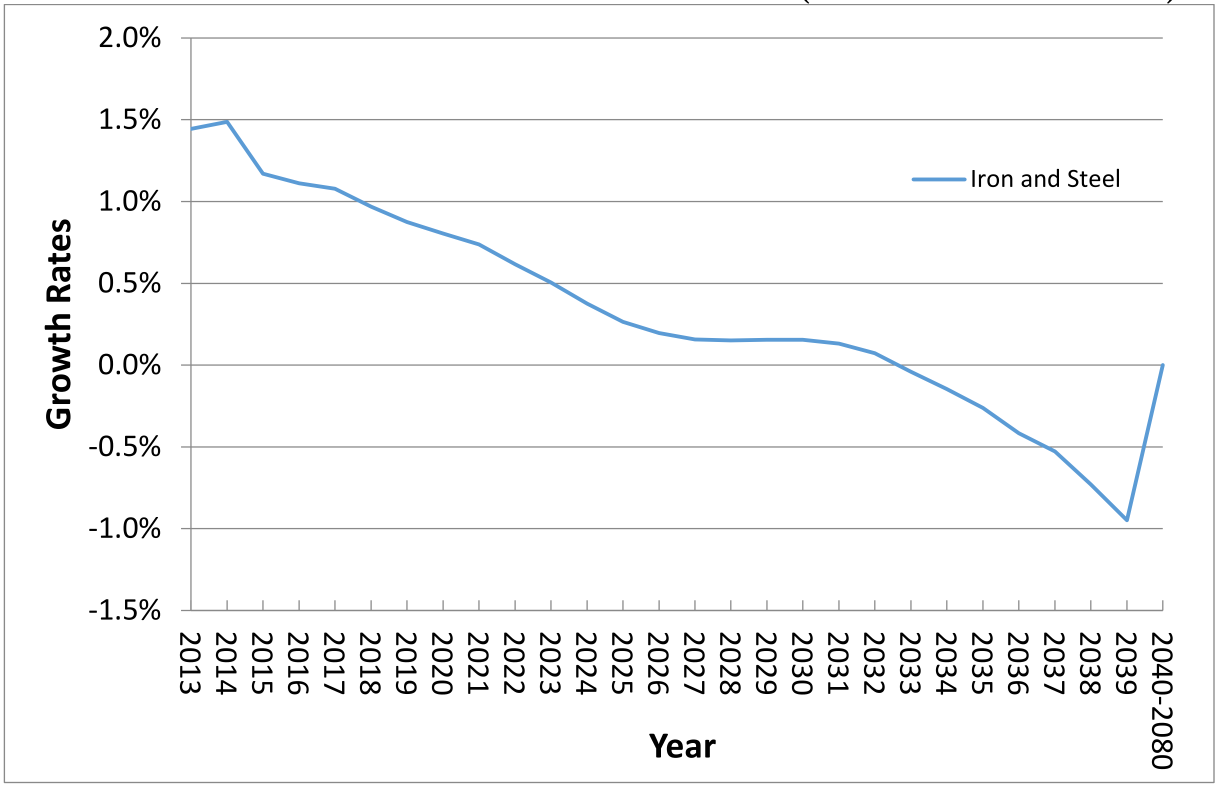


SOURCE: AEO 2015

3.2.2.2.5 Iron And Steel

No growth was assumed beyond 2040 to 2080. **FIGURE 3-11** depicts the AACGR, 2013-2040 and (no growth) extrapolation thereof to 2080 for iron and steel industry.

FIGURE 3-11: 2013 to 2040 Growth Rates of Iron and Steel (Assumed Flat 2040 to 2080)

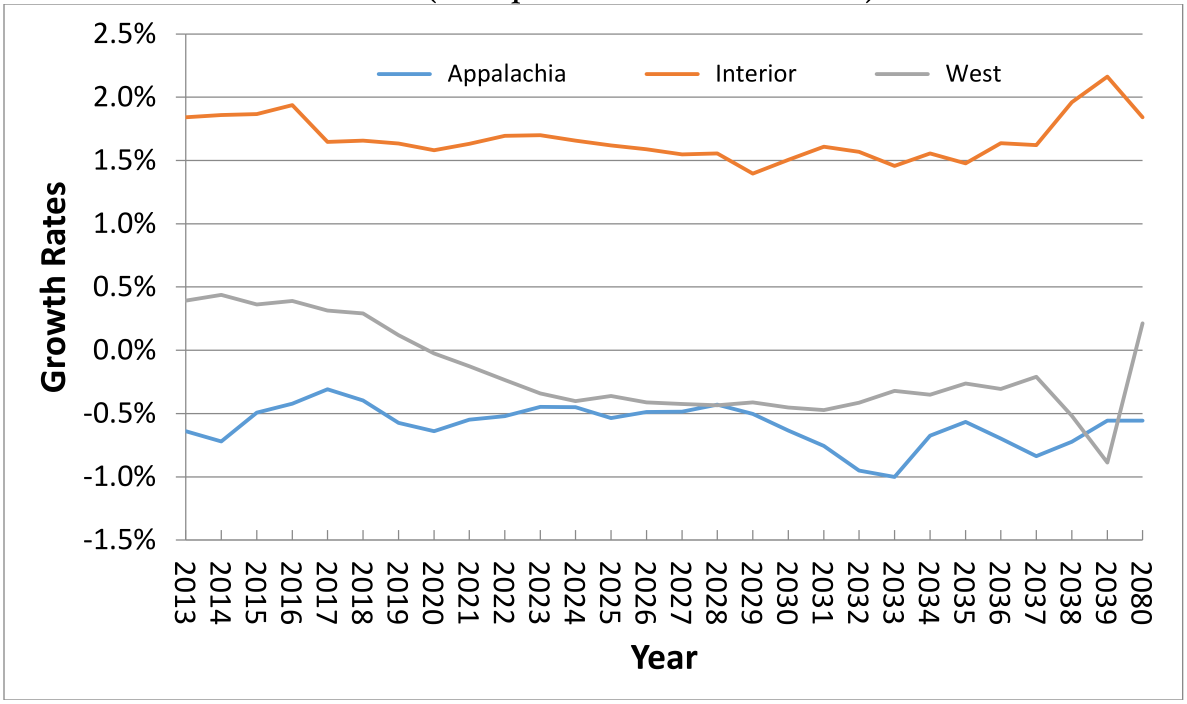


SOURCE: AEO 2015

3.2.2.2.6 Coal Supply

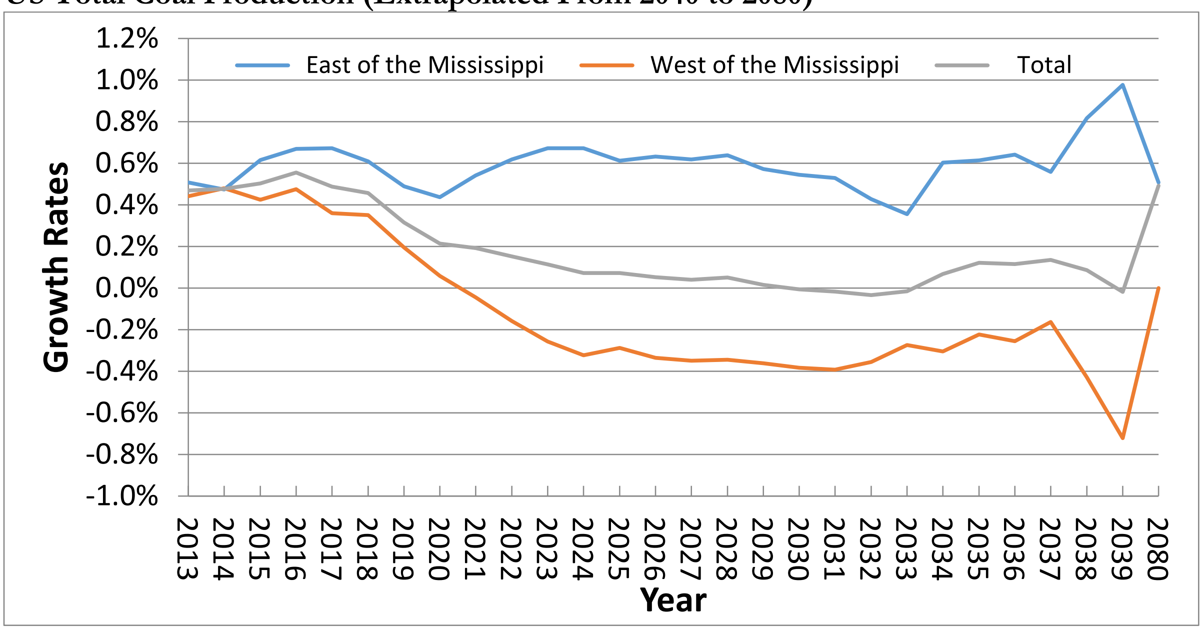
The time series was used to develop AACGR for all the sectors except West and West of the Mississippi. The Appalachia and Interior sectors have AACGR for the period 2040-2080 of (0.555) percent (2039-2040 extrapolation) and 1.840 percent (2013-2040 extrapolation), respectively. East of the Mississippi sector has AACGR between 2040 and 2080 of 0.508 percent. West of the Mississippi sector is assumed "no growth". Consequently, total US coal production (sum of East and West of Mississippi) would increase 0.212 percent annually after 2040. Coal imports were assumed "no growth" and coal imports were assumed to grow 1.000 percent annually after 2040 based on extrapolating the AEO 2015 forecasts. **FIGURE 3-12** depicts the AACGR, 2013-2040 for Appalachia, Interior and West sectors and extrapolations thereof to 2080. **FIGURE 3-13** depicts the AACGR, 2013-2040 for East of Mississippi, West of Mississippi, and total US and extrapolations thereof to 2080.

FIGURE 3-12: 2013 to 2040 Growth Rates of Appalachia, Interior and West Sectors of Coal Production (Extrapolated From 2040 to 2080)



SOURCE: AEO 2015

FIGURE 3-13: 2013 to 2040 Growth Rates of East of Mississippi, West of Mississippi, and US Total Coal Production (Extrapolated From 2040 to 2080)

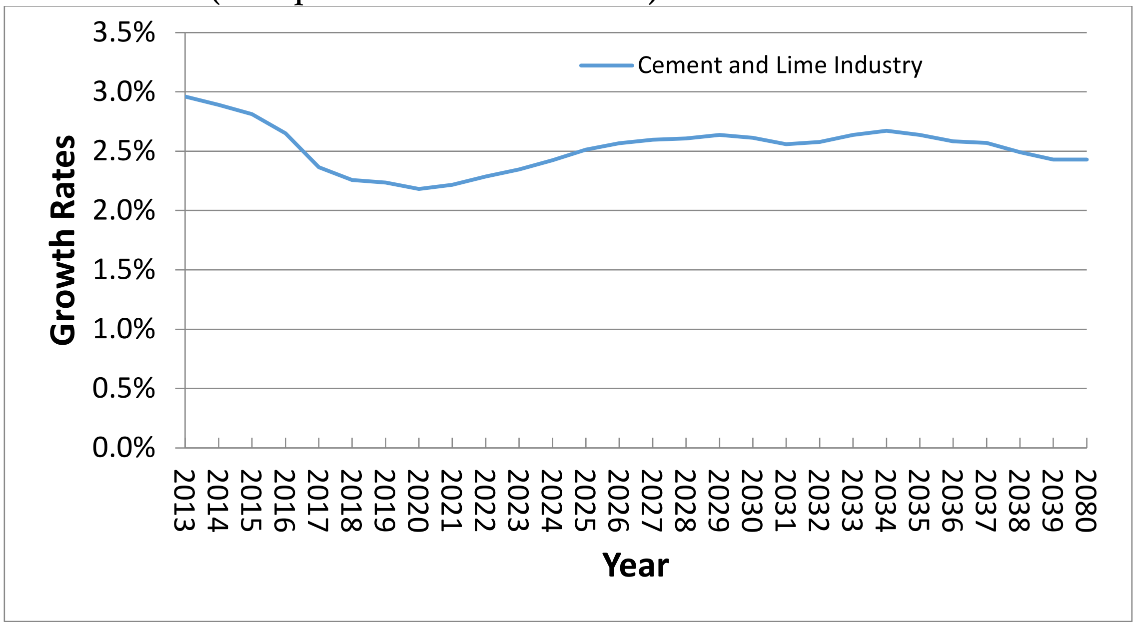


SOURCE: AEO 2015

3.2.2.2.7 Cement And Lime Industry

The time series was extrapolated beyond 2040 using the growth rate between 2039 and 2040, 2.428 percent. Intuitively this may seem high but it is the lowest AACGR for the cement and lime annual forecasts after year 2024. **FIGURE 3-14** depicts the AACGR, 2013-2040 and extrapolations thereof to 2080 for cement and lime industry.

FIGURE 3-14: 2013 to 2040 Growth Rates of Cement and Lime Industry Production (Extrapolated From 2040 to 2080)

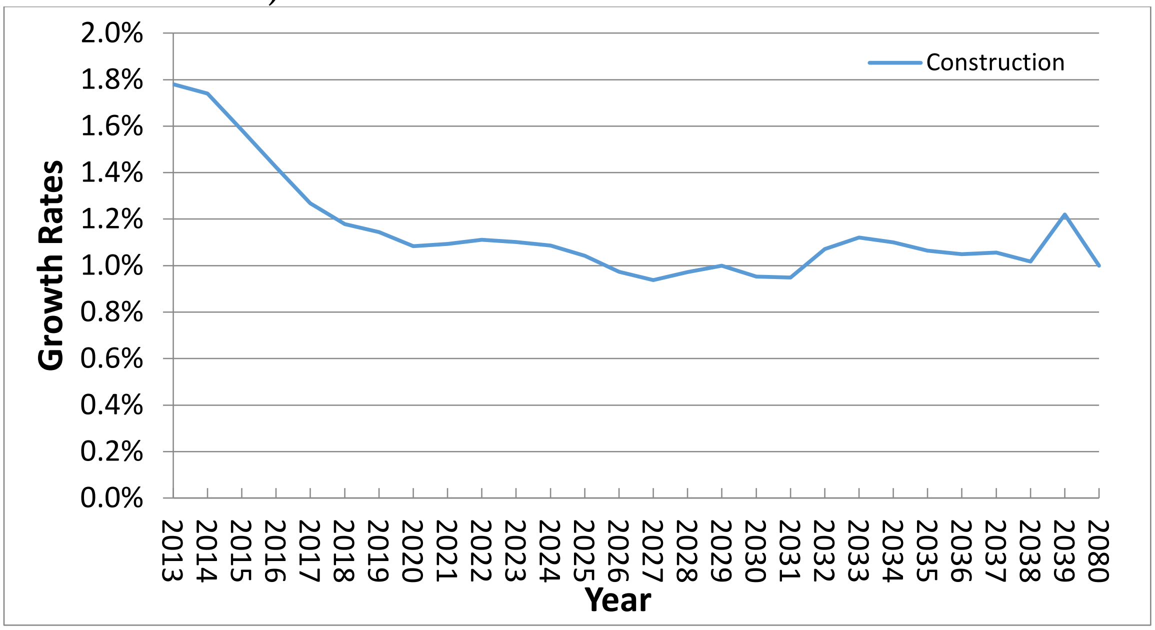


SOURCE: AEO 2015

3.2.2.2.8 Construction

The time series was extrapolated beyond 2040 using a growth rate of 1.000 percent that is close to the AACGR slightly more or less than 1 percent for nearly all of the forecast years between 2013 and 2040. **FIGURE 3-15** depicts the AACGR, 2013-2040 and extrapolation thereof to 2080 for construction industry.

FIGURE 3-15: AEO 2015-2040 Growth Rates of Construction (Extrapolated From 2040 to 2080)

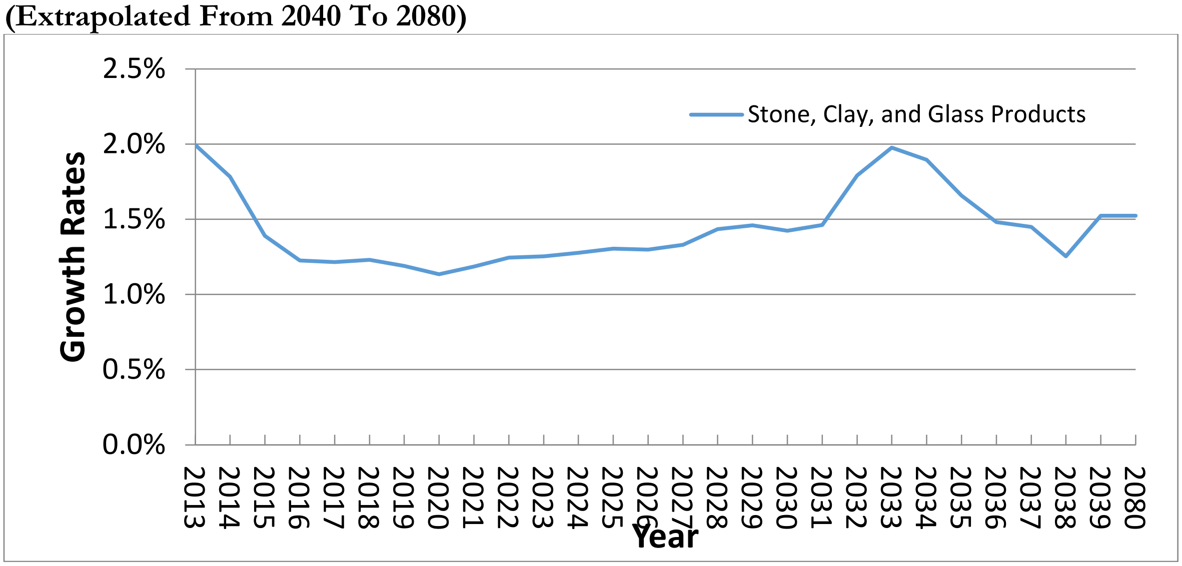


SOURCE: AEO 2015

3.2.2.2.9 Stone, Clay And Glass Products

The AACGR of the last year of the forecast, 2039-2040, was used, 1.524 percent. This growth rate is comparable with the AACGR in the later years of the forecast after 2028. **FIGURE 3-16** depicts the AACGR, 2013-2040 and extrapolation thereof to 2080 for stone, clay and the glass products industry.

FIGURE 3-16: AEO 2015-2040 Growth Rates of Stone, Clay, and Glass Products (Extrapolated From 2040 To 2080)

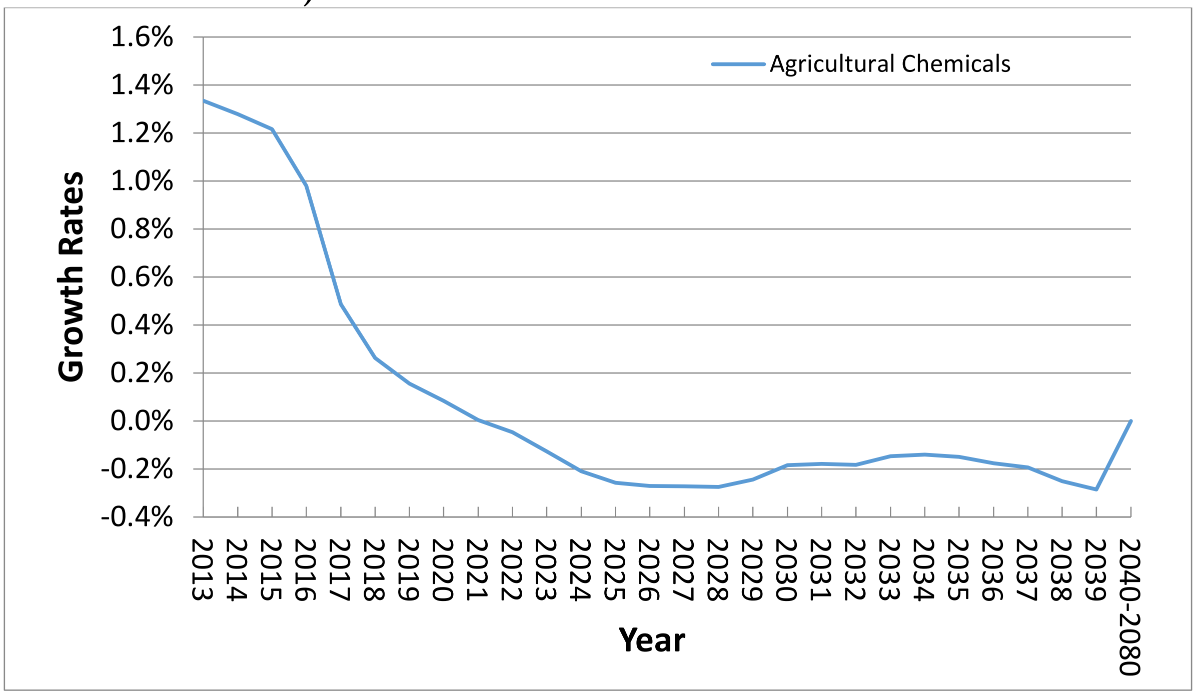


SOURCE: AEO 2015

3.2.2.2.10 Agricultural Chemicals

No growth was assumed beyond 2040 to 2080. **FIGURE 3-17** depicts the AACGR, 2013-2040 and (no growth) extrapolation thereof to 2080 for agricultural chemicals.

FIGURE 3-17: 2013 to 2040 Growth Rates of Agricultural Chemicals (Assumed Flat 2040 to 2080)



3.2.2.3 IHNC Lock Commodity Tons Forecasts, 2013 - 2080

3.2.2.3.1 Commodity Forecast Groups

The Department of Energy (DOE) Energy Information Administration (EIA) Annual Energy Outlook (AEO) 2015-2040 projections were applied to the IHNC using 2013 lock commodity tonnages as the baseline. The baseline represents the most current year of Waterborne Commerce Statistics for IHNC lock tonnages.

TABLE 3-0 presents the Waterborne Commerce Statistics compilations of annual vessel trips and tons for major commodity groups and subgroups for year 2013 for the IHNC (see also tables 2-1, 2-2 and 2-3). Total vessel trips and commodity tons compiled for the IHNC for the 2013 baseline year of the forecast were 7,394 and 16,372,929, respectively. The commodity groups and subgroups to be forecasted for the IHNC using the 2013 baseline out to 2040 (AEO 2015) and extrapolated to 2080 are in bold print in **TABLE 3-0**. Total commodity groups and subgroups to be forecasted beyond 2013 represent a subtotal of 7,200 and 16,082,551 of the 2013 total IHNC vessel trips and commodity tons, respectively. **FIGURE 3-18** depicts the IHNC 2013 baseline tonnages for the commodity groups and subgroups to be forecasted from **TABLE 3-0** including: (1) subtotal petroleum products; (2) subtotal other chemicals; (3) subtotal crude petroleum; (4) subtotal soil, sand, gravel, rock and stone; (5) subtotal iron ore and scrap; (6) subtotal primary iron and steel products; (7) subtotal lime, cement and glass; (8) subtotal fertilizers; (9) subtotal other nonmetallic minerals; (10) total coal; (11) total food and farm products; and (12) subtotal slag.

The commodity groups and subgroups not specifically forecasted for the IHNC using the 2013 baseline are considered to be "other". The "other" category represents a subtotal of 194 and 290,376 of all IHNC vessel trips and commodity tons in 2013, respectively. **TABLE 3-0** indicates that the commodity groups to be specifically forecasted beyond 2013 (7,200 vessel trips and 16,082,551 cargo tons) represent 97.376 percent (7,200/7,394 = 0.97376) of total vessel trips and 98.226 percent (16,082,551/16,372,927 = 0.98226) of total commodity tons reported to transit the IHNC in 2013 baseline year of the forecast.

Correspondingly, the "other" commodity groups reported to transit the IHNC in 2013 that are not specifically forecasted are a very small percentage of the total 2013 baseline vessel trips and cargo tons. The "other" represent 2.623 percent of total 2013 vessel trips (194/7,394 = 0.02623) and 1.773 percent of total 2013 cargo tons (290,376/16,372,927 = 0.01773). **FIGURE 3-19** depicts the IHNC composition of 2013 baseline "other" commodities that will not be specifically forecasted from **TABLE 3-0**, including: (1) subtotal primary non-ferrous products; (2) subtotal non-ferrous ores and scrap; (3) total all manufactured equipment, machinery and products; (4) total unknown or not elsewhere classified; (5) subtotal sulphur, clay and salt; and (6) subtotal marine shells.

TABLE 3-0: IHNC Forecast Categories of Major Commodity Group and Subgroup Tons, 2013

COMMODITY NAME	TRIPS	TONS	TRIPS	TONS
	7,394	16,372,927		
Total, all commodities	7,394	16,372,927	7,394	15,576,408
Total Coal	**192**	**313,781**	**192**	**313,781**
Total petroleum and petroleum products	1,812	6,323,369		
Subtotal crude petroleum	**747**	**2,475,458**	**747**	**2,475,458**
Subtotal petroleum products	**1,065**	**3,847,911**	**1,065**	**3,847,911**
Total chemicals and related products	1,662	3,747,612		
Subtotal fertilizers	**323**	**510,554**	**323**	**510,554**
Subtotal other chemicals and related products	**1,339**	**3,237,058**	**1,339**	**3,237,058**
Total crude materials inedible except fuels	2,417	3,847,461		
Subtotal florets products, wood and chips	3	10,206		
Subtotal and waste paper	0	0		
Subtotal soil, sand, gravel, rock and stone	**1,072**	**1,688,784**	**1,072**	**1,688,784**
Subtotal iron ore and scrap	**965**	**1,536,757**	**965**	**1,536,757**
Subtotal marine shells	2	2,903		
Subtotal non-ferrous ores and scrap	68	110,708		
Subtotal sulphur, clay and salt	3	3,713		

Subtotal slag	**108**	**176,767**	**108**	**176,767**
Subtotal other non-metallic minerals	**196**	**317,623**	**196**	**317,623**
Total primary manufactured goods	1,203	1,888,054		
Subtotal lime, cement and glass	**457**	**796,976**	**457**	**796,976**
Subtotal paper products	0	0	0	0
Subtotal primary iron and steel products	**632**	**939,275**	**632**	**939,275**
Subtotal primary non-ferrous metal products	114	151,803		
Subtotal primary wood products	0	0	0	0
Total food and farm products	**104**	**241,607**	**104**	**241,607**
Subtotal fish	0	0		
Subtotal grain	19	40,852		
Subtotal oilseeds	56	87,862		
Subtotal vegetable products	0	0		
Subtotal processed grain and animal feed	17	28,108		
Subtotal other agricultural products	12	84,785		
Total all manufactured equipment, machinery and products	4	6,105		
Waste and Scrap NEC	0	0	0	0
Total unknown or not elsewhere classified	0	4,938		
Subtotal Forecasted	**7,200**	**16,082,551**	**7,200**	**16,082,551**
Other	**194**	**290,376**	**194**	**290,376**
Total	**7,394**	**16,372,927**	**7,394**	**16,372,927**

FIGURE 3-18: IHNC 2013 Baseline Tonnages for Commodity Groups and Subgroups to be Forecasted

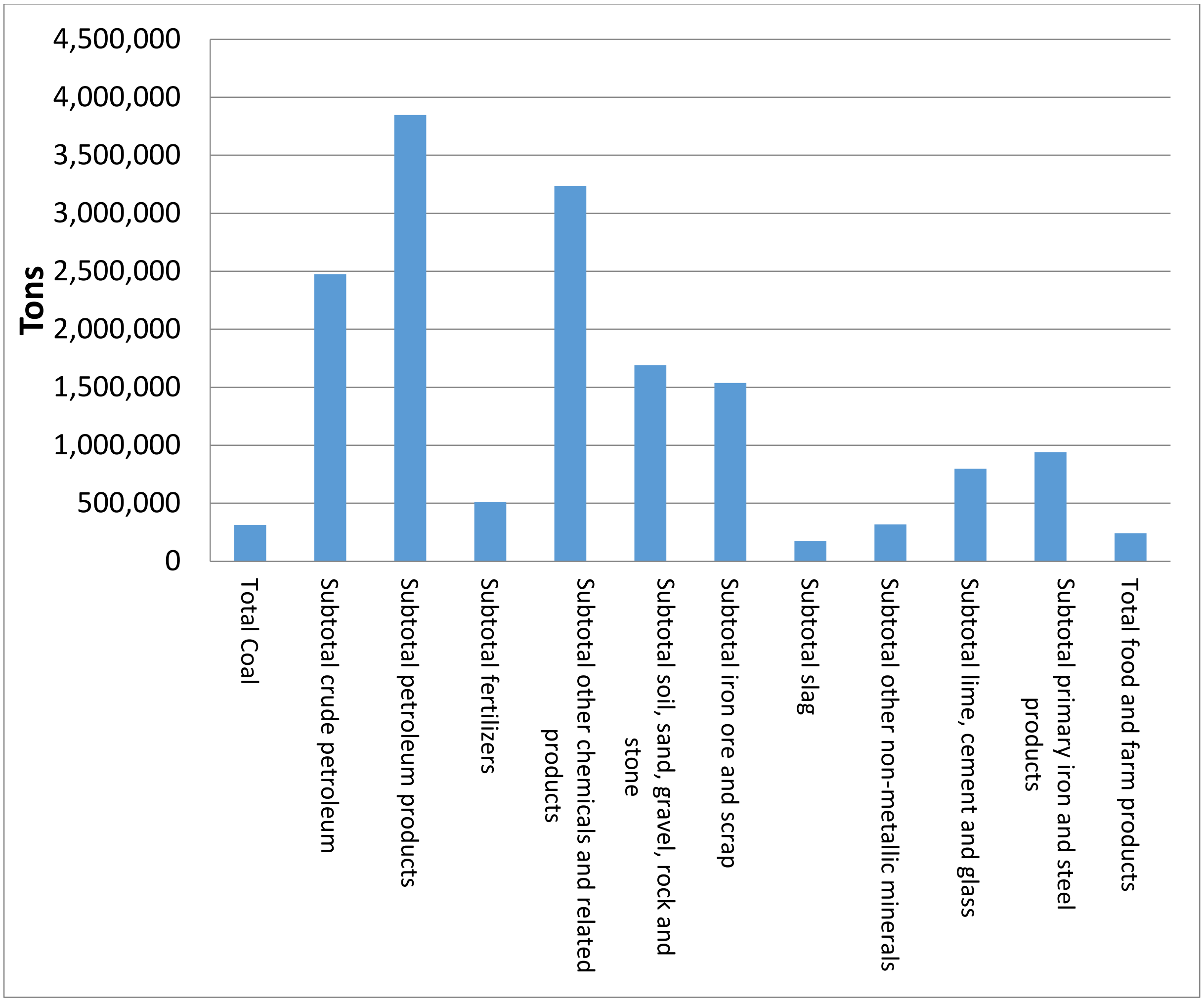


FIGURE 3-19: IHNC 2013 Baseline Tonnages for Commodity Groups and Subgroups to be Classified as "Other"

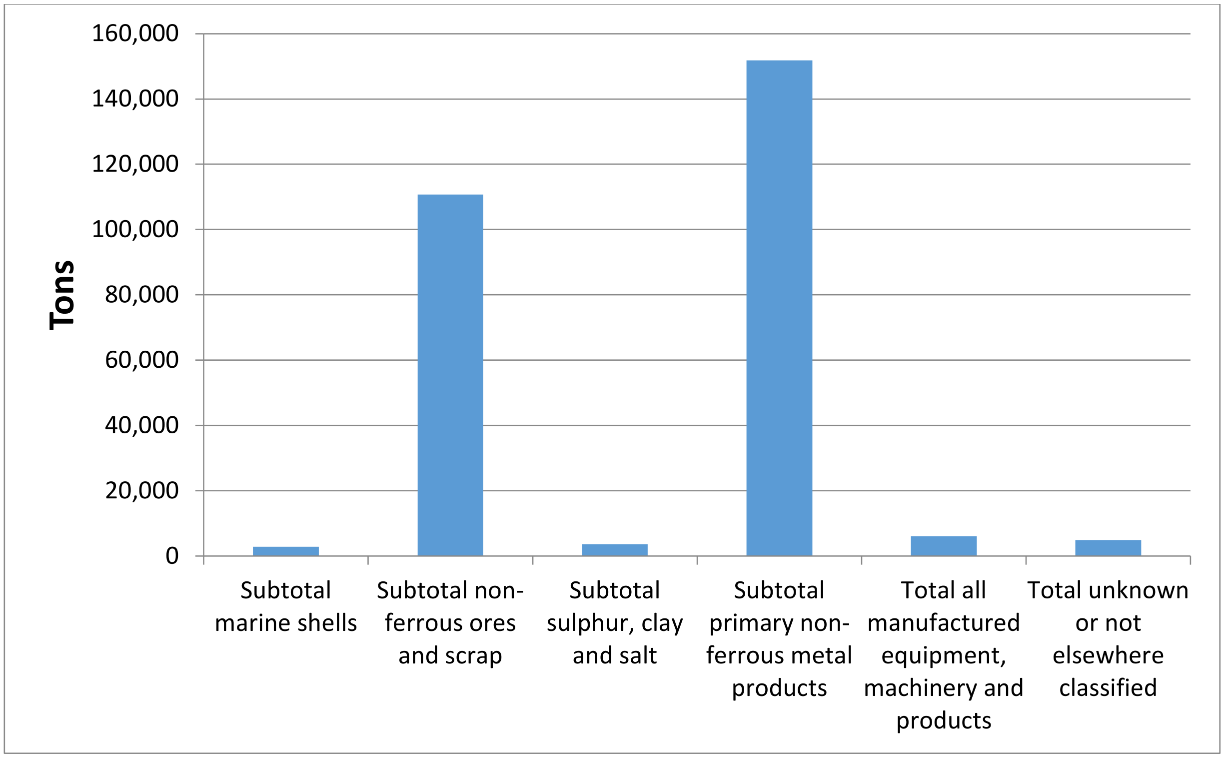


TABLE 3-1 presents the commodity tons forecasts for all of the groups and subgroups forecasted for the IHNC. The 2013 total IHNC baseline tonnage, 16.372 million, is forecasted to increase to 22.522 million by 2040. Extrapolations of AEO 2015 beyond 2040 result in further increases in total IHNC commodity tons to 28.058 by 2080. **FIGURE 3-20** depicts the IHNC 2013 baseline total tonnage (all commodities) forecasted to 2080.

TABLE 3-1: IHNC Commodity Tons Forecast, 2013-2080

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Liquefied Petroleum Gases and Other	41,619	40,435	40,542	42,284	44,465	46,654	48,397	49,541	50,247	51,412	52,533	53,453
Motor Gasoline	1,207,457	1,214,105	1,211,345	1,208,983	1,200,643	1,189,823	1,177,858	1,165,193	1,151,171	1,135,605	1,118,514	1,100,412
Distillate Fuel Oil	694,057	720,738	725,627	740,966	747,384	753,371	758,797	762,541	762,850	764,032	766,347	769,432
Residual Fuel Oil	1,221,686	1,009,763	924,146	891,814	874,692	905,878	841,575	862,464	877,795	892,267	900,762	908,217
Petrochemical Feedstocks	203,817	192,004	201,702	199,394	216,867	236,144	249,938	260,174	268,467	278,861	288,684	295,258
Other Petroleum	479,275	470,345	474,777	479,488	479,588	486,753	492,039	498,786	504,981	508,058	511,269	513,488
Petroleum and Other Liquids Subtotal	3,847,911	3,647,391	3,578,139	3,562,929	3,563,639	3,618,622	3,568,605	3,598,697	3,615,511	3,630,234	3,638,108	3,640,261
Total Crude Oil Lock Tons, 2013-2080	2,475,458	3,014,754	3,359,550	3,439,118	3,642,460	3,766,233	3,845,801	3,766,233	3,633,619	3,536,369	3,421,437	3,350,709
Bulk Chemical Lock Tons, 2013-2080	3,237,058	3,307,521	3,430,477	3,498,915	3,767,418	4,001,972	4,186,638	4,309,658	4,395,140	4,517,722	4,645,340	4,742,973
Iron and Steel Lock Tons, 2013-2080	939,275	942,336	1,034,006	1,060,806	1,080,632	1,118,995	1,152,181	1,178,400	1,202,865	1,238,219	1,269,761	1,302,456
Iron Ore and Scrap Lock Tons, 2013-2080	1,536,757	1,541,765	1,691,747	1,735,596	1,768,033	1,830,798	1,885,095	1,927,991	1,968,020	2,025,862	2,077,468	2,130,960
Coal Lock Tons, 2013-2080	313,781	324,200	319,533	318,217	308,579	312,611	319,403	325,179	324,453	324,560	326,368	330,962
Cement and Lime Lock Tons, 2013-2080	796,976	835,259	875,760	934,729	1,023,077	1,071,650	1,100,762	1,137,266	1,154,756	1,165,905	1,180,694	1,194,125
Slag Lock Tons, 2013-2080	176,767	181,783	192,217	202,774	213,012	219,954	224,176	229,458	231,518	233,349	236,279	239,496
Soil, Sand, Gravel, Rock and Stone Lock Tons, 2013-2080	1,688,784	1,817,041	2,037,310	2,147,094	2,179,276	2,198,510	2,244,194	2,295,651	2,299,603	2,303,046	2,328,045	2,348,763
Agricultural Chemicals Lock Tons, 2013-2080	510,554	524,977	539,883	577,871	653,252	689,349	706,787	718,127	729,788	736,415	746,248	755,244
Other Nonmetallic Minerals Lock Tons, 2013-2080	317,623	344,338	396,439	419,706	420,310	419,969	427,728	436,602	434,322	432,294	435,855	438,341
Food and Farm Products Lock Tons, 2013-2080	241,607	246,051	250,566	257,227	262,715	268,085	273,298	278,507	283,467	288,610	294,075	299,742
Other Commodities Lock Tons, 2013-2080	290,376	290,376	290,376	290,376	290,376	290,376	290,376	290,376	290,376	290,376	290,376	290,376
Total	16,372,927	17,017,790	17,996,002	18,445,357	19,172,781	19,807,124	20,225,043	20,492,146	20,563,437	20,722,961	20,890,054	21,064,409

	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
Liquefied Petroleum Gases and Other	54,113	54,483	55,011	55,669	55,983	56,109	56,069	55,961	55,831	55,696	55,565	55,479
Motor Gasoline	1,080,900	1,063,263	1,047,898	1,034,592	1,022,748	1,012,275	1,003,177	995,157	988,056	981,765	975,879	970,659
Distillate Fuel Oil	771,610	772,185	773,524	774,495	775,728	777,989	778,602	778,114	779,341	782,043	785,225	787,579
Residual Fuel Oil	914,522	921,078	917,992	914,103	911,564	908,820	909,380	909,236	909,443	909,949	910,268	911,396
Petrochemical Feedstocks	301,846	308,139	310,087	311,502	313,358	314,247	315,457	317,552	317,698	319,110	320,180	320,531
Other Petroleum	516,251	519,328	519,523	518,782	518,419	519,652	521,766	521,028	523,359	526,042	528,442	530,927
Petroleum and Other Liquids Subtotal	3,639,243	3,638,475	3,624,036	3,609,144	3,597,800	3,589,092	3,584,451	3,577,048	3,573,729	3,574,606	3,575,560	3,576,572
Total Crude Oil Lock Tons, 2013-2080	3,244,618	3,156,209	3,138,527	3,182,732	3,209,254	3,173,891	3,120,845	3,076,641	3,014,754	2,944,027	2,926,345	2,908,663
Bulk Chemical Lock Tons, 2013-2080	4,818,074	4,867,740	4,919,345	4,976,925	5,007,825	5,022,253	5,031,241	5,040,386	5,036,912	5,039,910	5,042,609	5,045,627
Iron and Steel Lock Tons, 2013-2080	1,329,360	1,345,843	1,355,415	1,358,257	1,359,905	1,362,076	1,367,055	1,375,096	1,387,170	1,395,429	1,401,427	1,406,449
Iron Ore and Scrap Lock Tons, 2013-2080	2,174,979	2,201,947	2,217,607	2,222,258	2,224,954	2,228,506	2,236,653	2,249,809	2,269,562	2,283,075	2,292,888	2,301,105
Coal Lock Tons, 2013-2080	336,255	339,585	343,828	346,146	353,875	355,251	356,975	362,168	367,277	367,070	370,978	373,051
Cement and Lime Lock Tons, 2013-2080	1,206,995	1,228,436	1,255,057	1,286,115	1,315,272	1,353,433	1,395,139	1,428,820	1,459,770	1,495,207	1,537,613	1,581,608
Slag Lock Tons, 2013-2080	243,682	248,552	252,157	253,465	255,183	258,901	261,479	261,414	263,314	266,586	269,997	273,035
Soil, Sand, Gravel, Rock and Stone Lock Tons, 2013-2080	2,368,809	2,401,841	2,423,396	2,425,009	2,452,938	2,497,935	2,524,887	2,496,292	2,508,755	2,570,730	2,650,098	2,712,843
Agricultural Chemicals Lock Tons, 2013-2080	759,072	758,558	756,632	754,785	750,183	743,885	742,118	741,032	737,853	736,453	735,779	735,479
Other Nonmetallic Minerals Lock Tons, 2013-2080	440,790	446,157	448,855	446,633	451,560	460,253	464,306	454,899	456,338	469,434	486,254	498,651
Food and Farm Products Lock Tons, 2013-2080	305,079	310,207	315,492	320,838	326,086	331,188	336,071	341,022	346,104	351,355	356,682	362,030
Other Commodities Lock Tons, 2013-2080	290,376	290,376	290,376	290,376	290,376	290,376	290,376	290,376	290,376	290,376	290,376	290,376
Total	21,233,926	21,233,926	21,340,722	21,472,684	21,595,213	21,667,040	21,711,596	21,695,002	21,711,914	21,784,257	21,936,605	22,065,489

TABLE 3-1: IHNC Commodity Tons Forecast, 2013-2080

	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048
Liquefied Petroleum Gases and Other	55,755	56,041	55,818	55,335	55,335	55,335	55,335	55,335	55,335	55,335	55,335	55,335
Motor Gasoline	966,206	962,470	959,097	956,138	953,188	950,247	947,315	944,392	941,478	938,573	935,677	932,790
Distillate Fuel Oil	787,681	787,836	785,967	784,310	784,310	784,310	784,310	784,310	784,310	784,310	784,310	784,310
Residual Fuel Oil	912,776	914,763	915,776	916,836	917,897	918,960	920,024	921,089	922,155	923,223	924,292	925,362
Petrochemical Feedstocks	322,954	325,536	327,344	330,448	332,931	335,433	337,954	340,494	343,053	345,631	348,229	350,846
Other Petroleum	533,451	535,892	538,323	541,174	543,835	546,509	549,195	551,896	554,609	557,336	560,076	562,830
Petroleum and Other Liquids Subtotal	3,578,823	3,582,538	3,582,325	3,584,240	3,587,495	3,590,793	3,594,133	3,597,515	3,600,940	3,604,408	3,607,918	3,611,472
Total Crude Oil Lock Tons, 2013-2080	2,890,981	2,917,504	2,899,822	2,961,709	2,961,709	2,961,709	2,961,709	2,961,709	2,961,709	2,961,709	2,961,709	2,961,709
Bulk Chemical Lock Tons, 2013-2080	5,081,231	5,115,839	5,110,657	5,096,253	5,096,253	5,096,253	5,096,253	5,096,253	5,096,253	5,096,253	5,096,253	5,096,253
Iron and Steel Lock Tons, 2013-2080	1,405,323	1,403,584	1,396,434	1,383,200	1,383,200	1,383,200	1,383,200	1,383,200	1,383,200	1,383,200	1,383,200	1,383,200
Iron Ore and Scrap Lock Tons, 2013-2080	2,299,263	2,296,418	2,284,720	2,263,067	2,263,067	2,263,067	2,263,067	2,263,067	2,263,067	2,263,067	2,263,067	2,263,067
Coal Lock Tons, 2013-2080	377,105	378,745	382,652	387,969	392,479	397,083	401,783	406,581	411,480	416,479	421,582	426,791
Cement and Lime Lock Tons, 2013-2080	1,623,064	1,667,261	1,709,886	1,751,406	1,793,935	1,837,496	1,882,114	1,927,816	1,974,628	2,022,577	2,071,690	2,121,995
Slag Lock Tons, 2013-2080	275,834	278,962	281,239	284,670	287,517	290,392	293,296	296,229	299,191	302,183	305,205	308,257
Soil, Sand, Gravel, Rock and Stone Lock Tons, 2013-2080	2,755,653	2,806,454	2,834,030	2,877,216	2,905,988	2,935,048	2,964,398	2,994,042	3,023,983	3,054,222	3,084,765	3,115,612
Agricultural Chemicals Lock Tons, 2013-2080	734,561	733,971	732,394	730,304	728,843	727,385	725,930	724,479	723,030	721,584	720,140	718,700
Other Nonmetallic Minerals Lock Tons, 2013-2080	506,069	515,725	519,920	528,386	536,990	545,734	554,620	563,651	572,830	582,157	591,637	601,270
Food and Farm Products Lock Tons, 2013-2080	367,420	372,871	378,296	383,890	389,566	395,326	401,171	407,103	413,122	419,231	425,430	431,720
Other Commodities Lock Tons, 2013-2080	290,376	290,376	290,376	290,376	290,376	290,376	290,376	290,376	290,376	290,376	290,376	290,376
Total	22,185,702	22,360,249	22,402,753	22,522,685	22,617,416	22,713,860	22,812,051	22,912,021	23,013,807	23,117,445	23,222,971	23,330,422

	2049	2050	2051	2052	2053	2054	2055	2056	2057	2049	2050	2051
Liquefied Petroleum Gases and Other	55,335	55,335	55,335	55,335	55,335	55,335	55,335	55,335	55,335	55,335	55,335	55,335
Motor Gasoline	929,912	927,043	924,183	921,331	918,488	915,654	912,829	910,013	907,205	929,912	927,043	924,183
Distillate Fuel Oil	784,310	784,310	784,310	784,310	784,310	784,310	784,310	784,310	784,310	784,310	784,310	784,310
Residual Fuel Oil	926,433	927,506	928,580	929,655	930,731	931,809	932,887	933,967	935,049	926,433	927,506	928,580
Petrochemical Feedstocks	353,483	356,139	358,816	361,512	364,229	366,967	369,725	372,503	375,303	353,483	356,139	358,816
Other Petroleum	565,597	568,377	571,172	573,980	576,802	579,638	582,488	585,351	588,229	565,597	568,377	571,172
Petroleum and Other Liquids Subtotal	3,615,069	3,618,710	3,622,394	3,626,123	3,629,895	3,633,712	3,637,573	3,641,479	3,645,430	3,615,069	3,618,710	3,622,394
Total Crude Oil Lock Tons, 2013-2080	2,961,709	2,961,709	2,961,709	2,961,709	2,961,709	2,961,709	2,961,709	2,961,709	2,961,709	2,961,709	2,961,709	2,961,709
Bulk Chemical Lock Tons, 2013-2080	5,096,253	5,096,253	5,096,253	5,096,253	5,096,253	5,096,253	5,096,253	5,096,253	5,096,253	5,096,253	5,096,253	5,096,253
Iron and Steel Lock Tons, 2013-2080	1,383,200	1,383,200	1,383,200	1,383,200	1,383,200	1,383,200	1,383,200	1,383,200	1,383,200	1,383,200	1,383,200	1,383,200
Iron Ore and Scrap Lock Tons, 2013-2080	2,263,067	2,263,067	2,263,067	2,263,067	2,263,067	2,263,067	2,263,067	2,263,067	2,263,067	2,263,067	2,263,067	2,263,067
Coal Lock Tons, 2013-2080	432,106	437,530	443,065	448,713	454,475	460,355	466,353	472,473	478,716	432,106	437,530	443,065
Cement and Lime Lock Tons, 2013-2080	2,173,522	2,226,300	2,280,360	2,335,732	2,392,449	2,450,543	2,510,048	2,570,998	2,633,428	2,173,522	2,226,300	2,280,360
Slag Lock Tons, 2013-2080	311,339	314,453	317,597	320,773	323,981	327,221	330,493	333,798	337,136	311,339	314,453	317,597
Soil, Sand, Gravel, Rock and Stone Lock Tons, 2013-2080	3,146,768	3,178,236	3,210,018	3,242,119	3,274,540	3,307,285	3,340,358	3,373,762	3,407,499	3,146,768	3,178,236	3,210,018
Agricultural Chemicals Lock Tons, 2013-2080	717,263	715,828	714,397	712,968	711,542	710,119	708,699	707,281	705,867	717,263	715,828	714,397
Other Nonmetallic Minerals Lock Tons, 2013-2080	611,061	621,011	631,123	641,400	651,844	662,458	673,245	684,208	695,349	611,061	621,011	631,123
Food and Farm Products Lock Tons, 2013-2080	438,103	444,581	451,155	457,826	464,595	471,465	478,436	485,510	492,689	438,103	444,581	451,155
Other Commodities Lock Tons, 2013-2080	290,376	290,376	290,376	290,376	290,376	290,376	290,376	290,376	290,376	290,376	290,376	290,376
Total	23,439,836	23,551,254	23,664,714	23,780,257	23,897,926	24,017,762	24,139,810	24,264,113	24,390,718	23,439,836	23,551,254	23,664,714

TABLE 3-1: IHNC Commodity Tons Forecast, 2013-2080

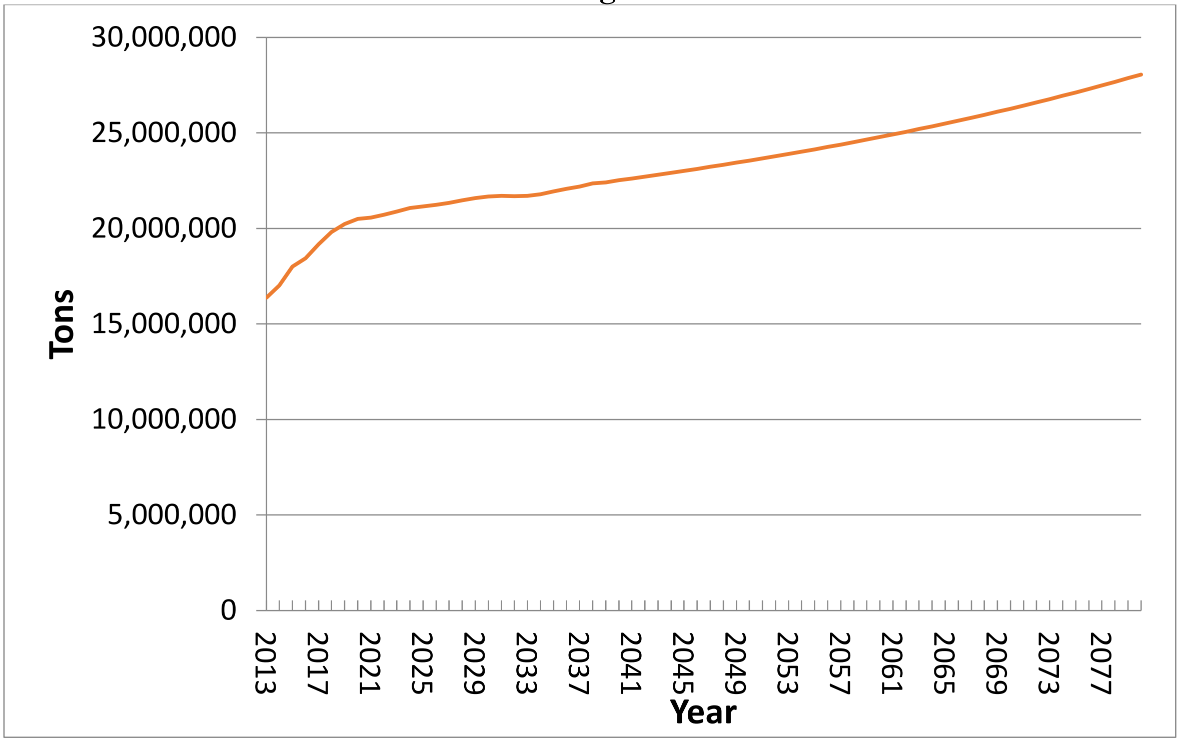
	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063
Liquefied Petroleum Gases and Other	55,335	55,335	55,335	55,335	55,335	55,335	55,335	55,335	55,335	55,335	55,335	55,335
Motor Gasoline	921,331	918,488	915,654	912,829	910,013	907,205	904,406	901,615	898,833	896,060	893,295	890,539
Distillate Fuel Oil	784,310	784,310	784,310	784,310	784,310	784,310	784,310	784,310	784,310	784,310	784,310	784,310
Residual Fuel Oil	929,655	930,731	931,809	932,887	933,967	935,049	936,131	937,215	938,300	939,386	940,474	941,563
Petrochemical Feedstocks	361,512	364,229	366,967	369,725	372,503	375,303	378,123	380,965	383,828	386,713	389,619	392,547
Other Petroleum	573,980	576,802	579,638	582,488	585,351	588,229	591,121	594,028	596,948	599,883	602,832	605,796
Petroleum and Other Liquids Subtotal	3,626,123	3,629,895	3,633,712	3,637,573	3,641,479	3,645,430	3,649,426	3,653,468	3,657,554	3,661,687	3,665,866	3,670,090
Total Crude Oil Lock Tons, 2013-2080	2,961,709	2,961,709	2,961,709	2,961,709	2,961,709	2,961,709	2,961,709	2,961,709	2,961,709	2,961,709	2,961,709	2,961,709
Bulk Chemical Lock Tons, 2013-2080	5,096,253	5,096,253	5,096,253	5,096,253	5,096,253	5,096,253	5,096,253	5,096,253	5,096,253	5,096,253	5,096,253	5,096,253
Iron and Steel Lock Tons, 2013-2080	1,383,200	1,383,200	1,383,200	1,383,200	1,383,200	1,383,200	1,383,200	1,383,200	1,383,200	1,383,200	1,383,200	1,383,200
Iron Ore and Scrap Lock Tons, 2013-2080	2,263,067	2,263,067	2,263,067	2,263,067	2,263,067	2,263,067	2,263,067	2,263,067	2,263,067	2,263,067	2,263,067	2,263,067
Coal Lock Tons, 2013-2080	448,713	454,475	460,355	466,353	472,473	478,716	485,084	491,580	498,205	504,963	511,856	518,886
Cement and Lime Lock Tons, 2013-2080	2,335,732	2,392,449	2,450,543	2,510,048	2,570,998	2,633,428	2,697,374	2,762,872	2,829,961	2,898,679	2,969,066	3,041,162
Slag Lock Tons, 2013-2080	320,773	323,981	327,221	330,493	333,798	337,136	340,507	343,912	347,351	350,825	354,333	357,876
Soil, Sand, Gravel, Rock and Stone Lock Tons, 2013-2080	3,242,119	3,274,540	3,307,285	3,340,358	3,373,762	3,407,499	3,441,574	3,475,990	3,510,750	3,545,857	3,581,316	3,617,129
Agricultural Chemicals Lock Tons, 2013-2080	712,968	711,542	710,119	708,699	707,281	705,867	704,455	703,046	701,640	700,237	698,836	697,438
Other Nonmetallic Minerals Lock Tons, 2013-2080	641,400	651,844	662,458	673,245	684,208	695,349	706,672	718,179	729,873	741,758	753,836	766,111
Food and Farm Products Lock Tons, 2013-2080	457,826	464,595	471,465	478,436	485,510	492,689	499,973	507,366	514,868	522,481	530,206	538,046
Other Commodities Lock Tons, 2013-2080	290,376	290,376	290,376	290,376	290,376	290,376	290,376	290,376	290,376	290,376	290,376	290,376
Total	23,780,257	23,897,926	24,017,762	24,139,810	24,264,113	24,390,718	24,519,670	24,651,017	24,784,808	24,921,091	25,059,919	25,201,343

	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075
Liquefied Petroleum Gases and Other	55,335	55,335	55,335	55,335	55,335	55,335	55,335	55,335	55,335	55,335	55,335	55,335
Motor Gasoline	887,791	885,052	882,321	879,599	876,885	874,180	871,482	868,793	866,113	863,440	860,776	858,120
Distillate Fuel Oil	784,310	784,310	784,310	784,310	784,310	784,310	784,310	784,310	784,310	784,310	784,310	784,310
Residual Fuel Oil	942,653	943,744	944,837	945,931	947,026	948,122	949,220	950,319	951,419	952,521	953,623	954,727
Petrochemical Feedstocks	395,498	398,470	401,465	404,482	407,522	410,584	413,670	416,779	419,911	423,067	426,247	429,450
Other Petroleum	608,775	611,768	614,776	617,798	620,835	623,888	626,955	630,038	633,135	636,248	639,376	642,520
Petroleum and Other Liquids Subtotal	3,674,361	3,678,679	3,683,043	3,687,454	3,691,913	3,696,418	3,700,972	3,705,573	3,710,223	3,714,921	3,719,667	3,724,462
Total Crude Oil Lock Tons, 2013-2080	2,961,709	2,961,709	2,961,709	2,961,709	2,961,709	2,961,709	2,961,709	2,961,709	2,961,709	2,961,709	2,961,709	2,961,709
Bulk Chemical Lock Tons, 2013-2080	5,096,253	5,096,253	5,096,253	5,096,253	5,096,253	5,096,253	5,096,253	5,096,253	5,096,253	5,096,253	5,096,253	5,096,253
Iron and Steel Lock Tons, 2013-2080	1,383,200	1,383,200	1,383,200	1,383,200	1,383,200	1,383,200	1,383,200	1,383,200	1,383,200	1,383,200	1,383,200	1,383,200
Iron Ore and Scrap Lock Tons, 2013-2080	2,263,067	2,263,067	2,263,067	2,263,067	2,263,067	2,263,067	2,263,067	2,263,067	2,263,067	2,263,067	2,263,067	2,263,067
Coal Lock Tons, 2013-2080	526,055	533,366	540,822	548,425	556,178	564,084	572,144	580,363	588,742	597,286	605,996	614,876
Cement and Lime Lock Tons, 2013-2080	3,115,008	3,190,648	3,268,124	3,347,482	3,428,766	3,512,025	3,597,305	3,684,656	3,774,128	3,865,772	3,959,642	4,055,791
Slag Lock Tons, 2013-2080	361,455	365,070	368,720	372,408	376,132	379,893	383,692	387,529	391,404	395,318	399,271	403,264
Soil, Sand, Gravel, Rock and Stone Lock Tons, 2013-2080	3,653,300	3,689,833	3,726,732	3,763,999	3,801,639	3,839,655	3,878,052	3,916,833	3,956,001	3,995,561	4,035,516	4,075,872
Agricultural Chemicals Lock Tons, 2013-2080	696,044	694,651	693,262	691,876	690,492	689,111	687,733	686,357	684,984	683,615	682,247	680,883
Other Nonmetallic Minerals Lock Tons, 2013-2080	778,586	791,264	804,148	817,243	830,550	844,074	857,818	871,787	885,982	900,409	915,071	929,971
Food and Farm Products Lock Tons, 2013-2080	546,001	554,075	562,267	570,581	579,017	587,579	596,267	605,083	614,030	623,109	632,322	641,672
Other Commodities Lock Tons, 2013-2080	290,376	290,376	290,376	290,376	290,376	290,376	290,376	290,376	290,376	290,376	290,376	290,376
Total	25,345,415	25,492,190	25,641,723	25,794,071	25,949,291	26,107,443	26,268,587	26,432,784	26,600,099	26,770,594	26,944,337	27,121,395

TABLE 3-1: IHNC Commodity Tons Forecast, 2013-2080

	2076	2077	2078	2079	
Liquefied Petroleum Gases and Other	55,335	55,335	55,335	55,335	
Motor Gasoline	855,473	852,833	850,202	847,579	8
Distillate Fuel Oil	784,310	784,310	784,310	784,310	7
Residual Fuel Oil	955,833	956,939	958,047	959,156	9
Petrochemical Feedstocks	432,678	435,929	439,206	442,507	4
Other Petroleum	645,679	648,853	652,043	655,249	6
Petroleum and Other Liquids Subtotal	3,729,306	3,734,200	3,739,142	3,744,135	3
Total Crude Oil Lock Tons, 2013-2080	2,961,709	2,961,709	2,961,709	2,961,709	2
Bulk Chemical Lock Tons, 2013-2080	5,096,253	5,096,253	5,096,253	5,096,253	5
Iron and Steel Lock Tons, 2013-2080	1,383,200	1,383,200	1,383,200	1,383,200	1
Iron Ore and Scrap Lock Tons, 2013-2080	2,263,067	2,263,067	2,263,067	2,263,067	2
Coal Lock Tons, 2013-2080	623,928	633,157	642,564	652,154	6
Cement and Lime Lock Tons, 2013-2080	4,154,275	4,255,151	4,358,476	4,464,310	4
Slag Lock Tons, 2013-2080	407,297	411,370	415,483	419,638	4
Soil, Sand, Gravel, Rock and Stone Lock Tons, 2013-2080	4,116,630	4,157,797	4,199,375	4,241,368	4
Agricultural Chemicals Lock Tons, 2013-	679,521	678,162	676,806	675,452	6
Other Nonmetallic Minerals Lock Tons,	945,114	960,503	976,144	992,039	1
Food and Farm Products Lock Tons,	651,159	660,788	670,558	680,473	6
Other Commodities Lock Tons, 2013-	290,376	290,376	290,376	290,376	2
Total	27,301,836	27,485,731	27,673,152	27,864,173	2

FIGURE 3-20: IHNC Baseline Total Tonnage Forecasted to 2080



3.2.2.4 Traffic Forecast Sensitivity

The objective of this section is to present a range of alternative commodity forecasts for the IHNC to be used in comparison with the most likely (reference case) very long term forecast previously presented. The purpose of alternative commodity forests is to develop a range for the expected level of commerce to transit the IHNC under different underlying conditions affecting the supply and demand of waterborne commerce particular to the situation.

The base, most likely forecasts described previously utilized the Department of Energy (DOE) Energy Information Administration (EIA) Annual Energy Outlook (AEO) 2015 version. This forecast applies to domestic energy production and consumption annually for the period 2015 through 2040. The AEO is updated annually and extended every five years. The annual AEO also includes alternative forecasts for domestic energy production and consumption for the period 2015 through 2040. The alternative forecasts are for "high economic growth" and "low economic growth."

The methodology used to develop the alternative low and high long term traffic forecasts closely follows what was done for the most likely forecasts so as to allow comparison between the most likely and the high and low economic growth forecasts. The alternative high and low economic growth energy production and consumption forecasts will be presented for the major categories applicable to IHNC waterborne commerce for the AEO forecast period between 2015 and 2040. Subsequently, the AEO high and low economic growth forecasts will be extrapolated to 2080 consistent with the extrapolation of the most likely (reference case) forecasts described previously.

FIGURE 3-21 and **FIGURE 3-22** depict the reference case (most likely) forecast and high economic growth and reference case and low economic growth, respectively, forecasts of total tonnage for IHNC, 2013-2080. IHNC 2013 base line total tonnage is 16.372 million. The forecasts of total tonnage to 2040 using AEO 2015 are 22.522 million (most likely), 28.748 million (high economic growth) and 19.395 million (low economic growth. Extrapolations of AEO forecasts beyond 2040 to 2080 result in total tonnage forecasts of 28.058 million (most likely), 37.589 million (high economic growth) and 22.197 million (low economic growth).

FIGURE 3-21: IHNC Most Likely and High Economic Growth Forecasts for Total Tonnages of All Commodities, 2013-2080

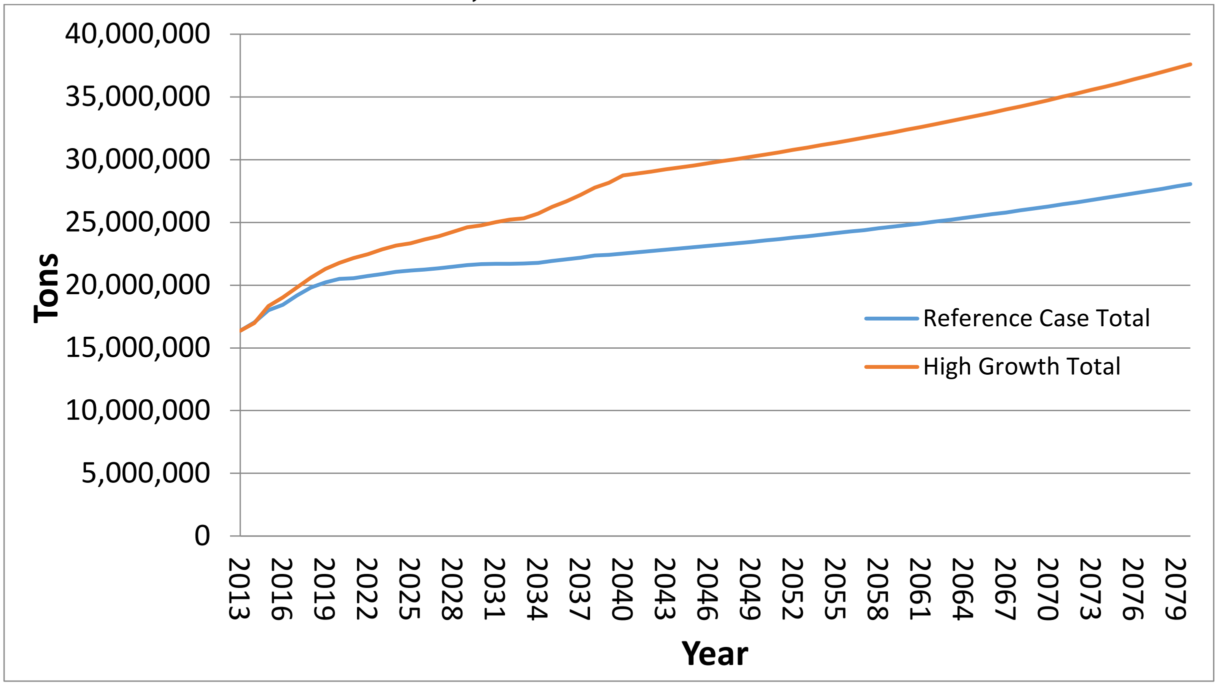
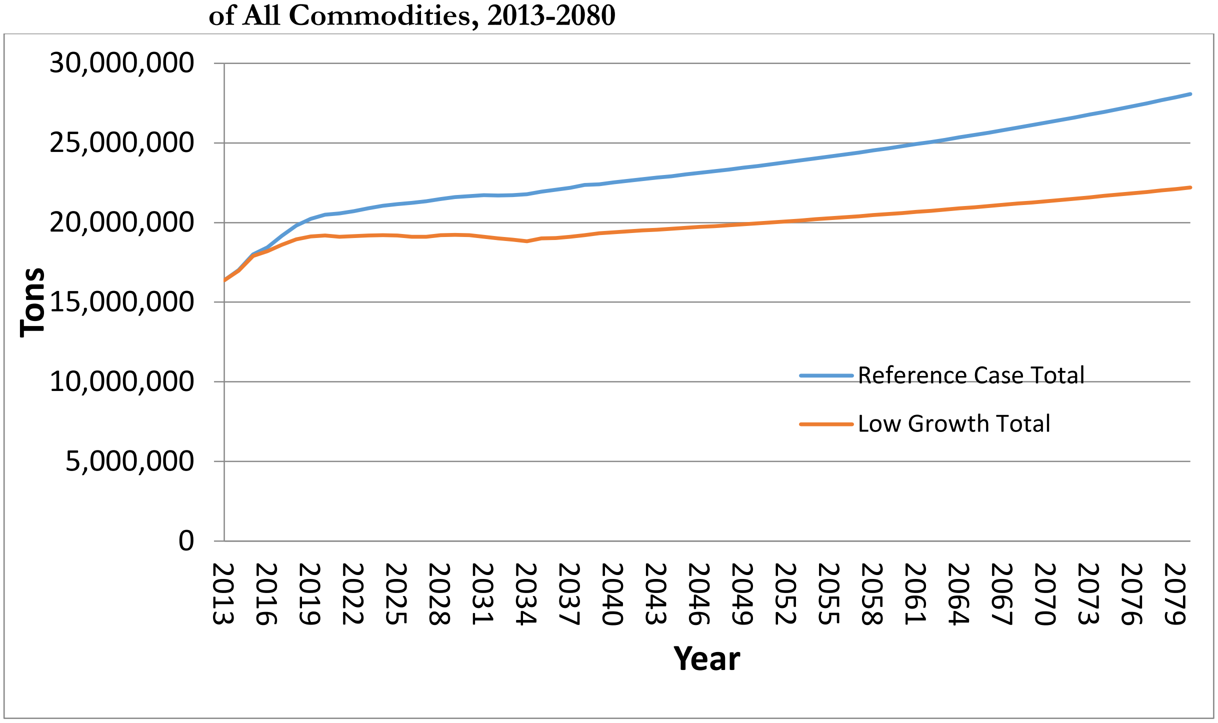


FIGURE 3-22: IHNC Most Likely and Low Economic Growth Forecasts for Total Tonnages of All Commodities, 2013-2080



3.3 Future With Project Condition

3.3.1 Types of NED Benefits

NED benefits for a navigation project investment (WPC) are composed primarily of the reductions in transportation costs attributable to the availability of the improved waterway system. These reductions in transportation costs are achieved by increasing the efficiency of existing waterway movements, by providing for shifts of waterway and overland traffic to more efficient modes and routes, and by providing for shifts to more efficient origin destination combinations. Further benefits accrue from traffic that is transported only because of the lower transportation cost deriving from an improved project, and from creating or enhancing the potential for other productive uses of the waterway, such as the generation of hydropower. National defense benefits can also be argued from the regional and national growth, and from diversity in transportation modes that the improvement provides. In some situations lower emissions can be achieved by transportation of goods on the waterway. Regardless, the conceptual basis for the "… basic economic benefit of a navigation project is the reduction in the value of resources required to transport commodities." These reductions in transportation costs can be classified as:

- Cost-reduction benefits for commodity movements having the same origin, destination and waterway routing that realize cost reductions because of a navigation improvement. This reduction represents an NED gain because resources will be released for productive use elsewhere in the economy. Examples for inland navigation are reductions in costs incurred from trip delays (e.g. reduction in lock congestion), reduction in costs associated with the use of larger or longer tows, and reduction in costs due to more efficient use of barges. Examples for deep draft navigation are reductions in costs associated with the use of larger vessels, with more efficient use of existing vessels, with more efficient use of larger vessels, with reductions in transit time, with lower cargo handling and tug assistance costs, and with reduced interest and storage costs.

- Shift-of-mode benefits for commodity movements having the same origin and destination that realize a cost savings by shifting from their current mode/routing to the improved waterway. In this case, benefits are the difference in costs of transport between the without-project condition (when rails, trucks or different waterways or ports are used) and the with-project condition (improved locks, waterways or channels). The economic benefit to the national economy is the savings in resources from not having to use a more costly mode or point of transport.

- Shift-in-origin and / or destination benefits that would provide benefits by either reducing the cost of transport if a new origin is used or by increasing net revenue of the producer, if a change in destination is realized. This benefit cannot exceed the reduction in transportation costs achieved by the project.

- New movement benefits are claimed when there are additional movements in a commodity or there are new commodities transported due to decreased transportation costs as a result of a navigation improvement. The new movement benefit is defined as the increase in producer and consumer surplus, thus the estimate is limited to increases in production and consumption due to lower transportation costs. Increases in shipments resulting from a shift in origin or destination are not included in the new movement benefits. This benefit cannot exceed the reduction in transportation costs achieved by the project.

- Induced movement benefits are the value of a delivered commodity less production and transportation costs when a commodity or additional quantities of a commodity are produced and consumed due to lower transportation costs. The benefit, in this case, is measured as the difference between the cost of transportation with the project and the maximum cost the shipper would be willing to pay.

Basically, the economic analysis of waterway investments focuses on the evaluation and comparison of the costs and benefits of the existing waterway system with three basic alternative measures: 1) increase capacity (decrease transit times and thereby reduce delay costs); 2) increase reliability (replace or rehabilitate aging structures, thereby reduce the probability of structural failure and its consequences); and / or 3) reduce demand (e.g. congestion fees).

For the IHNC analysis, WPCs were the following:

- Plan 2 - 75' x 900' x 22'
- Plan 3 - 110' x 900' x 22'
- Plan 4 - 75' x 1200' x 22'
- Plan 5 - 110' x 1200' x 22'

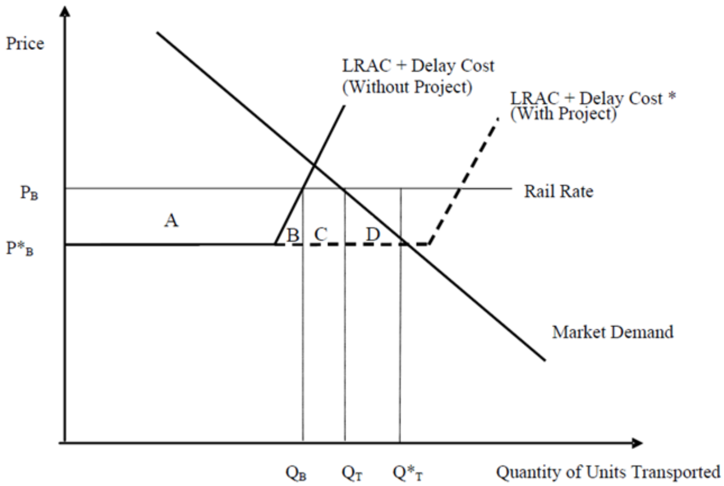
These new larger lock chambers increase capacity and lower transportation costs through the canal by increasing tow-sizes, reducing the number of trip vessels, and less frequent maintenance outages.

3.3.2 Theoretical Equilibrium and Incremental Benefit Framework

The P&G provides general guidance for doing benefit assessments and benefit-cost analysis, but it does not overly restrict or dictate how the assessments should be done. As discussed in IWR Report 09-R-2, National Economic Development Procedures Manual (dated June 2009), transportation cost reduction is the principal inland navigation benefit category and the other benefit categories reflect the different ways that cost reduction can give rise to non-marginal changes in the use of inland navigation.

IWR Report 09-R-2 also describes calculation of transportation cost reduction, shift-of-mode, and new movement benefits through the hypothetical project example shown in **FIGURE 3-23**. This example depicts the calculation of benefits to shippers from expanding locks along a specific origin-destination route as a means to alleviate barge traffic congestion and associated passage delays at the locks. The vertical axis represents the unit prices (rates) for transport, and the horizontal axis shows the total quantity of commodity units transported in response to different rates.

FIGURE 3-23: Benefits to Shippers from Lock Expansion



The downward sloping line shows shippers' total market (derived) demand function for transporting a specific commodity from a given origin to a given destination. The slope of the demand function, or Market Demand for all available transportation methods, represents the response of the quantity of the commodity transported to changes in transportation rates. For simplicity, it is assumed that this market is served by only two transport modes (barge and rail), and there is no qualitative difference between the services they provide.

In the **FIGURE 3-23** example, it is assumed that, because of the open access nature of the barge industry, competition forces barge rates to the level of the long-term average costs (LRAC) of providing barge transportation. Further, the example assumes that the long-run average cost function for barge transportation is horizontal over some initial range of shipments, reflecting constant marginal costs of moving that range of shipments by barge. However, the example also assumes that as the level of barge shipments increases beyond a certain point, increased barge traffic results in congestion and queuing delays at the locks on the system. The increasing waiting times for passage through the locks reflects diseconomies for barge transportation due to increasing factor input costs, which is represented in **FIGURE 3-23** by the portion of the barge long-run average cost function that suddenly veers upwards and to the right. The difference between the horizontal and upward sloping sections of this function is the delay (congestion) cost.

In the WOPC, the total quantity of units shipped is Q_T. Of this total, Q_B is shipped by barge at price P_B that approaches but remains slightly below the prevailing rail rate. Since barge rates are set equal to barge long-run average costs, the barge price for Q_B includes a lock delay cost that is imposed on all barge shippers. The remaining quantity transported ($Q_T – Q_B$) is carried by rail, since the prevailing rail rate is below the rate that barges would need to charge shippers to accommodate the increased delay cost if total barge shipments were to increase beyond Q_B. Expansion of the locks would increase total potential barge shipments to Q^*_T by eliminating delay costs for this level of shipment. This is illustrated by the horizontal section of the without-project average cost function and the extending dashed line. This represents the new long-run average cost function for barge shipment with lock expansion. The new average cost function eventually turns upward, reflecting that even with lock expansion, delay costs would reappear if barge shipments increased much beyond Q^*_T.

Estimation of the benefits of lock expansion begins with a prediction by planners of the amount of barge shipments that would result if the new lock capacity were fully utilized, which in this example is

Q^*_T. At this new level of barge shipment, project benefits would be the sum of 1) cost reduction benefits for the level of barge shipments that existed in the without-project condition, 2) shift of mode benefits associated with the level of without-project shipments that were carried by rail, but with the project will now switch to barge, and 3) new movement benefits associated with any increase in total market shipments beyond the WOPC level.

Cost reduction benefits are equal to the sum of areas A and B in **FIGURE 3-23** and are calculated by multiplying existing barge shipments (Q_B) by the difference between the without-project barge rate (P_B) and the estimated with-project barge rate (P^*_B). Shift of mode benefits are equal to area C, and are calculated by multiplying the quantity previously carried by rail ($Q_T – Q_B$) by the difference between the prevailing rail rate and the with-project barge rate. Finally, new movement benefits are equal to area D.

3.3.3 Modeling Framework

Since the inland navigation investments analyzed have long lives (and regulation requires a CBA assuming a 50-year investment life), costs and benefits must be estimated through time. These estimated life-cycle WOPC and WPC benefit and cost cash flows then serve as the basis for the CBA.

To accomplish a life-cycle analysis, NIM is designed to estimate and analyze the benefits of incremental improvements in a river system and then to compare the benefits against the costs. NIM operates within the supply and demand framework discussed, with inputs that describe the long-run average cost of water transportation (supply) and movement level demand for water transportation. NIM determines WOPC and WPC movement demand equilibrium and incremental benefits, however, the analysis of an investment within a system is much more complex than the simple commodity origin-destination route used as an example in the previous section (**FIGURE 3-23**). Additionally there are other considerations beyond equilibrium and surplus calculations that must be factored into the investment decision. The modeling requires a movement from the theoretical model to an empirical model that appropriately addresses the empirical question at hand and does so in a way that provides the most useful insights for decision-making, given modeling and resource constraints placed on the overall analysis. This section briefly describes the modeling framework used to apply the theoretical framework discussed.

3.3.3.1 Life-Cycle Analysis Accounting

A CBA is sensitive to the life-cycle period being considered and to the handling and comparison of the life-cycle cash flows. This is especially true for inland navigation investments which are costly and have long payback periods. Before proceeding further, the planning period and cash flow analysis will be discussed.

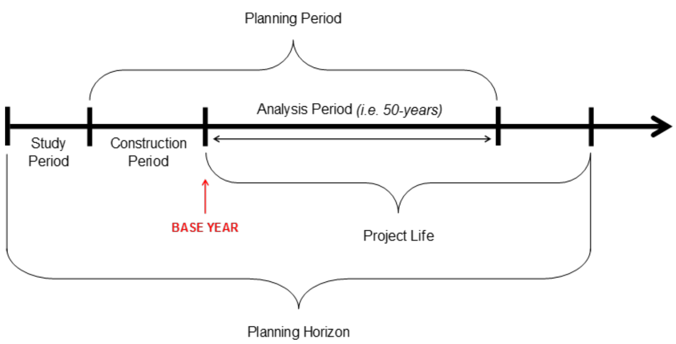
3.3.3.1.1 The Planning Period

Corps guidance requires that the period of analysis should be the same for each plan, and include the time required for plan implementation plus the time period over which any plan would have significant beneficial or adverse effects. In studies for which plans have different implementation periods, Corps guidance says that a common "*base year*" should be established for calculating total NED benefits and costs, reflecting the year when the project is expected to be "*operational*".

Guidance also specifies that for inland navigation projects, the time period over which WPC alternatives have significant beneficial or adverse effects is 50-years. This is not to say that the project or plan will only last 50-years (the actual life is often much longer), but that only 50-years' worth of benefits can be considered to off-set the investment cost. The 50-year period is often referred to as the analysis period or assumed economic project life.

The plan implementation period, however, must also be considered in the analysis. This does not mean the entire time leading up to the plan completion including both the study and construction periods, but instead the period when costs are incurred that are to be compared against the project benefits (i.e. the construction period). **FIGURE 3-24** displays the terminology that will be used in the remainder of this document.

FIGURE 3-24: Planning Period



For the IHNC Lock analysis the implementation (or construction period) is 13 years from 2019 through 2031. As a result, the planning period extended over 63-years. The first year of the construction period was set as 2019 (the first possible budget year), resulting in a base year of 2032 and a final analysis period year of 2081.

3.3.3.1.2 Compounding, Discounting, and Amortization

The life-cycle cash flows (whether costs or benefits) often fluctuate through time over the planning period. Project costs are incurred primarily at the time of construction while benefits accrue in varying amounts over the project life. Costs spent on construction today cannot be directly compared to the dollars in benefits that will be realized years from now. Even when inflation is not a concern, a rational person prefers one dollar now (a given level of consumption today) more highly than one dollar in the future (the same amount of consumption at some future point in time). Comparison of life-cycle benefits and costs is impossible without temporal aggregation of the cash flows; specifically compounding, discounting and amortization.

Compounding and discounting is the process of equating monetary values over time; measuring the "*time value*" of cash flows (costs and benefits) that occur in different time periods. Compounding defines past sums of money into a single equivalent value. Discounting defines future sums of money into a single equivalent value. This equivalent value is also known as a present value or present worth. Compounding and discounting requires the use of an interest rate which represents society's opportunity cost of current consumption. The same rate is used for both compounding and discounting.

The appropriate rate can be a matter of debate; however, Congress has resolved the dilemma for water resource agencies. The rate used in evaluating water resource projects is set annually, by law (Section 80 of PL 93-251), using a prescribed formula based on the cost of government borrowing. The rate is published each year by Corps Headquarters as an Economic Guidance Memorandum (EGM). The FY 2016 project evaluation and formulation rate is 2.875%. These compounding / discounting rates are typically referred to as the Federal discount rate. The Federal discount rate is used for the Corps formulation, selection of the NED plan, and reporting.

The estimated benefit and cost cash flows expected to occur in time periods following the base year are to be discounted back to the base year using the prescribed interest rate. Since the implementation period for some plan may begin prior to the base year, any estimated NED costs and benefits for that plan expected to be realized before the base year are to be "*compounded*" forward to the base year. That is, for plan benefits or often known as "*benefits during construction*" and costs expected to be realized before the base year, the discounting procedure is applied in reverse, so that the interest rate serves to compound rather than discount those effects to the base year. The same prescribed interest rate is to be used for both compounding benefit and cost streams that occur prior to the base year, and for discounting benefit and costs streams that occur after the base year. The present values of all cash flows are then amortized over 50-years for comparison.

3.3.3.2 Calculation of Transportation Surplus

As discussed previously, the primary benefits of an inland navigation improvement are transportation cost reductions. Another way to view the benefits is to compare the WOPC and WPC transportation benefits (i.e. transportation benefits increase when transportation costs decrease). In **FIGURE 3-23** the transportation benefit is the area between the market demand curve and the LRAC (including delay cost) curve. There are however, two ways to define this market demand in NIM; inelastic and elastic. And there are actually two ways to define elastic demand; constant or piecewise-linear. For the IHNC Lock analysis, all movements were defined as piecewise-linear elastic based on the Wilson, Campbell, and Gleasman "*2010 Shipper Response Models for the Calcasieu Lock and GIWW-West*" report. The inelastic and elastic demands, and the calculation of waterway transportation savings, are briefly discussed below.

3.3.3.3 Cost-Benefit Analysis

Given the itemization of all the various cost categories over the life-cycle for both the WOPC and WPC, the CBA can be completed. Essentially the WPC WOPC costs foregone (benefits) can be compared against the WPC investment cost.

In the model, the various cost categories (waterway savings and system performance statistics) are itemized under four shipper-based equilibrium scenarios (Normal-operations, Scheduled-maintenance, Probabilistic without scheduled maintenance, and Probabilistic with scheduled maintenance). The non-probabilistic scenarios are itemized to allow incremental comparison against the probabilistic scenarios to enumerate risk effects. Additionally multiple forecast scenarios are summarized. The user then manually selects the NED plan from either the Probabilistic (without scheduled maintenance) scenario or the Probabilistic (with scheduled maintenance) scenario with consideration of the forecast scenario variation. Typically the Probabilistic (with scheduled maintenance) scenario is used with the results between the forecast scenarios averaged.

Note that the WOPC costs avoided under the WPC can be itemized as a benefit or they could be subtracted from the WPC investment cost which converts the CBA to a benefit-to-incremental-cost analysis. Either way the net benefits remain the same, however, the benefit-cost ratio BCR) will be higher under a benefit-to-incremental-cost analysis.

The net benefits are calculated by subtracting total economic costs from total economic benefits. Corps planning policy dictates selection of the NED plan as the plan that maximizes net NED benefits. The BCR is calculated by dividing total economic benefits by total economic costs.

3.3.4 Risk and Uncertainty

Corps of Engineers guidelines as presented in the P&G have long recognized that risk and uncertainty is inherent in all phases of the analysis of waterway investments. Here, risk is defined as inputs or potential results that can be described probabilistically, while uncertainty is defined as inputs or potential results that cannot be defined with a probability. Inputs that can be defined probabilistically are modeled stochastically and the modeling results are displayed as expected values (often with minimum and maximum results displayed). Uncertain inputs are often modeled through sensitivity testing.

In the IHNC Lock analysis structural, mechanical, and electrical risk and uncertainty was assumed manageable through cyclical maintenance. The only probabilistic lock service disruption described comes from hurricane events that occur in both the WOPC and WPCs. The service disruption duration and repair costs were similar between the WOPC and all WPCs. Regardless, the hurricane event was simulated in NIM at an annual occurrence probability of 20% (see ATTACHEMENT 1 Construction and Maintenance Event Data).

In the IHNC Lock analysis, as in most studies, the traffic demand forecast scenarios are not probabilistically defined, and as such are analyzed through sensitivity testing. The GEC "*reference*", or most-likely, traffic demand forecast scenario is used to formulate the recommended plan and then the GEC low and high traffic demand forecast scenarios are analyzed to access the economic viability of the recommended plan to varying traffic levels.

3.4 Models

Since the 1970s, the Corps has been performing inland waterway cost-benefit analysis with a system level evaluation. Through the USACE Planning Center of Expertise for Inland Navigation located in the Huntington District's Planning Center of Expertise for Inland Navigation and Risk Informed Economics Division (PCXIN-RED), Navigation Planning Center Branch (CELRH-PX-NC)[1] the Corps has adopted and maintains a set of computerized analytical models for estimating the NED benefits of proposed improvements to the inland navigation system.

The initial decentralized nature of Corps program execution resulted in the early development of several system models. The first model was developed by the North Central Division for the Illinois Waterway in the 1960s. In the early 1970s, with more complex studies on the horizon, a centralized research and development program was initiated within the Office of the Chief of Engineers called the Inland Navigation Systems Analysis (INSA) Coordination Group. In the mid-1970s the Waterway Analysis Model (WAM) and the Flotilla Model were developed. The Flotilla Model evolved into what is now called the Navigation Investment Model (NIM). These two models, WAM and NIM, have been used in a countless number of inland navigation feasibility studies and was utilized in this IHNC Lock analysis.

3.4.1 The Waterway Analysis Model

The WAM is a vessel-level discrete-event stochastic simulation model used to estimate lock performance (i.e., transit time) under a given operating condition, operating policy, defined fleet, and at a specified traffic level. WAM is capable of modeling single, or multiple, navigation projects each with multiple lock chambers. WAM has been used in navigation studies on the Ohio River and its

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[1] *The PCXIN-RED traces its evolution back to a regional center established in 1981 by the former Ohio River Division (ORD). The U.S. Army Corps of Engineers Director of Civil Works then designated LRD's Navigation Planning Center as the National Planning Center of Expertise for Inland Navigation in August, 2003, which was renamed to PCXIN-RED in 2013.*

tributaries for over three decades and a version of WAM was modified into a deep-draft simulation in 1993 and a version was modified to simulate Calcasieu Lock drainage events and develop tonnage-transit curves for the March 2014 Calcasieu Lock Feasibility Report[2].

The current shallow-draft version of WAM-SD-10-01 received HQ Planning Model corporate model certification 15 August 2011; however, it was a short duration certification given anticipation of a new project level vessel simulation model in development being stood up. The new model is still in development and the shallow-draft WAM was required for the IHNC Lock analysis. A HQ Planning Model Certification approved for use in the IHNC Lock analysis was received 9 August 2016.

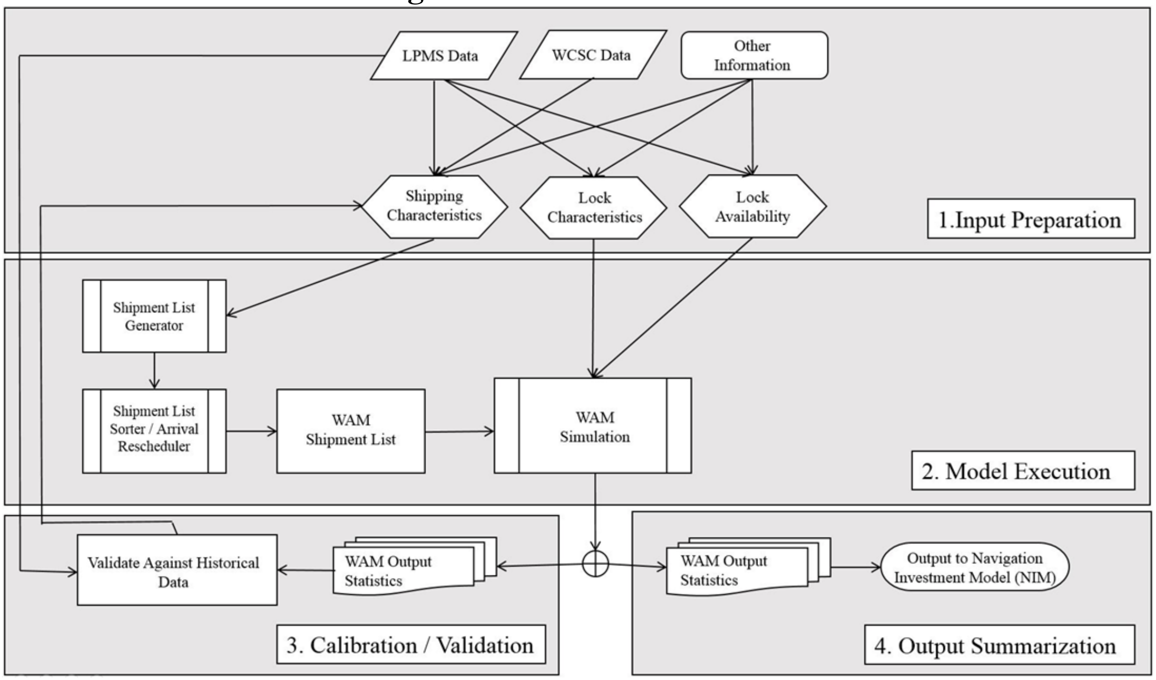
Being a stochastic simulation, WAM uses arrival and processing time distributions derived from historic Lock Performance Monitoring System (LPMS) data. For example, instead of a vessel of a set size arriving every 30 minutes, a large tow can arrive 2 minutes or 2 hours after a smaller tow or recreational vessel, all using values derived from historical distributions. For example, instead of a chambering process taking a fixed five minutes, WAM selects from a distribution of likely values that have been observed historically. ***TABLE 3-2*** shows a simplified representation of a standard WAM lockage.

TABLE 3-2: WAM Lockage Operation Times

Description	Wam Component	LPMS Time
Arrival	Input to WAM from Shipment list	Arrival
Delay	Determined by WAM based on Conditions at Lock	Start of Lockage
Approach	Approach Distribution Fit From Data	Bow Over Sill
Entry	Entry Distribution Fit From Data	End of Entry
Chambering	Chambering Distribution Fit From Data	Start of Exit
Exit	Exit Distribution Fit From Data	End of Lockage

[2] *This Calcasieu version of WAM received HQ Planning Model approval for use 7 November 2012.*

FIGURE 3-25: WAM Modeling Process



WAM modeling consists of 4 basic steps (**FIGURE 3-25**): 1) input preparation; 2) system simulation; 3) calibration and validation; and 4) output summarization. The main input into WAM is derived from LPMS data, which is recorded at the lock and contains information on the characteristics and timing of each lockage operation. Data on chamber closures are also recorded in LPMS. Data on the flotilla processed includes vessel type, number of loaded and empty barges by size, and tonnages by commodity. Waterborne Commerce Statistics (WCS) Center data is used to supplement the LPMS and provides information on barge loading tonnages and commodities as reported by the shippers. Other input information sources include industry interviews, USACE operations information, and USACE engineering information as it relates to future lock performance, transit conditions, and planned outages. All of this information is fed into WAM during the model execution phase. Prior to production of a tonnage-transit curves for input into NIM, base year results are validated against historical LPMS data to insure that WAM is producing reasonable / defendable results.

3.4.2 The Navigation Investment Model

The Flotilla Model developed in the mid-1970s evolved into what is now known as NIM. In 1977 the Transportation Systems Center of the U.S. Department of Transportation sponsored the expansion of the Flotilla Model into the Resource Requirements Model and a Post-Processor program. Additional modifications were made from 1979-80 under the direction of the CELRH-NC, and a third program, the Marginal Economic Analysis Model, was added. Collectively, these three programs (Resource Requirements Model, Post-Processor and the Marginal Economic Analysis Model) were known as the Tow Cost Model (TCM). Further modifications led to the development of the Equilibrium (EQ) Model in the mid-1980s, and the Marginal Economic Analysis Model was dropped. Collectively, the TCM and EQ Model were known as the Tow Cost / Equilibrium (TC/EQ) Models. In the early-1990s structural reliability analytical techniques advanced, allowing for a more quantitative assessment of project maintenance requirements and the probability of unscheduled project closures. In the mid-1990s the TC/EQ Model suite was supplemented with the inclusion of the Life Cycle Lock Model (LCLM), which was developed to estimate the expected transportation impacts of unscheduled closures under both the without- and with-project conditions external to the TC/EQ. During this time period the WAM was also modified to capture re-scheduling effects observed during historic long-duration closure events. In the mid to late-1990s, modernization and expansion of TC/EQ into the NIM began as engineering reliability data multiplied and the need to dynamically link the reliability analysis (LCLM) with a simultaneous investment optimization algorithm. NIM was built by Oak Ridge National Laboratory (ORNL) in collaboration with CELRH-NC / PCXIN.

From 2005-2009 under the U.S. Army Engineer Institute of Water Resources (IWR) Navigation Economic Technologies (NETS) program empirically derived demand elasticity's were developed and NIM was expanded to equilibrate using downward-sloping movement-level demand curves. In 2014, for the Bayou Sorrel analysis, NIM was expanded with waterway route equilibration logic. In 2016, for this IHNC Lock analysis, NIM was expanded to track self-propelled vessels and apply the existing movement-response logic to scheduled service disruption events in addition to unscheduled events.

Like its predecessors, NIM is an annual model which can be described as a spatially-detailed partial-equilibrium waterway transportation cost and equilibrium model. While it is not really designed to estimate the total benefits of a river system, or the benefits the nation would lose if the river system no longer existed (something like a computable general equilibrium model would be needed), it is appropriate to estimate the benefits of incremental improvements to river systems. NIM is a behavioral model which serves two tasks: develop least-cost movement level shipping-plans and estimate equilibrium system traffic levels from a bottom-up movement level analysis. By using detailed data describing the waterways network, the equipment used for towing operations, and the commodity flow volume and pattern, NIM calculates the resources (i.e., number towboats, trip time, and fuel consumption) required to satisfy the demand on a least-cost basis for each movement in the system and how much of that movement demand can move in system equilibrium with a positive willingness-to-pay for barge transportation. NIM received its HQ Planning Model Corporate Certification 14 February 2012.

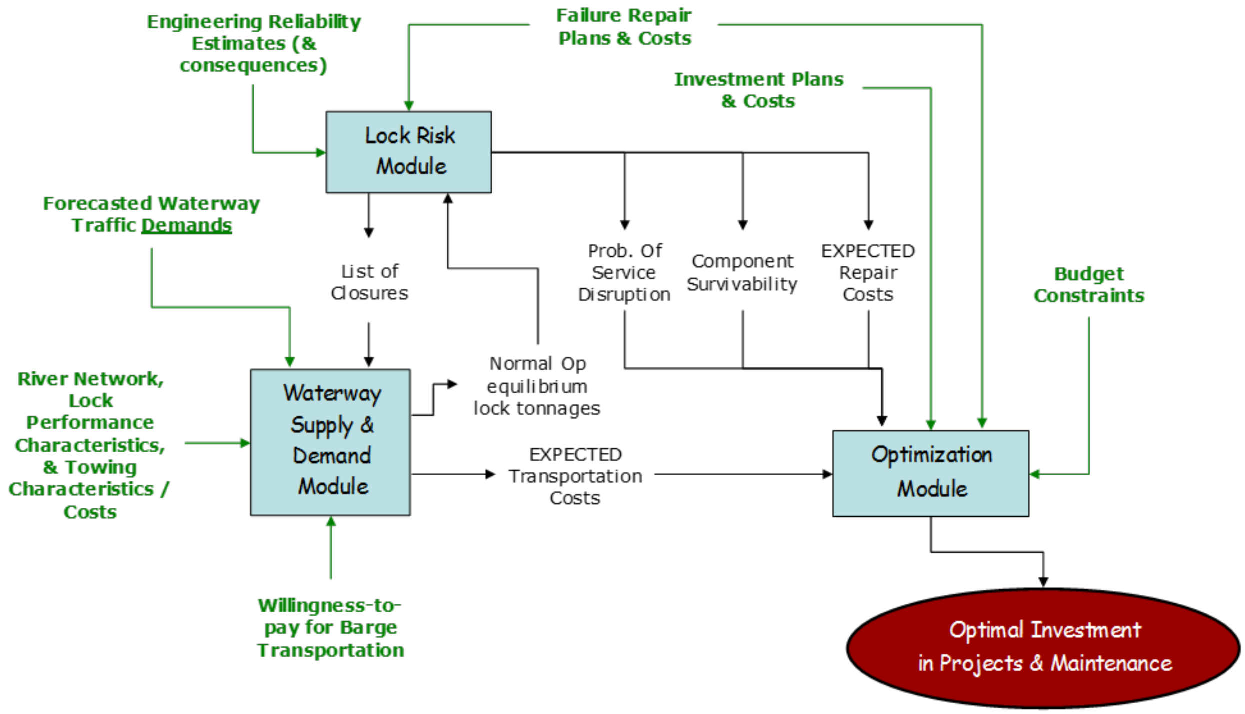
3.4.2.1 Model Development and Structure

Development of a model requires a number of design decisions and technology choices. NIM utilizes a relational database structure which allows flexibility in input and output structure, eliminating model code changes if analysis resolution (e.g. increasing the number of towboat classes considered) and / or assumptions change. Input, output, and execution data is stored in Microsoft Sequel (SQL) Server 2012 database in the PCXIN-RED Inland Navigation Database Warehouse (INDW). Data loading, model execution, and report generation is controlled through a desktop application. The model code is actually housed and executed on the PCXIN-RED application server.

Simulation models fall into two basic categories: event-based and period-based. In an event-based model, a set of events that the model is concerned with are defined, and time moves forward in jumps, as each event takes place. Period-based models divide time into discrete periods of know length (e.g. years). All calculations are made for a given period, and then time is advanced to the next period. Both types of approaches have their advantages and disadvantages. In general, period-based models are easier to formulate and contain simpler calculations, but the assumptions required about averaging of data may be limiting. NIM is classified as a period-based model running on yearly time increments.

The NIM System is composed of three primary modules – the Lock Risk Model (LRM), the Waterway Supply and Demand Model (WSDM), and the Optimal Investment Module (Optimization). The general linkage of the model modules are shown in **FIGURE 3-26**.

FIGURE 3-26: NIM Primary Modules



The LRM Module forecasts structural performance by simulating component-level engineering reliability data (hazard functions and event-trees) to determine life-cycle repair costs and service disruptions. The LRM summarizes the probabilities of reliability driven service disruptions (typically lock closures) for each lock for each component for each year, which are then used by the WSDM and Optimization modules to estimate expected transportation impacts resulting from the service disruptions.

The WSDM Module estimates equilibrium waterway traffic levels and transportation costs given a traffic demand forecast, movement willingness-to-pay, and waterway system performance characteristics. NIM's major economic assumptions are embedded within WSDM.

The Optimization Module organizes and analyzes the investment life-cycle benefit and cost streams and recommends optimally timed investments (what and when).

3.4.2.2 Sectoral, Spatial, and Temporal Simplifying Assumptions

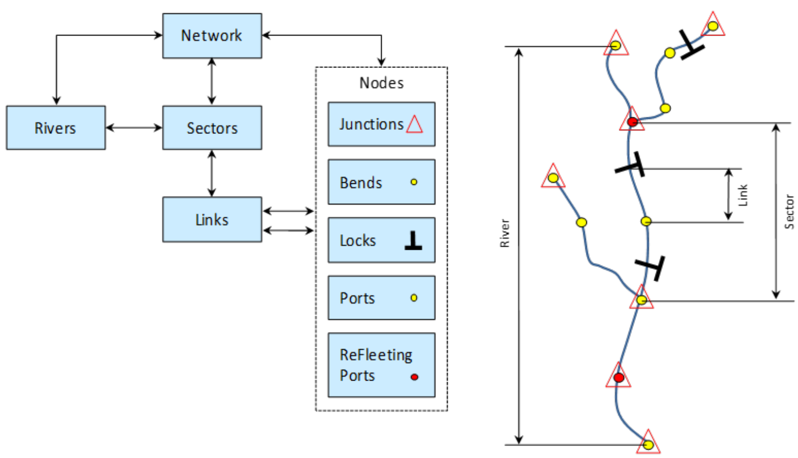
As noted, economic models vary in terms of sectoral, spatial, and temporal detail. Simplifying assumptions are made in empirical models because of data, time, computational, and resource limitations. The keys in making these simplifying assumptions are to clearly understand: (1) the theoretical model that serves as a starting point for the analysis; (2) how the simplifying assumptions deviate from the theoretical model; (3) the reasonableness of the assumptions as compared to what we know about real-world markets; and (4) the implications of the assumptions in terms of biasing and/or reducing the accuracy of the model's results (i.e. the estimation of WPC benefits). As a result, the fundamental sectoral assumption in the NIM model framework is to analyze inland navigation investments under a spatially-detailed barge transportation partial-equilibrium framework. The spatial and temporal detail level in NIM is data driven (i.e. user specified) as discussed in the sections below.

3.4.2.2.1 Spatial Detail

The spatial detail is defined by the model user through the waterway transportation network, and through the aggregation level of the commodity groups and barge types. In the model a commodity origin-destination route and barge type defines the shipment which demands barge transportation. Spatial detail does not come without a cost. Since each and every movement (commodity origin-destination barge type) must be equilibrated with every other movement, each increment of detail increases computational time exponentially.

The NIM link-node network specifies the topology of the inland waterway network and the characteristics of the locks, ports, bends and junctions for each river. In short, the NIM network provides the framework for much of the other NIM data (e.g., movement flows, lock performance characteristics, fees, etc.). **FIGURE 3-27** provides a graphical view of the network data relationships. The network is defined based on a set of nodes and links between the nodes. Nodes can be locks, ports, bends or junctions. Locks and bends represent the points that cause delay based on traffic levels. A network (NIM can store multiple networks) is made up of one or more rivers. Each river is divided into sectors at junctions (e.g., the head and mouth of the river and points where tributaries enter the river). Each sector is then divided into links between nodes. A link is defined with an upstream and a downstream node, length, depth (minimum and average), current speed, and coefficients for calculating tow speed.

FIGURE 3-27: Relationships of the NIM Network Entities



For the IHNC Lock analysis, the 212 5-digit WCS commodity codes moving in the GIWW were aggregated into the 23 GEC commodity groups, the 2,573 docks were aggregated into 476 pick-up / drop-off port nodes, the 20,408 unique barges were aggregated into 16 barge types, the 1,407 unique towboats were aggregated into 5 towboat classes, and the 172 unique self-propelled vessels were aggregated into 6 ship types. This resulted in 12,066 unique commodity origin-destination-route barge type movements in the model.

3.4.2.2.2 Temporal Detail

The model does not simulate individual waterway shipments (e.g., tow), but operates off a movement-level (an aggregation of shipments) cost in discrete annual time periods[3]. To summarize, a movement is defined as the annual volume of shipments for the commodity origin-destination barge type. There are 12,066 unique commodity origin-destination-route vessel type movements defined in the IHNC Lock analysis, each of which are forecasted by year over the planning period.

3.4.2.2.3 Inter-Temporal Detail

Each time period in the model is independent of the other time periods, however, there is an inter-temporal effect interjected into the modeling process through user specification of infrastructure change and through any engineering reliability data included in the analysis.

Lock performance characteristics can be specified by the user to change through time. This allows for currently authorized projects (e.g., Olmsted) to come online and change the waterway system transportation characteristics at the appropriate time. Additionally, the analysis of the WPC alternatives requires the investment to be timed and the characteristics of the waterway system transportation to be adjusted accordingly at the correct times.

Lock performance can also change through time probabilistically through reliability. In this respect, the expected benefits and costs calculated in a given year is dependent upon the results in the previous years. With increasing service disruption through time, expected equilibrium traffic levels can decline as expected capacity declines. If, however, the user desires to model declining demand from increased reliability risk, this must be done through the forecasted demand input (i.e., development of a forecasted demand scenario assuming risk aversion or facility closure from decreased shipment reliability).

3.4.2.3 Network and Movement Detail

Much of the model's spatial detail comes through the waterway transportation network definition. The transportation network not only defines the pick-up / drop-off nodes (476 of them in the IHNC Lock analysis network) but it also defines constraint points in the system (bottlenecks). These constraint nodes can be any obstruction where vessel queuing can occur and congestion effects can be felt. While these constraint nodes can be areas such as bends or one-way channel sections, typically the only constraint nodes modeled are the navigation projects. In the IHNC Lock analysis 9 navigation projects were modeled in the GIWW system.

In order to determine the impact of congestion effects on a movement's transportation costs (and ultimately the movement's equilibrium and transportation surplus), the movement's trip time needs to be estimated. Distances between each model node (both pickup / drop-off nodes and the constraint nodes) are defined through the input data. Additionally, data on current speeds, channel depths, and equipment drag are input and utilized by a speed function and combined with the trip distance to estimate line-haul trip time. Estimating the trip time at the constraint points is a different story and requires the utilization of the lock project tonnage-transit curves.

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[3] While the model's temporal detail is tied to a time period, the user can redefine the definition of a time period through the inputs. For example, instead of running the model as a yearly model over 50 years (i.e. 50-periods), the inputs could be aggregated to a quarterly level and 200 quarterly periods could be run to complete a 50-year life-cycle analysis. As with the spatial detail, increased detail significantly increases the computation time and too much granularity can complicate, if not invalidate, the theoretical framework (e.g. trip times spanning multiple periods).

3.4.2.3.1 Lock Project Maintenance and Reliability

Capacity of the navigation system is a function of the availability of the lock projects. Service disruptions, both from a scheduled maintenance event or an unscheduled failure, can decrease the project capacity in that year, inhibit traffic flow, and increase waterway transportation costs. While NIM itself utilizes an annual period-based framework, impacts from these intermittent events are calculated.

For scheduled maintenance events, engineering / operation maintenance schedules are utilized. Often a new lock will require less frequent and / or shorter duration and / or less cost maintenance. Given that scheduled events are known to shippers, NIM assumes average trip time through the project given the reduced capacity is known and that the movement level equilibrium tonnage and transportation surplus is so estimated.

For unscheduled maintenance events, engineering / operation reliability data is utilized (i.e., probabilities of unsatisfactory performance and event / consequence trees). Given that unscheduled events are not known to shippers in advance, NIM assumes an equilibrium traffic level given known / scheduled maintenance and then adjusts the waterway movement trip cost given the increased average trip times through the project given the unscheduled event. This increase in waterway transportation cost is then weighted into the system statistics given the probability of occurrence in that year.

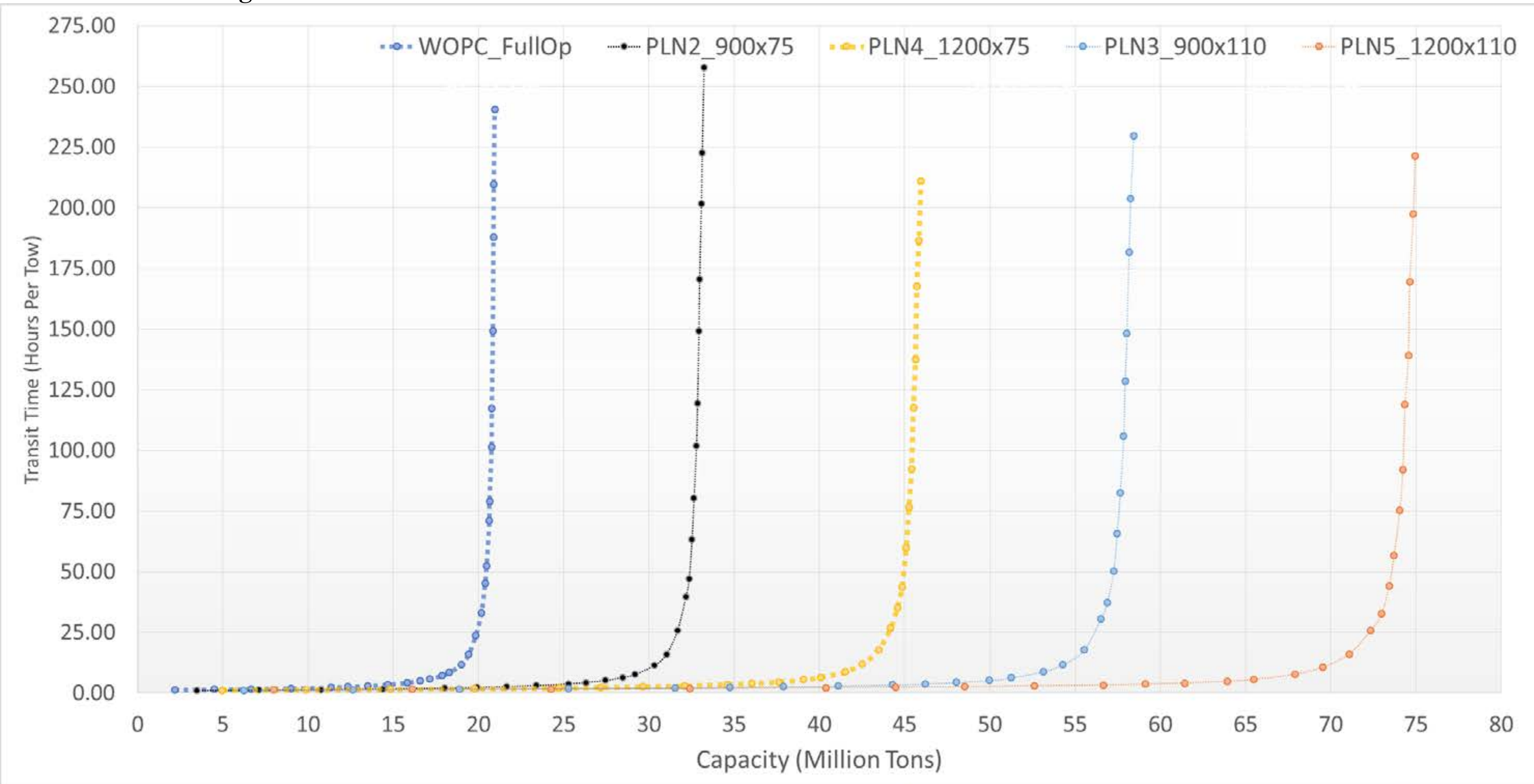
3.4.2.3.2 Tonnage-Transit Curves

At the constraint points (i.e., lock projects), the transit times are characterized by a tonnage-transit curve. As shown in **FIGURE 3-28**, tonnage-transit curve plots an average vessel (e.g., tow) transit time against annual tonnage at the lock project. The transit time not only includes the processing time to transfer to the next pool, but it also includes delay time from queuing resulting from the congestion effect. As utilization of the lock project increases, the delay exponentially increases once persistent queuing starts.

Given a traffic level at the project, the average transit time is pulled from the tonnage-transit curve and applied to each movement transiting the project. All projects transited are polled for transit times along each movement's route and added to the movement's line-haul time to determine the movement's total transportation time.

The tonnage-transit curves are externally derived (typically through vessel-level simulation) and input into the model. Additional detail on the tonnage-transit curve development can be found in the **ATTACHMENT 2 Capacity Analysis**.

FIGURE 3-28: Tonnage Transit Curves for IHNC Lock and Alternatives



3.4.2.3.3 Movement Shipping-Plans

Congestion in the waterway transportation system does not affect all movements equally. In order to determine the impact of congestion effects on a movement's transportation costs, the shipping costs and characteristics of that movement must be known. The shipment characteristics for tows are referred to as the "*shipping-plan*". A shipping-plan is needed for each of the 11,759 non-self-propelled commodity origin-destination-route barge type movements in the model.

The tow shipping-plan drives the shipping cost and is stored in dollars per hour per ton. The tow shipping-plan includes specification of the shipment tow-size, the towboat class used, empty backhaul requirements, re-fleeting points, and tons per trip. Given the movement tonnage and the trip time, a movement cost can be calculated and then compared against the movement's willingness-to-pay for water transportation.

The shipping plans could be specified by the user and given to the model through input; however, this data is not readily available and difficult to compile for large systems and data sets. Instead, NIM is designed to develop a least-cost shipping-plan for each movement which is then calibrated against observed lock project level data. This NIM shipping-plan developer also allows for re-specification of shipping-plans under increased congestion and for what-if scenarios (e.g., new larger 1200' main chamber).

3.4.2.3.4 Movement Level Willingness-to-Pay For Water Transportation

Willingness-to-pay for water transportation is needed to determine the equilibrium traffic level and to calculate the waterway transportation surplus (benefit). As discussed, the willingness-to-pay can be defined as either inelastic or elastic. For the IHNC Lock analysis, all movements modeled were assigned a demand curve based on a study of demand elasticity conducted as part of the March 2014 Calcasieu Lock study.

When utilizing an elastic demand curve, an additional analysis setting / assumption must be specified; whether or not to allow the demand curve to be extrapolated beyond the forecasted demand point. The model can be run under either setting / assumption. The extrapolated demand curves are unbounded and problematic given their propensity to asymptotically approach the x-axis (i.e., infinite tonnage). Typically (and in this IHNC Lock analysis), the elastic demand curves are capped at the forecasted barge transportation demand.

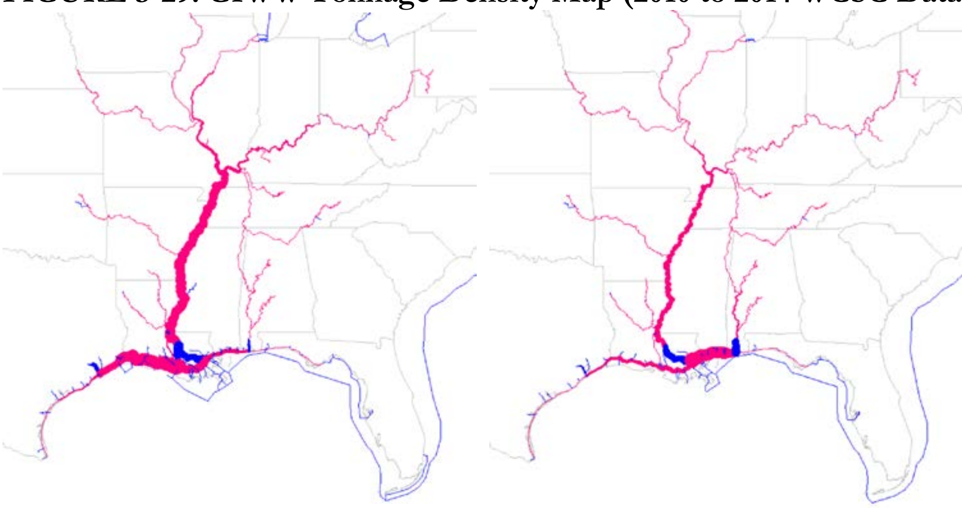
3.4.2.3.5 Movement Closure Response

As discussed in section 3.4.2.3.1, impacts for scheduled and unscheduled events are calculated by NIM. As discussed scheduled events are known in the equilibrium process and then unscheduled event impacts are probabilistically added. In some situations; however, there is a need to account for specific responses to specific complete river closure events and NIM is coded with a closure-response option. For a specified river closure event or events, a selected percentage of selected movements is diverted from the equilibrium tonnage level. Then a specified cost is added to the remaining tonnage in the case of a scheduled event or a specified cost is added to the diverted tonnage in the case of an unscheduled event. This NIM logic was utilized in the IHNC Lock 1,440-hour 24-Hour/Day maintenance event where an alternative Gulfport to Baptiste Collette alternate route is assumed and 50% of traffic during this 2-month period is penalized with an alternative route cost. The remaining 50% of traffic is assumed to divert off the waterway.

3.5 GIWW NIM

As discussed, NIM is data driven and can be set up for analysis of any inland waterway system or sub-system. For the IHNC Lock analysis, for consistency with the Calcasieu and Bayou Sorrel Lock studies, NIM was setup to model movement flows through the nine GIWW lock projects: IHNC Lock, Algiers, Bayou Boeuf, Bayou Sorrel, Calcasieu, Harvey, Leland Bowman, Old River, and Port Allen. Tonnage flows through one or more of these nine lock projects averaged over 2010-2014 is shown in the left pane of **FIGURE 3-29**. In the right pane, the IHNC Lock 2010 to 2014 averaged tonnage flows are shown. While GIWW flows are quite disperse, traffic is predominately flowing on the lower Mississippi River and the GIWW. IHNC Lock traffic is predominately flowing on the GIWW-E to Mobile Bay.

FIGURE 3-29: GIWW Tonnage Density Map (2010 to 2014 WCSC Data)



3.5.1 Inputs

NIM is a data-driven spatially-detailed annual planning-period transportation cost equilibrium model; the development and loading of up to 70 input data tables are required to perform an analysis. The major inputs include:

Determination of the study area, study movement flows, and the definition of the waterway system transportation network.

- WCSC data accuracy.
- Network links and nodes (including link shipping characteristics).
- Commodity grouping.
- Equipment grouping.

WPC construction navigation impacts, and lock project maintenance and reliability assumptions for the WOPC and each WPC.

Lock project tonnage-transit curves for the WOPC and each WPC.

Waterway system traffic demand forecasts specified at a movement level.

Willingness-to-pay for water transportation specified at a movement level.

3.5.1.1 The GIWW Waterway Network Definition

The first step in defining a network in an inland navigation analysis is verification of the WCSC data to make sure it is accurate enough for use. While WCSC data is very accurate in barge origin-to-destination information and barge loading, it does not identify how the barges are grouped into tows. Lock Performance Monitoring System (LPMS) data is very accurate at counting barges and whether they're loaded (or partially loaded) or empty, but tonnage is unreliable. As such, in verifying WCS data, the WCS tonnage through the locks is compared against an LPMS number of loaded barges multiplied by the WCS average loading. As shown in **TABLE 3-3**, WCS data is accurate when compared against the WCS-LPMS target tonnage.

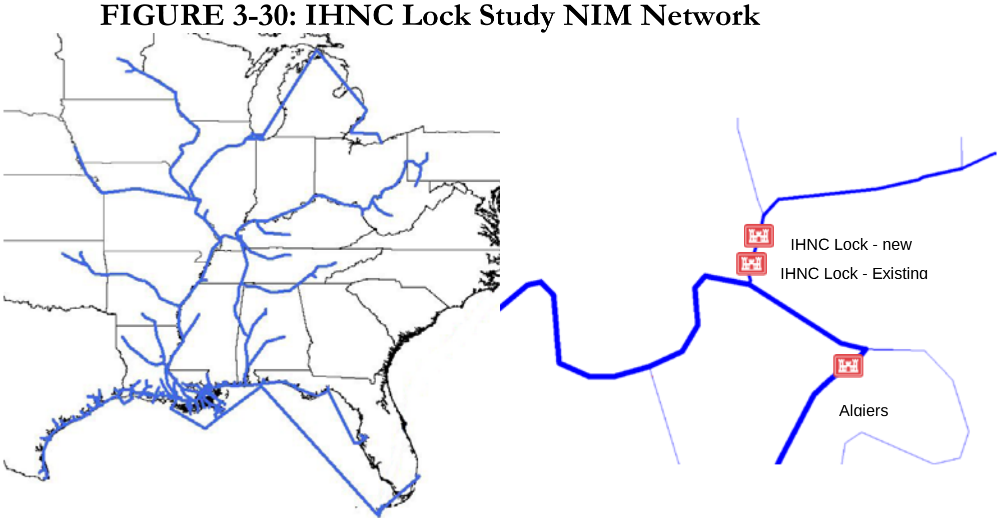
TABLE 3-3: WCS Data Verification (2010-2014 Averaged WCS and LPMS data)

Navigation Lock Project	Number of Loaded Barges				Tonnage			
			Difference				Difference	
	WCS	LPMS	Number	Pct.	WCS	Target *	Number	Pct.
Study Project								
IHNC Lock	7,167	8,462	(1,295)	-18%	15,661,462	15,529,160	132,302	1%
Gulf Intracoastal Waterway								
Algiers Lock	10,197	12,349	(2,152)	-21%	23,014,489	23,542,002	(527,513)	-2%
Bayou Boeuf Lock	12,028	14,389	(2,361)	-20%	25,219,857	25,329,495	(109,639)	0%
Bayou Sorrel Lock	9,066	9,994	(927)	-10%	18,831,342	18,870,287	(38,945)	0%
Calcasieu Lock	15,821	18,250	(2,429)	-15%	38,100,492	38,201,563	(101,071)	0%
Harvey Lock	1,323	2,065	(743)	-56%	2,897,143	2,615,920	281,222	10%
Leland Bowman Lock	15,856	18,483	(2,627)	-17%	37,970,261	37,616,345	353,916	1%
Port Allen Lock	9,379	10,862	(1,483)	-16%	19,485,628	19,999,254	(513,625)	-3%
Old River								
Old River Lock	3,821	4,151	(330)	-9%	7,408,874	7,239,370	169,504	2%

** LPMS number of loaded barges x WCS loaded barge average tonnage.*

As shown in **FIGURE 3-29**, the GIWW WCS dock to dock flows are quite disperse. To simplify modeling, in NIM docks are aggregated into ports which are generally defined as a pick-up / drop-off centroid between the waterway features (e.g., a lock and dam navigation pool, or between river junctions, or between a lock project and a river junction). While the extremities of the network could be trimmed back with little impact to an incremental WOPC and WPC analysis, it is often easier to let the dock aggregate to its nearest port and let the network spatially expand to its full extent. This allows for a more accurate mileage and trip time calculations for movements extending to the extremities of the network; however, this doesn't matter incrementally with changes at the lock project under study. Regardless, the network utilized for the IHNC Lock analysis (**FIGURE 3-30**) extends to all rivers visited by GIWW traffic flows.

FIGURE 3-30: IHNC Lock Study NIM Network



As shown in the right pane of **FIGURE 3-30**, given that the new IHNC Lock will be located north of the existing site, the network was structured with a lock node at this new site. The ports at either end of the IHNC were designated at re-fleeting ports so that the NIM tow-size limit parameters could be utilized to adjust the tow-size in the canal area as it changes between the existing / WOPC and the various WPCs.

The waterway network also includes specification of the fuel tax and fuel tax waterways as defined by the Inland Waterways Revenue Act of 1978, the Water Resources Development Act of 1986, and the Achieving a Better Life Experience (ABLE) Act of 2014. Since fuel tax waterways are defined at the Sector level Junctions must also be placed between fuel tax and non-fuel tax waterway reaches.

Additionally, the waterway network is defined by the movement commodity grouping, link level shipping characteristics, and equipment characteristics and costs. Prior to analyzing forecasted traffic demands and determining the equilibrium tonnage level for each movement in the system, NIM must estimate a shipping-plan and cost for each defined movement. This is accomplished by determination of the movement least-cost waterway shipping-plan given the waterway link constraints. As such, the shipping-plans are calibrated and the model is validated (see section 3.5.2).

Movements were aggregated to the GEC commodity group used in the forecasted demand work. As noted in section 3.4.2.2.1, for the IHNC Lock analysis, the 212 5-digit WCS commodity codes moving in the GIWW were aggregated into the 23 GEC commodity groups, the 2,573 docks were aggregated into 476 pick-up / drop-off port nodes, the 20,408 unique barges were aggregated into 16 barge types, the 1,407 unique towboats were aggregated into 5 towboat classes, and the 172 unique self-propelled vessels were aggregated into 6 ship types. This resulted in 12,066 unique commodity origin-destination-route barge type movements in the model.

Tow equipment costs were based on IWR's Informa Economics FY2009 Shallow-Draft / Inland Vessel Operating Costs, dated 5 December 2010. These FY2009 costs were indexed up to the FY 2016 price level using the Bureau of Labor Statistics' Inland Waterways Towing Transportation Producer Price Index. Deep-draft vessel costs were based on HQUSACE EGM 15-04 (Maritime Strategies International, Ltd.). These FY2013 costs were indexed up to the FY2016 price level using the Bureau of Labor Statistics' Deep Sea Freight Transportation Producer Price Index.

3.5.1.2 Maintenance and Reliability Assumptions

The reliability of the structures is determined by performing a reliability analysis or review on all the major mechanical and structural components to determine the likelihood of extended service disruptions or closures due to lock failure. Life-cycle maintenance assumptions, and in particular the lock service disruptions they can create, are often critical in the analysis of lock investment decisions. Not only are scheduled maintenance needs applicable, but also service disruption risk from unscheduled repairs.

In the case of the IHNC Lock study, while requiring regular maintenance, the lock's structural, electrical, and mechanical systems have either been determined reliable, or to have insignificant consequence to navigation service if a failure is experienced. In short, unscheduled failures and repairs are not expected and not included in this IHNC Lock analysis. In the gulf region, however, hurricane events can impact lock performance. As a result, unscheduled lock closure resulting from hurricane events have been included in this analysis. A detailed discussion of the cyclical maintenance assumption assumed in the economic modeling is summarized in ATTACHMENT 1 Construction and Maintenance Event Data.

3.5.1.3 Lock Project Tonnage-Transit Curves

While actually part of the NIM network definition, the lock project tonnage-transit curves are often discussed separately given the intense vessel level simulation modeling required. Tonnage-transit curves are required for each lock project specified in the system, and in situations where chamber service disruption is modeled, a unique tonnage-transit curve is required for each service disruption event. For the eight non-IHNC Lock projects, only the full-operation tonnage-transit curves developed as part of the March 2014 Calcasieu Lock Feasibility Report and the 2015 Bayou Sorrel Lock analysis were needed. For the existing / WOPC IHNC Lock and the proposed WPCs, a capacity analysis was performed as documented in ATTACHMENT 2 Capacity Analysis. A summary of the full-operation capacities is shown in **TABLE 3-4**. For the existing / WOPC IHNC Lock and the proposed WPCs service disruption tonnage-transit curves were also developed.

The IHNC Lock curves, however, were generated using LPMS data, which records the processed flotilla as it arrives at the end of the IHNC. Multi-cut tows break into powered cuts (canal tows) using trip vessels for their transit through the canal and through the IHNC Lock. At the end of the canal the arriving flotilla is reconfigured and the trip vessels released. As a result, the tonnage-transit curve represents the arriving flotilla average vessel transit time and not the canal vessel average transit time. The NIM network was loaded and calibrated to calculate the re-fleeting costs at both ends of the canal, to vary the canal tow-size between alternatives, and account for the cost of the trip vessels. Prior to loading the tonnage-transit curves discussed in ATTACHMENT 2 Capacity Analysis into NIM the curves were adjusted to reflect an average transit time per canal tow at a given annual tonnage level rather than the average transit time per arriving flotilla. The curves were essentially shifted left by a ratio of canal tows / arriving flotilla.

TABLE 3-4: Capacity Curve Summary

Navigation Lock Project	Chamber Dimensions	Full-Operations Capacity		
		Tonnage	Average Processing Time (hrs)	Optimal Lockage Policy
IHNC Lock (GIWW East) *				
Existing / Without-Project – 75' x 640' x 32'	75' x 640' x 31.5'	20,900,000	1.01	6-up / 6-down
Alternative #1 – 110' x 900' x 22'	110' x 900' x 22'	58,200,000	0.81	6-up / 6-down
Alternative #2 – 110' x 1200' x 22'	110' x 1200' x 22'	74,800,000	0.89	6-up / 6-down
Alternative #3 – 75' x 900' x 22'	75' x 900' x 22'	33,100,000	0.78	6-up / 6-down
Alternative #4 – 75' x 1200' x 22'	75' x 1200' x 22'	45,900,000	0.78	6-up / 6-down
GIWW West **				
Algiers Lock	75' x 760' x 13'	35,200,000	0.75	FIFO
Bayou Boeuf Lock	75' x 1156' x 13'	58,500,000	0.36	6-up / 6-down
Calcasieu Lock	75' x 1200' x 13'	78,900,000	0.99	FIFO
Harvey Lock	75' x 425' x 12'	13,600,000	0.64	FIFO
Leland Bowman Lock	110' x 1200' x 15'	86,300,000	0.31	6-up / 6-down
GIWW Alt. Route M.C. - P.A. **				
Bayou Sorrel Lock	56' x 797' x 14'	32,500,000	1.00	6-up / 6-down
Port Allen Lock	84' x 1202' x 14'	38,300,000	1.28	FIFO
Old River **				
Old River Lock	75' x 1200' x 11'	46,800,000	0.72	FIFO

** Source Attachment 2 Capacity.*

*** March 2014 Calcasieu Lock Feasibility Report and the 2015 Bayou Sorrel Lock analysis.*

3.5.1.4 Willingness-to-pay for water transportation

As discussed in section 3.3.3.2, NIM can equilibrate system traffic levels from either a movement level fixed quantity (inelastic) or price-responsive (elastic) assumption. For the IHNC Lock analysis piecewise-linear elastic movement level demand was assumed as defined by the Wilson, Campbell, and Gleasman "*2010 Shipper Response Models for the Calcasieu Lock and GIWW-West*" analysis developed for the March 2014 Calcasieu Lock Feasibility Report.

The piecewise-linear "*price responsive*" elastic demand curve show an n% increase in water price results in an x% decrease in tonnage being transported by barge. In the future, as system congestion increases and / or system reliability decreases, water transportation costs increase. For a movement, when the water price increases (regardless of the amount of increase), part of the movement tonnage is removed from the waterway (based on location on the demand curve). In short, as water price increases, parts of all movements are removed. The equilibrium traffic level under an elastic movement level demand assumption is more sensitive to waterway price changes than under an inelastic movement level demand assumption. Incrementally, between a WOPC and WPC, often the elastic or inelastic assumption is inconsequential.

Under the elastic demand assumption for barge transportation, in order to determine how increases in water costs affect barge transportation NIM uses the water rate developed from the transportation rate study used to perform an inelastic movement level demand analysis[4].

[4] The GIWW rates are derived primarily from two separate Texas A&M University Texas Transportation Institute (TTI) studies, the first completed in February 2011 which focused on GIWW West samples, and the second completed in January of 2013 which focused on GIWW East samples.

As an example, suppose the base water rate for a particular movement is $8.00 / ton (and for simplification say there are no overland legs or assessorial charges). In the future, as system congestion increases and / or system reliability decreases, NIM calculates a new water transportation cost. Let's assume it is now $9.50 / ton. NIM then calculates the movement's cost increase of $1.50 ($9.50 - $8.00). Under an inelastic equilibrium assumption NIM calculates the new water rate as $9.50 (base rate of $8 / ton plus $1.50). The movement's rate is less than its WTP (say the least-costly all-overland rate is $12 / ton, or a base rate-savings of $4 / ton) so the entire movement demand stays on the water. Its rate-savings is reduced from $4 / ton to $2.50 / ton. Its consumer surplus a.k.a. rate-savings is $2.50 / ton times the tonnage. Under the elastic equilibrium assumption NIM calculates that the water price has increased 18.8 percent (1 - $9.50/$8). The percent of quantity is looked up on the movement's demand curve and the tonnage calculated. This quantity of tonnage is something less than its total demand and less than in the inelastic example immediately above. Its consumer surplus is an integration under the elastic demand curve to this new water price.

3.5.1.5 Movement Closure Response

The assumption under the scheduled 1,440-hour 24-Hour/Day maintenance event was the availability of an alternative Gulfport to Baptiste Collette alternate route (the Chandeleur Sound Alternate Route). According to the Gulf Intracoastal Canal Association (GICA) only 50% of the traffic during the period is assumed to take this alternative route and the remaining traffic is assumed to divert off the waterway routing in the effected year. In short, in the 1,440-hour event year, 1/12 of the annual equilibrium traffic through IHNC Lock is diverted from the equilibrium solution and the traffic's transportation surplus is removed. Then additional waterway transportation cost is added to the remaining 1/12 of the annual equilibrium traffic through IHNC Lock for the additional Chandeleur Sound Alternate Route transit.

3.5.1.6 Forecasted Movement Demands

The waterway system traffic demand forecasts were developed off the Gulf Engineers and Consultants (GEC) "*Vessel Traffic Forecast for the Gulf Intracoastal Waterway System as it Relates to the OHNC Lock Economic Update Study*", dated July 2015. To utilize the GEC traffic demand forecasts, the 23 GEC commodity level forecast indices were applied to the 2013 WCS shipments transiting one or more of the nine lock projects specified in the GIWW system. The development of the GEC traffic demand indices is covered in ATTACHMENT 3 GEC Traffic Demand Forecasts.

3.5.2 Verification, Calibration, and Validation of Shipping-Plans

NIM, like any model, requires validation that it is capable of replicating observed shipper behavior and system performance / operating characteristics. To determine individual movement level equilibrium, and ultimately system equilibrium, movement shipping-plan characteristics and the shipping-plan cost must be known. There are three primary calibration steps: calibration of loaded barge flows; calibration of empty barge flows (movement barge dedication); and calibration of the shipping-plans.

Remember that WCS data only provides annual origin-to-destination barge flows by commodity[5]; information on shipment tow-size, towboat utilization, and empty return characteristics is not available for individual movements. Tow characteristics are only recorded by the Lock Performance Monitoring System (LPMS) at each of the locks, albeit at a past-the-point rather than at an origin-to-destination level. As such, the first thing NIM must do is determine shipping-plans for each movement analyzed in the study area. Specifically, the model requires calibration of movement empty barge backhaul flows,

[5] *WCS TOWS does contain towboat trips, however, the data is incomplete and matching the towboat data to barge data has proved unsuccessful to date.*

movement tow-sizes (including towboat type), and movement re-fleeting (if applicable). During this calibration process, the description of the waterway system being modeled is fine-tuned so the model most accurately replicates observed shipping behavior in the system.

Given the network transportation constraint parameters, NIM essentially creates and costs all allowable movement shipping-plans and selects the least-cost shipping-plan for each movement. This process however, requires calibration and validation. Unfortunately, movement level targets are not available and the validation is achieved by comparison of the model results against statistics observed and recorded at the navigation projects in the system. In short, NIM calibrates movement level shipping-plans to replicate the observed lock project level vessel fleet characteristics. Once the network link shipping characteristic parameters are set to where lock project fleet targets (e.g., number of tows, average tow size, etc.) are replicated, the model is considered valid and equilibrium what-if tests can be performed.

To verify, calibrate, and validate NIM, first the calibration targets are required. The calibration targets represent lock performance statistics that the model should replicate in order to be considered verified and validated. For the IHNC Lock analysis NIM was calibrated and validated against an average of 2010 through 2014 WCS and LPMS data. Multiple years are used for a smoothing of the data to avoid individual year irregularities. Second, the NIM network transportation constraint parameters are calibrated.

3.5.2.1 Lock Tonnage and Number of Loaded Barges Verification

The origin to destination WCS tonnage flows loaded into NIM are converted to loaded barge trips, which can then be used to tabulate the number of loaded barges transiting each navigation project. Through a barge draft algorithm NIM has the capability to calculate barge loadings for each movement based on route depth restrictions, the barge type loading capacity, and the commodity density. However, since the data are available, and barge loading characteristics are not expected to vary over the planning period in the IHNC Lock analysis, the model is supplied the WCS barge loading for each movement. As a result, the model simply calculates the required number of barge trips to move the tonnage by dividing the annual tonnage by the average barge loading. As such the number of loaded barges target is more a verification test (rather than a validation test). NIM output display the WCS tonnage and number of loaded barges given the movement inputs loaded (as shown in **TABLE 3-3**).

3.5.2.2 Number of Empty Barges Targets

The derivation of the target number of empty barges through each navigation project is not as straightforward as the tonnage and loaded barge targets. The lock number of empty barges target was developed by the equation below. By taking the minimum of either 1 or the LPMS empty to loaded barge ratio, the target is capped to no more than 50% empty.

$$\text{Lock No. of Empty Barges} = \text{MIN}\left(1\ ,\ \frac{\text{LPMS No. of Empty Barges}}{\text{LPMS No. of Loaded Barges}}\right) \times \text{Target No. of Loaded Barges} \qquad (1)$$

Movement level empty trips are recorded by WCS, however, the data files have been found to be incomplete (although improving through time). As a result, backhaul characteristics between specific origin-destinations can only be estimated. Empty barge flows in NIM are controlled through a movement level barge dedication factor specifying how dedicated the loaded barges are to the movement. This is done at the movement level so that the loaded front-haul movement can be cost with applicable charges for empty return trips.

If the dedication factor is 0.0, the barges are totally undedicated, meaning that when they have finished the loaded trip from the movement's waterside origin to its waterside destination, they are free to move to another movement and are no longer part of the movement's cost calculation. If the dedication factor is 1.0, the barges are totally dedicated to the movement, meaning that when they have finished the trip from the movement's origin to its destination, they are required to move empty back to the movement's origin. If the dedication factor is between 0.0 and 1.0, the barges are partially dedicated, and the dedication factor indicates what portion of the set of barges must make the trip back to the movement's origin empty.

3.5.2.3 Empty Barge Calibration

While the movement dedication factors can be manually set and adjusted by the user, an automated calibration program called the Movement Barge Dedication Factor Calibrator was developed. In this process, the dedication factor is assigned using a set of linear programming problems. In the first linear program the objective is to minimize the deviation from the target number of empty barges at each navigation project, given the path that each of the movements is taking. Solving this, the program determines a total "*best deviation from targets*" value. In general, there may be several assignments of dedication factors to movements that will achieve this best deviation. Tanker barges are more likely to be dedicated than are hopper barges, due to the nature of the cargo that they carry. The second linear program attempts to maximize the dedication factors for the tanker classes of barges, and minimize the dedication factors for the hopper classes of barges. Using this objective and the added constraint that the total deviation is equal to the "*best deviation*" found in the first linear program, the model determines a final setting of the dedication values which are then stored.

The empty barge flows are then aggregated and summarized at each navigation project in the system and compared against observed behavior. As shown in *TABLE 3-5*, calibration of movement level dedication factors reproduce system empty barge flows quite well.

TABLE 3-5: Empty Barge Calibration

Navigation Lock Project	Number of Empty Barges				Percent Empty			
	Estimated Target *	NIM Output	Difference		Estimated Target **	NIM Output	Difference	
			Number	Pct.			Absolute	Pct.
Study Project								
IHNC Lock	5,800	5,800	0.2	0%	44.0%	44.0%	0.0	0%
Gulf Intracoastal Waterway								
Algiers Lock	7,558	7,558	0.2	0%	41.7%	41.7%	0.0	0%
Bayou Boeuf Lock	9,834	9,834	0.2	0%	43.9%	43.9%	(0.0)	0%
Bayou Sorrel Lock	5,938	5,938	0.1	0%	37.4%	37.4%	0.0	0%
Calcasieu Lock	11,384	11,384	0.1	0%	39.9%	39.9%	(0.0)	0%
Harvey Lock	1,312	1,312	(0.0)	0%	48.9%	48.9%	0.0	0%
Leland Bowman Lock	11,417	11,417	0.1	0%	39.9%	39.9%	0.0	0%
Port Allen Lock	6,428	6,428	0.0	0%	38.6%	38.6%	0.0	0%
Old River								
Old River Lock	3,898	3,898	0.0	0%	49.6%	49.6%	0.0	0%

** WCS adjusted averaged 2010-2014 LPMS data.*
*** Averaged 2010-2014 LPMS data.*

Since the empty barge flows are generated from loaded movements through the movement's dedication factor, when the model is exercised with a future traffic demand, the empty barge flows automatically adjust as the loaded barge flows adjust to equilibrium. Given that the demand growth and equilibrium mix of movements could, and most likely will be, different than in the calibrated year, the percent empty barges at the projects can, and most likely will, vary from the values shown. For an extreme example, say the demand for movements in the system with 0.0 barge dedication factors decline through time to zero, while demand for movements in the system with 1.0 barge dedication factors increase. Through time the percent empty at all projects will rise to 50% empty as more and more trips in the system require empty barge returns.

3.5.2.4 Tow-size and Towboat Horsepower Targets

Targets and calibration of the shipping-plan tow-size and towboat class is much more complex than calibration of the movement barge dedication factors. These shipping-plan characteristics are interrelated; larger tow-sizes require larger towboats. As such the network parameters used in the tow-size and horsepower specification are calibrated together.

The lock project average barges-per-tow (tow-size) and the barges-per-tow distribution for each of the nine lock projects in the analysis were calculated from 2010 through 2014 LPMS data. The IHNC Lock distributions; however, required adjustment. In the LPMS data, vessel data is recorded as the flotilla arrives at the canal and not as the flotilla transits the canal and IHNC Lock. Multi-cut flotilla are broken into powered cuts utilizing "*trip vessels*" to transit the canal. Currently (2010-2014), 36% of the flotilla's arriving at the canal require multiple cuts through IHNC Lock and are broken into powered cuts with the use of trip vessels. The overwhelming majority of the multi-cut flotilla require 2-cuts (i.e., one trip vessel).

While MVN directed the assumption that tow-sizes arriving at the canal would not change with implementation of a WPC, an advantage of the new larger lock chambers is the reduction in the number of arriving flotilla requiring breaking and the use of trip vessels. To capture the re-fleeting costs and trip vessel costs in the canal, and the differences between the WOPC and WPCs, the NIM network was set-up with re-fleeting ports on either end of the canal and tow-size limits were specified in the canal to control the tow-sizes under each alternative. Shipping-plan tow-size selection in the entire network is influenced through link level tow-size limits which specify a maximum barges-per-tow limit by barge type. The shipping-plan can up-size or down-size at specified re-fleeting ports (e.g., on either end of the canal). The NIM shipping-plan port-to-port algorithm then essentially creates and costs all "*allowable*" movement shipping-plans and selects the least-cost shipping-plan for each movement. The tow-size limit constraints limit and influence the selection of the least-cost shipping-plan tow-size. As such, tow-sizes required calibration in both the WOPC and each WPC scenario. The estimated target number of canal tows for the WOPC and each WPC are shown in **TABLE 3-6**. As the chamber sizes increase, fewer arriving flotilla require multi-cutting and fewer trip vessels. With the smallest new lock plan (75' x 900') trip vessels are reduced by 23%. The incremental differences in trip vessels between the new lock alternatives; however, are relatively minimal given the arriving flotilla tow-size and that the majority of multi-cut flotilla only require 2-cuts in the existing IHNC Lock chamber (75' x 640'). As can be noted in **TABLE 3-6**, the existing / WOPC targets are not straight LPMS data since NIM cannot be expected to replicate data it is not loaded with. The lock number of tows target was developed by the equation (2) below.

TABLE 3-6: Target Number of Canal Vessels

Year	LPMS			NIM Targets: Existing Condition WCS adjusted LPMS			NIM Targets: Alt.#1 110' x 900' x 22'		NIM Targets: Alt.#2 110' x 1200' x 22'		NIM Targets: Alt.#3 75' x 900' x 22'		NIM Targets: Alt.#4 75' x 1200' x 22'	
	Arriving Flotilla	Add. Trip Vessels	No. of Canal Tows	Arriving Flotilla	Est.Add. Trip Vessels	No. of Canal Tows	Est.Add. Trip Vessels	No. of Canal Tows	Est.Add. Trip Vessels	No. of Canal Tows	Est.Add. Trip Vessels	No. of Canal Tows	Est.Add. Trip Vessels	No. of Canal Tows
2010	7,260	2,408	8,828	6,420	2,129	8,549	131	6,550	18	6,437	210	6,629	99	6,519
2011	6,314	2,322	7,542	5,220	1,920	7,140	150	5,370	16	5,236	244	5,464	111	5,331
2012	6,586	2,494	8,232	5,738	2,173	7,911	152	5,890	43	5,781	315	6,053	213	5,951
2013	6,050	2,346	7,444	5,098	1,977	7,074	169	5,266	68	5,166	397	5,494	301	5,398
2014	5,984	2,526	7,477	4,951	2,090	7,041	199	5,149	98	5,048	465	5,416	367	5,318
AV.	6,439	2,419	7,904	5,485	2,058	7,543	160	5,645	48	5,534	326	5,811	218	5,703
			NIM Targets :			7,543		5,645		5,534		5,811		5,703

SOURCE: 2010-2014 LPMS and WCS data.

The lock project average horsepower and horsepower distribution targets for each of the nine lock projects in the analysis were also calculated from 2010 through 2014 LPMS data. Since the LPMS database does not track vessel horsepower, the LPMS recorded vessel number was matched to horsepower data from the WCS TOWS master vessel database table. Only 186 of the 1,407 unique towboats in the study area were not located in the WCS data (i.e., an 87% sample).

$$\text{Lock No. of Tows} = \frac{\left(\text{Target No. of Loaded Barges} + \text{LPMS No. of Empty Barges}\right)}{\text{LPMS Av. Barges per Tow}} \quad (2)$$

Horsepower selection in the NIM port-to-port algorithm least-cost shipping-plan is influenced through a link level towboat class efficiency factor. Each towboat class is identified with a maximum number of barges per tow it can maneuver by barge type. This efficiency can be reduced by towboat class by network link. Similar to the tow-size limit link constraints, the towboat efficiency factors limit and influence the selection of the least-cost shipping-plan towboat class.

3.5.2.5 Shipping-Plan Calibration

If movement tow-sizes and towboat types were set based solely on the physical limitations of the river and the towing capacity of the equipment, NIM would tend to produce shipping-plans with larger tows and smaller towboats than historically observed. This occurs because NIM calculates the resources (i.e., number towboats, trip time, and fuel consumption) required to satisfy the demand on a least-cost basis. Because of economies of scale, the smallest towboat to move the largest tow is the least-cost shipping plan, however, the world is not perfect and other factors are considered in the shipping-plan determination.

Unlike the calibration of empty barge flows in the system where movement dedication factors are adjusted, calibration of the movement shipping-plans involves two sets of calibration parameters specified at the river link or segment level (rather than at the movement level). When the model develops a shipping-plan for a movement, it considers all the river segment restrictions in its route. To account for the factors causing shippers to use smaller tow-sizes than possible, NIM contains a calibration parameter specifying river segment tow-size limitations. To account for the factors causing shippers to use larger horsepower towboats than possible, NIM contains a calibration parameter specifying river segment towboat class efficiency limitations. These two calibration parameters are interrelated in their effect on the selection of a movement's least-cost shipping plan and ultimately the fleet distributions observed at each navigation project.

Given a specified river segment tow-size limit and towboat class efficiency characteristic NIM calculates the least-cost shipping-plan for each movement in the system. Note that this shipping-plan might involve multiple waterway legs, each having their own tow-size and towboat characteristics. The shipping-plans for all the movements can then be aggregated and summarized at each navigation project in the system and compared against observed behavior (i.e., target number of tows and average horsepower).

Shipping-plan calibration is a sequential process involving iterative cycles; at each step in a cycle specific static components of the model's waterway system description / network (i.e., link tow-size limits and / or towboat class efficiency factors) are adjusted, the model is exercised at an observed historic level, and results are compared with corresponding target values.

In the past (late 1970's through mid-1990's) these calibrations were completed essentially manually; however, NIM now has automated routines to fine-tune the calibration parameters to the user specified target statistics (the Sector Tow-size Limits and Sector Towboat Efficiency Factor Calibrators). These auto tow-size and towboat type calibration programs use a heuristic approach to minimize the difference between the model's least-cost shipping plan tow configurations and the target (observed) lock statistics in the system. The calibration process begins by determining summary lock statistics and comparing them to the specified targets. It calculates three "*offness*" measures based on: (1) difference in the number of tows ("*offTows*"), (2) difference in the number of tows of each size ("*offTowSize*"), and (3) difference in average horsepower ("*offHorsepower*"). In each case, the absolute difference between the model results and the target at each lock is weighted by the lock's "*calibration weight*" which reflects the importance of the lock in the overall analysis. Generally speaking this heuristic approach generates a set of potential changes to each sector's tow-size and towboat constraints, regenerates all the movement shipping plans under each changed constraint one at a time, and then chooses the single change that produces the greatest improvement. This process continues until no significant improvement can be made. This automated calibration process is very CPU intensive, and to speed up the calibration process NIM allows the specification of a sector range to consider in calibration (i.e., not all sectors need to be considered for adjustment).

These three offness values are measured independently, but they are related. In general, as the number of tows at a lock decreases, the size of the tows going through the lock and the average horsepower of the towboats will tend to increase. For an overall measure of how well the model parameters have been calibrated to achieve the target values, a single system-wide "*calibration fitness*" value is calculated.

To calculate the calibration fitness value these three offness measures are combined. For the IHNC Lock analysis the lock project weights and offness weighting factors used were:

IHNC Lock weighting factor = 1

Algiers, Harvey, and Port Allen Locks weighting factor = 0.75 each

Old River Lock weighting factor = 0.5

Bayou Boeuf, Bayou Sorrel, Calcasieu, and Leland Bowman Locks weighting factor = 0.1 each

offTows weighting factor = 1

offHorsePower weighting factor = 1

offTowSize weighting factor = 500

Lock project weights were set according to proximity and commonality of traffic with IHNC Locks. NIM calibration results for the existing / WOPC and each WPC are shown in **TABLE 3-7** though **TABLE 3-10**. The WPC's should only alter the IHNC Lock fleet and the fleet at the other lock projects in the study area remained the same as the WOPC. The WPC canal tow targets were not hit as close as would have been desired, but each WPC was consistently short 19-21% so incrementally the results between alternatives should be reliable.

TABLE 3-7: Plan 1: Existing / WOPC Calibration Results

Navigation	Number of Canal Tows				Average Canal Tow Barges Per Tow				Average Horsepower			
	Estimated	NIM	Difference		LPMS	NIM	Difference		LPMS	NIM	Difference	
Lock Project	Target *	Output	Count	Pct.	Target **	Output	Abs.	Pct.	Target ***	Output	Count	Pct.
Study Project												
IHNC Lock	7,543	7,577	(34)	0%	1.7	1.7	0	0%	1,604	1,693	(89)	-6%
Gulf Intracoastal Waterway												
Algiers Lock	6,820	6,977	(157)	-2%	2.7	2.6	0	2%	1,698	1,675	23	1%
Bayou Boeuf Lock	11,163	7,872	3,291	29%	2.0	2.8	(1)	-42%	1,405	1,500	(95)	-7%
Bayou Sorrel Lock	4,588	4,679	(91)	-2%	3.5	3.4	0	2%	1,884	1,629	255	14%
Calcasieu Lock	11,658	11,495	163	1%	2.4	2.5	(0)	-1%	1,737	1,179	558	32%
Harvey Lock	2,030	2,023	7	0%	1.3	1.3	(0)	0%	1,279	1,544	(265)	-21%
Leland Bowman Lock	11,536	11,216	320	3%	2.5	2.6	(0)	-3%	1,729	1,359	370	21%
Port Allen Lock	5,517	5,515	2	0%	3.0	3.0	(0)	0%	1,738	1,606	132	8%
Old River												
Old River Lock	2,286	2,175	111	5%	3.4	3.6	(0)	-5%	1,962	1,723	239	12%

** Sum of WCS loaded barges plus estimated empty barges (using averaged 2010-2014 LPMS percent empty) divided by averaged 2010-2014 LPMS barges per*
*** Averaged 2010-2014 LPMS data.*
**** Averaged 2010-2014 LPMS vessels utilizing WCS vessel horsepowers.*

TABLE 3-8: Plan 2, 75' x 900' Calibration Results

Navigation	Number of Canal Tows				Average Canal Tow Barges Per Tow				Average Horsepower			
	Estimated	NIM	Difference			NIM	Difference		LPMS	NIM	Difference	
Lock Project	Target *	Output	Count	Pct.	Target **	Output	Abs.	Pct.	Target ***	Output	Count	Pct.
Study Project												
IHNC Lock	5,811	5,811	(0)	0%	2.3	2.3	0	0%	1,604	1,644	(40)	-2%
Gulf Intracoastal Waterway												
Algiers Lock	6,820	7,080	(260)	-4%	2.7	2.6	0	4%	1,698	1,656	42	2%
Bayou Boeuf Lock	11,163	7,872	3,291	29%	2.0	2.8	(1)	-42%	1,405	1,495	(90)	-6%
Bayou Sorrel Lock	4,588	4,679	(91)	-2%	3.5	3.4	0	2%	1,884	1,629	255	14%
Calcasieu Lock	11,658	11,495	163	1%	2.4	2.5	(0)	-1%	1,737	1,179	558	32%
Harvey Lock	2,030	2,034	(4)	0%	1.3	1.3	0	0%	1,279	1,539	(260)	-20%
Leland Bowman Lock	11,536	11,216	320	3%	2.5	2.6	(0)	-3%	1,729	1,359	370	21%
Port Allen Lock	5,517	5,515	2	0%	3.0	3.0	(0)	0%	1,738	1,606	132	8%
Old River												
Old River Lock	2,286	2,175	111	5%	3.4	3.6	(0)	-5%	1,962	1,723	239	12%

** PCXIN-RED estimated WPC number of canal tows.*
*** PCXIN-RED estimated WPC barges / tow.*
**** Averaged 2010-2014 LPMS vessels utilizing WCS vessel horsepowers.*

TABLE 3-9: Plan 3, 110' x 900' Calibration Results

Navigation Lock Project	Number of Canal Tows				Average Canal Tow Barges Per Tow				Average Horsepower			
	Estimated Target *	NIM Output	Difference Count	Difference Pct.	Target **	NIM Output	Difference Abs.	Difference Pct.	LPMS Target ***	NIM Output	Difference Count	Difference Pct.
Study Project												
IHNC Lock	5,645	5,733	(88)	-2%	2.3	2.3	0	2%	1,604	1,650	(46)	-3%
Gulf Intracoastal Waterway												
Algiers Lock	6,820	7,071	(251)	-4%	2.7	2.6	0	4%	1,698	1,661	37	2%
Bayou Boeuf Lock	11,163	7,872	3,291	29%	2.0	2.8	(1)	-42%	1,405	1,498	(93)	-7%
Bayou Sorrel Lock	4,588	4,679	(91)	-2%	3.5	3.4	0	2%	1,884	1,629	255	14%
Calcasieu Lock	11,658	11,495	163	1%	2.4	2.5	(0)	-1%	1,737	1,179	558	32%
Harvey Lock	2,030	2,032	(2)	0%	1.3	1.3	0	0%	1,279	1,540	(261)	-20%
Leland Bowman Lock	11,536	11,216	320	3%	2.5	2.6	(0)	-3%	1,729	1,359	370	21%
Port Allen Lock	5,517	5,515	2	0%	3.0	3.0	(0)	0%	1,738	1,606	132	8%
Old River												
Old River Lock	2,286	2,175	111	5%	3.4	3.6	(0)	-5%	1,962	1,723	239	12%

** PCXIN-RED estimated WPC number of canal tows.*
*** PCXIN-RED estimated WPC barges / tow.*
**** Averaged 2010-2014 LPMS vessels utilizing WCS vessel horsepowers.*

TABLE 3-10: Plan 4, 75' x 1200' Calibration Results

Navigation Lock Project	Number of Canal Tows				Average Canal Tow Barges Per Tow				Average Horsepower			
	Estimated Target *	NIM Output	Difference Count	Difference Pct.	Target **	NIM Output	Difference Abs.	Difference Pct.	LPMS Target ***	NIM Output	Difference Count	Difference Pct.
Study Project												
IHNC Lock	5,703	5,733	(30)	-1%	2.3	2.3	0	1%	1,604	1,650	(46)	-3%
Gulf Intracoastal Waterway												
Algiers Lock	6,820	7,071	(251)	-4%	2.7	2.6	0	4%	1,698	1,661	37	2%
Bayou Boeuf Lock	11,163	7,872	3,291	29%	2.0	2.8	(1)	-42%	1,405	1,498	(93)	-7%
Bayou Sorrel Lock	4,588	4,679	(91)	-2%	3.5	3.4	0	2%	1,884	1,629	255	14%
Calcasieu Lock	11,658	11,495	163	1%	2.4	2.5	(0)	-1%	1,737	1,179	558	32%
Harvey Lock	2,030	2,032	(2)	0%	1.3	1.3	0	0%	1,279	1,540	(261)	-20%
Leland Bowman Lock	11,536	11,216	320	3%	2.5	2.6	(0)	-3%	1,729	1,359	370	21%
Port Allen Lock	5,517	5,515	2	0%	3.0	3.0	(0)	0%	1,738	1,606	132	8%
Old River												
Old River Lock	2,286	2,175	111	5%	3.4	3.6	(0)	-5%	1,962	1,723	239	12%

** PCXIN-RED estimated WPC number of canal tows.*
*** PCXIN-RED estimated WPC barges / tow.*
**** Averaged 2010-2014 LPMS vessels utilizing WCS vessel horsepowers.*

TABLE 3-11: Plan 5, #2 110' x 1200' Calibration Results

	Number of Canal Tows				Average Canal Tow Barges Per Tow				Average Horsepower			
Navigation	Estimated	NIM	Difference			NIM	Difference		LPMS	NIM	Difference	
Lock Project	Target *	Output	Count	Pct.	Target **	Output	Abs.	Pct.	Target ***	Output	Count	Pct.
Study Project												
IHNC Lock	5,534	5,733	(199)	-4%	2.4	2.3	0	3%	1,604	1,650	(46)	-3%
Gulf Intracoastal Waterway												
Algiers Lock	6,820	7,071	(251)	-4%	2.7	2.6	0	4%	1,698	1,661	37	2%
Bayou Boeuf Lock	11,163	7,872	3,291	29%	2.0	2.8	(1)	-42%	1,405	1,498	(93)	-7%
Bayou Sorrel Lock	4,588	4,679	(91)	-2%	3.5	3.4	0	2%	1,884	1,629	255	14%
Calcasieu Lock	11,658	11,495	163	1%	2.4	2.5	(0)	-1%	1,737	1,179	558	32%
Harvey Lock	2,030	2,032	(2)	0%	1.3	1.3	0	0%	1,279	1,540	(261)	-20%
Leland Bowman Lock	11,536	11,216	320	3%	2.5	2.6	(0)	-3%	1,729	1,359	370	21%
Port Allen Lock	5,517	5,515	2	0%	3.0	3.0	(0)	0%	1,738	1,606	132	8%
Old River												
Old River Lock	2,286	2,175	111	5%	3.4	3.6	(0)	-5%	1,962	1,723	239	12%

** PCXIN-RED estimated WPC number of canal tows.*
*** PCXIN-RED estimated WPC barges / tow.*
**** Averaged 2010-2014 LPMS vessels utilizing WCS vessel horsepowers.*

4. RESULTS

4.1 Comparison of Alternatives

4.1.1 Cost and Benefit Results - Summary

As discussed in introduction to the **Methods Section**, the National Economic Development (NED) analysis equates to an economic benefit-cost analysis for plan evaluation and selection. The benefit-cost analysis (BCA) is a technique to evaluate in monetary terms what is achieved (benefits) in comparison to what is invested (costs). To assist in the BCA, the Navigation Investment Model (NIM) generates cost outputs such as construction costs, maintenance costs, and real estate costs and benefit outputs such as the savings in transportation costs attributable to the improved waterway system. However, before delving into the details of the costs and benefits, it is useful to examine the rolled up results of total costs, total benefits, net benefits, and the benefit to cost ratio (BCR) for each plan to help identify a Tentatively Selected Plan.

Several trends are noticeable within **TABLE 4-0** which presents the total costs, total benefits, net benefits, and benefit-cost ratios for all evaluated plans for the mid-level forecasted traffic scenario. The first notable trend is Plan 3 rates the best when considering these metrics. Plan 2 and Plan 3 have the same BCR (4.78), but Plan 3 has the greatest net benefits ($172.35 million) for the mid traffic forecast scenario. While Plan 3 performs the best, **TABLE 4-0** shows that of the four plans Plan 5 performs the worst by having the greatest average annual cost ($48.0 million) and lowest BCR (4.55) for the mid traffic scenario. This is due to the higher costs for construction of the 110' x 1200' chamber ($32.74 million). A final notable trend is that the difference between the worst plan and best plan is not too great. For example, the difference in total average annual costs between Plan 2 and Plan 5 is less than $3.2 million for the mid-traffic forecasted scenario and difference in net benefits is less than $2.6 million for the mid traffic scenario.

TABLE 4-0: Total Costs, Total Benefits, Net Benefits, and Benefit-Cost Ratio for Each Plan For Mid Demand Assumptions (Millions of FY2017 dollars, 2.875% discount/amortization rate, 2019-2082 with 2032 base year)

Inner Harbor Navigation Canal
Lock Replacement GRR
Average Annual Benefit - Cost Summary[1]
Elastic Movement-Level Demand[2]
(Dollars, Average annual 2.875% discount/amortization rate, 2019-2082 with 2032 base year)

Lock Alternative	Plan 2: 75' x 900'	Plan 3: 110' x 900'	Plan 4: 75' x 1,200'	Plan 5: 110' x 1,200'
First Cost of Construction	$936,935,713	$951,313,468	$972,055,987	$1,001,735,370
Interest During Construction	$209,862,182	$213,652,900	$218,346,610	$225,589,465
Total Investment	$1,146,797,895	$1,164,966,369	$1,190,402,597	$1,227,324,835
Average Annual Const. Cost	$43,518,785	$44,208,244	$45,173,500	$46,574,628
Average Annual Increm. O&M	$1,366,399	$1,353,464	$1,435,237	$1,435,237
Total Average Annual Cost	$44,885,184	$45,561,708	$46,608,737	$48,009,865
Total Average Annual Benefits	$214,683,201	$217,916,647	$216,793,536	$218,269,611
Net Excess Benefits	$169,798,018	$172,354,940	$170,184,799	$170,259,746
B/C Ratio	4.78	4.78	4.65	4.55

[1]PCXIN-RED Results 28-NOV-2016

[2]GEC Reference Traffic Demand Forecasts and Wilson Calcasieu study commodity group elasticities.

Worst performing plan according to the metric

Best performing plan according to metric

As shown in **TABLE 4-0**, Plan 2 and Plan 3 perform the best, so **TABLE 4-1** examines the difference between the two options. Under the most likely traffic forecast scenarios, Plan 3 provides the highest total benefits ($217.92 million) and net benefits ($172.35 million). While both plans have an equal BCR and are relatively close in terms of impact (<2 percent difference), Plan 3 is the better option for the Tentatively Selected Plan due to having greater total benefits and greater net benefits.

TABLE 4-1: Comparison of Total Costs, Total Benefits, Net Benefits, and BCR of Plan 2 and Plan 3 (Millions of FY2017 dollars, 2.875% discount/amortization rate, 2019-2082 with 2032 base year)

Traffic Forecast Scenario	Metric	Plan 2 75' x 900' x 22'	Plan 3 110' x 900' x 22'	(Plan 3 - Plan 2)	Percent Difference Between Plan 2 and Plan 3
Mid	Total Costs	$ 44.89	$ 45.56	$ 0.68	2%
	Total Benefits	$ 214.68	$ 217.92	$ 3.23	2%
	Net Benefits	$ 169.80	$ 172.35	$ 2.56	2%
	Benefit-Cost Ratio (BCR)	4.78	4.78	0.00	0%

Worst performing plan according to the metric

Best performing plan according to metric

4.1.2 Cost and Benefits Results - Details

While both **TABLE 4-2** present the components for the total cost and total benefit calculations for the mid traffic forecast scenario, **TABLE 4-2** shows the BCR results found using the average annual method. In terms of benefits, the table contains the difference between the transportation benefits without the project (WOPC) and the difference in transportation benefits with the project (WPC) which resulted in $211.96 million to $215.55 million. Also tables contains the construction costs, engineering and design costs, supervisory and administration costs, mitigation costs, real estate costs, operation and maintenance costs for the lock, scheduled maintenance cost for the lock, and schedule maintenance costs for the waterway system. These components led to total costs increasing from $44.93 million to $48.05 million as the size of the lock plan increases.

TABLE 4-2: Average Annual Benefit to Cost Summary for Mid Traffic Forecast Scenario (Millions of FY2017 dollars, 2.875% discount/amortization rate, 2019-2082 with 2032 base year)

	Plan 2 75' x 900' x 22'	Plan 3 110' x 900' x 22'	Plan 4 75' x 1200' x 22'	Plan 5 110' x 1200' x 22'
Construction	$ 30.26	$ 30.55	$ 31.60	$ 32.74
Engineering & Design (E&D)	$ 5.26	$ 5.51	$ 5.47	$ 5.65
Supervisory/Administration (S&A)	$ 2.51	$ 2.66	$ 2.61	$ 2.70
Mitigation	$ 2.54	$ 2.54	$ 2.54	$ 2.54
Real Estate	$ 2.95	$ 2.95	$ 2.95	$ 2.95
Normal O&M - Lock	$ 0.30	$ 0.30	$ 0.30	$ 0.30
Normal O&M - System	$ -	$ -	$ -	$ -
Scheduled Maintenance - Lock	$ 0.42	$ 0.42	$ 0.42	$ 0.42
Scheduled Maintenance - System	$ 0.65	$ 0.63	$ 0.71	$ 0.71
Total Cost	$ 44.89	$ 45.56	$ 46.61	$ 48.01
Transportation Benefits	$ 211.96	$ 215.20	$ 214.07	$ 215.55
WOPC Transporation Benefits (w/ Disruptions)	$ 3,103.83	$ 3,103.83	$ 3,103.83	$ 3,103.83
WPC Transporation Benefits (w/ Disruptions)	$ 3,315.80	$ 3,319.03	$ 3,317.91	$ 3,319.38
Without-Project Costs Foregone	$ 2.72	$ 2.72	$ 2.72	$ 2.72
Normal O&M - Lock	$ 0.30	$ 0.30	$ 0.30	$ 0.30
Normal O&M - System	$ -	$ -	$ -	$ -
Scheduled Maintenance - Lock	$ 2.42	$ 2.42	$ 2.42	$ 2.42
Scheduled Maintenance - System	$ -	$ -	$ -	$ -
Total Benefits	$ 214.68	$ 217.92	$ 216.79	$ 218.27
Net Benefits	$ 169.80	$ 172.35	$ 170.18	$ 170.26
Benefit-Cost Ratio (BCR)	4.78	4.78	4.65	4.55

4.2 Costs

4.2.1 Total Costs

The models assumed a with-project on-line year of 2032. Construction costs used within the analysis are summarized by year in **TABLE 4-3**. This tables shows that construction costs are expected to ramp up

TABLE 4-3: With-Project Condition Construction Costs by Alternative (FY 2016 Dollars)

Year	Plan 2 75' x 900' x 22'	Plan 3 110' x 900' x 22'	Plan 4 75' x 1200' x 22'	Plan 5 110' x 1200' x 22'
2019	$ 33,798,699	$ 35,433,022	$ 35,190,332	$ 36,326,993
2020	$ 33,798,699	$ 35,433,022	$ 35,190,332	$ 36,326,993
2021	$ 117,285,295	$ 118,346,064	$ 118,243,728	$ 119,807,013
2022	$ 110,105,115	$ 111,893,027	$ 116,494,339	$ 121,925,964
2023	$ 114,994,198	$ 117,124,839	$ 122,074,527	$ 127,831,005
2024	$ 140,880,907	$ 143,069,423	$ 147,957,946	$ 153,710,357
2025	$ 150,187,576	$ 152,410,390	$ 157,262,666	$ 163,012,667
2026	$ 91,234,563	$ 92,486,471	$ 95,017,971	$ 98,203,021
2027	$ 40,377,022	$ 40,510,744	$ 40,369,422	$ 40,360,024
2028	$ 53,927,658	$ 54,126,277	$ 53,916,369	$ 53,902,410
2029	$ 22,066,851	$ 22,118,816	$ 22,063,898	$ 22,060,246
2030	$ 18,526,179	$ 18,578,143	$ 18,523,225	$ 18,519,573
2031	$ 9,752,952	$ 9,783,228	$ 9,751,231	$ 9,749,104
TOTAL	**$ 936,935,713**	**$ 951,313,468**	**$ 972,055,987**	**$ 1,001,735,370**
IDC	$209,862,182	$213,652,900	$218,346,610	$225,589,465
Present Value	$1,146,797,895	$1,164,966,369	$1,190,402,597	$1,227,324,835
Av.Ann.	$43,518,785	$44,208,244	$45,173,500	$46,574,628

4.2.2 Operation and Maintenance Costs

Since the BCRs between the plans are relatively close, an examination of how the costs change over the period of analysis is also useful. As shown in ***FIGURE 4-0FIGURE 4-***, the cyclical maintenance costs for each plan are relatively similar for the period of analysis. While the costs for all plans varies significantly from Plan 1 (Without-Project), the costs for Plan 2 (75' x 110') and Plan 3 (75' x 110') become less than other plans after 2058. This supports the assertion that Plan 2 and Plan 3 are the best options. It should also be noted that the only significant variance in costs between Plan 2 and Plan 3 is in 2078 when Plan 2 experiences a small closure period.

FIGURE 4-0: Cyclical Maintenance Costs For IHNC Lock Without Project Condition and Alternatives (Millions of FY2017 dollars, Average annual 2.875% discount/amortization rate, 2019-2082 with 2032 base year)

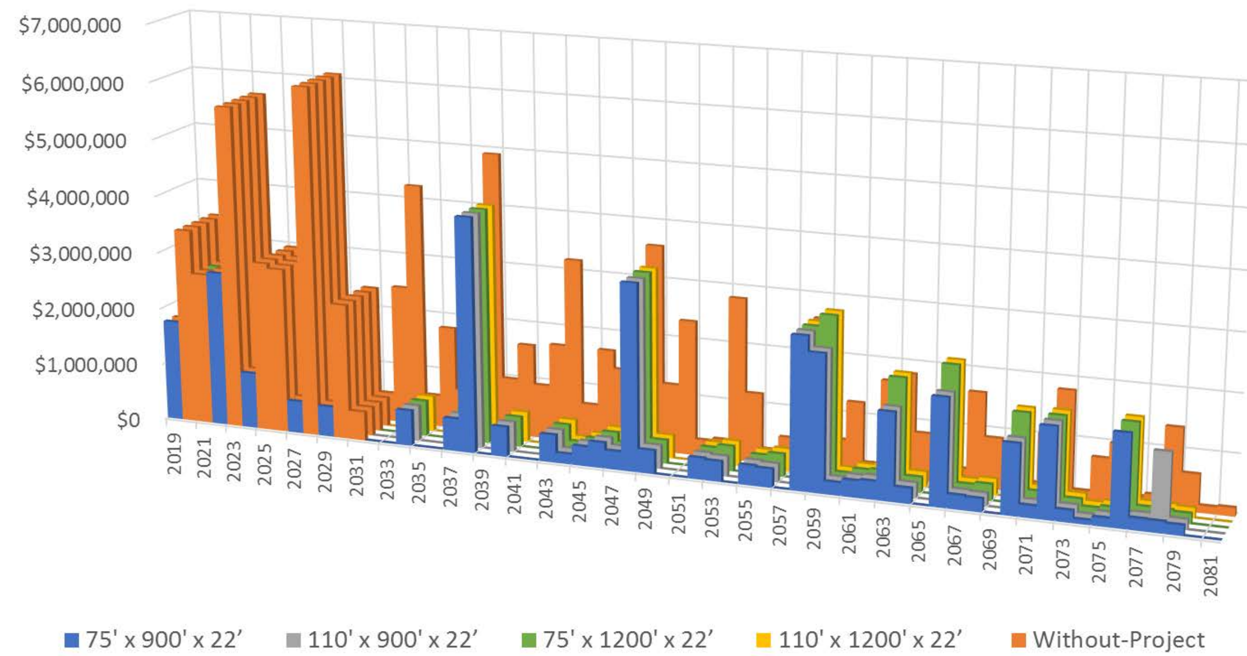


TABLE 4-4: Cyclical Maintenance Costs (Millions of FY2017 dollars, Average annual 2.875% discount/amortization rate, 2019-2082 with 2032 base year)

Year	Without-Project Condition	Plan 2 75' x 900' x 22'	Plan 3 110' x 900' x 22'	Plan 4 75' x 1200' x 22'	Plan 5 110' x 1200' x 22'
2019	$1,756,419	$1,756,419	$1,756,419	$1,756,419	$1,756,419
2020	$3,414,667	$3,414,667	$3,414,667	$3,414,667	$3,414,667
2021	$2,655,391	$2,655,391	$2,655,391	$2,655,391	$2,655,391
2022	$2,710,241	$2,710,241	$2,710,241	$2,710,241	$2,710,241
2023	$5,645,356	$5,645,356	$5,645,356	$5,645,356	$5,645,356
2024	$975,571	$975,571	$975,571	$975,571	$975,571
2025	$2,963,460	$2,963,460	$2,963,460	$2,963,460	$2,963,460
2026	$2,880,642	$2,880,642	$2,880,642	$2,880,642	$2,880,642
2027	$560,028	$560,028	$560,028	$560,028	$560,028
2028	$6,097,019	$6,097,019	$6,097,019	$6,097,019	$6,097,019
2029	$529,163	$529,163	$529,163	$529,163	$529,163
2030	$2,366,125	$2,366,125	$2,366,125	$2,366,125	$2,366,125
2031	$500,000	$500,000	$500,000	$500,000	$500,000
2032	$2,430,134	$0	$0	$0	$0
2033	$4,251,996	$0	$0	$0	$0
2034	$551,089	$619,975	$619,975	$619,975	$619,975
2035	$1,785,626	$0	$0	$0	$0
2036	$694,290	$0	$0	$0	$0
2037	$2,109,021	$569,436	$569,436	$569,436	$569,436
2038	$4,920,195	$4,100,162	$4,100,162	$4,100,162	$4,100,162
2039	$996,394	$0	$0	$0	$0
2040	$1,627,162	$523,016	$523,016	$523,016	$523,016
2041	$941,481	$0	$0	$0	$0
2042	$1,683,912	$0	$0	$0	$0
2043	$3,202,538	$480,381	$480,381	$480,381	$480,381
2044	$691,786	$172,947	$207,536	$172,947	$207,536
2045	$1,681,133	$336,227	$302,604	$336,227	$302,604
2046	$1,372,687	$441,221	$441,221	$441,221	$441,221
2047	$317,697	$317,697	$285,927	$317,697	$285,927
2048	$3,582,289	$3,242,589	$3,273,471	$3,242,589	$3,273,471
2049	$1,200,750	$405,253	$405,253	$405,253	$405,253
2050	$2,334,387	$0	$0	$0	$0
2051	$283,644	$0	$0	$0	$0

TABLE 4-3: Cyclical Maintenance Costs (Millions of FY2017 dollars, Average annual 2.875% discount/amortization rate, 2019-2082 with 2032 base year)

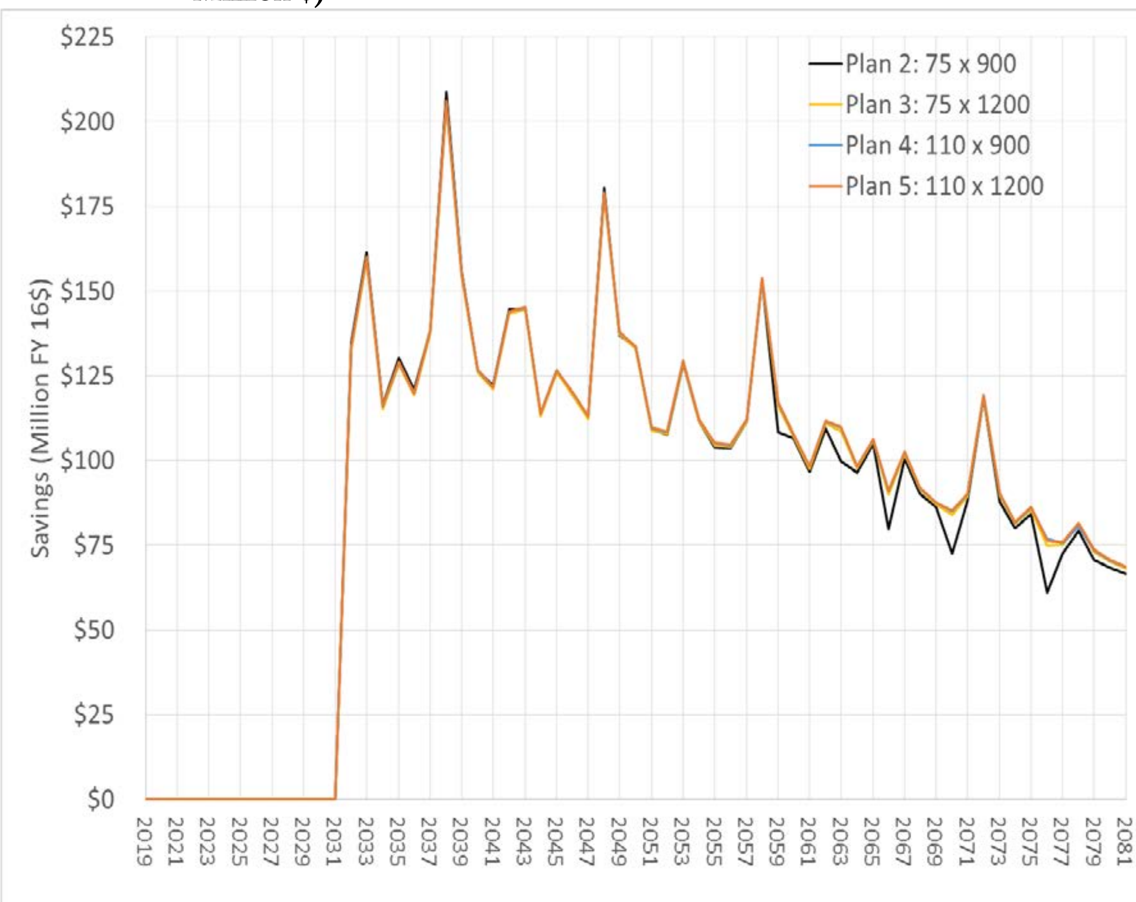
Year	Without-Project Condition	Plan 2 75' x 900' x 22'	Plan 3 110' x 900' x 22'	Plan 4 75' x 1200' x 22'	Plan 5 110' x 1200' x 22'
2052	$330,860	$372,218	$372,218	$372,218	$372,218
2053	$2,814,120	$348,415	$348,415	$428,818	$428,818
2054	$1,198,399	$0	$0	$0	$0
2055	$253,241	$341,875	$341,875	$341,875	$341,875
2056	$492,327	$320,013	$320,013	$393,862	$393,862
2057	$1,196,421	$0	$0	$0	$0
2058	$2,605,086	$2,639,976	$2,639,976	$2,639,976	$2,639,976
2059	$565,242	$2,374,016	$2,374,016	$2,848,819	$2,848,819
2060	$1,230,757	$219,778	$219,778	$197,800	$197,800
2061	$213,636	$288,409	$288,409	$288,409	$288,409
2062	$1,661,325	$311,499	$311,499	$311,499	$311,499
2063	$1,816,759	$1,513,966	$1,513,966	$1,917,690	$1,917,690
2064	$824,127	$264,898	$264,898	$264,898	$264,898
2065	$1,335,160	$0	$0	$0	$0
2066	$296,651	$1,854,067	$1,854,067	$2,224,880	$2,224,880
2067	$1,622,027	$243,304	$243,304	$243,304	$243,304
2068	$875,943	$227,745	$227,745	$280,302	$280,302
2069	$170,293	$0	$0	$0	$0
2070	$198,640	$1,216,671	$1,216,671	$1,547,738	$1,547,738
2071	$1,045,898	$209,180	$209,180	$257,452	$257,452
2072	$1,814,363	$1,564,106	$1,564,106	$1,564,106	$1,564,106
2073	$152,039	$205,253	$205,253	$205,253	$205,253
2074	$738,953	$73,895	$73,895	$88,674	$88,674
2075	$1,005,622	$143,660	$143,660	$129,294	$129,294
2076	$167,575	$1,584,976	$188,521	$1,584,976	$1,584,976
2077	$217,189	$203,614	$203,614	$203,614	$203,614
2078	$1,385,468	$197,924	$1,253,518	$197,924	$197,924
2079	$641,309	$173,153	$173,153	$173,153	$173,153
2080	$124,677	$0	$0	$0	$0
2081	$145,432	$0	$0	$0	$0

4.3 Transportation Rate Savings For System

The introduction of this document discusses how the primary benefit for barge transportation is calculated as the cost savings for barge shipment over the long-run least costly all-overland alternative routing. This benefit estimation is referred to as the waterway transportation rate-savings which also accounts for any difference in transportation costs arising from loading, unloading, trans-loading, demurrage, and other activities involved in the ultimate point to point transportation of goods. The impact of each IHNC plan on incremental transportation rate savings for the system is shown in **FIGURE 4-1**. The transportation rate savings are incremental because the transportation rate savings for the WOPC have been subtracted from the transportation rate savings for each plan.

For each plan in **FIGURE 4-1**, the system transportation rate savings start at 0 while construction is occurring, but increase to $133 million in 2032 when construction is assumed to be completed. All IHNC plans demonstrate a similar wavy, gradually decreasing relationship for the system transportation rate savings. . However, Plan 2 (the black solid line) does experience years when the transportation rate savings drops below the other plans. The spikes in transportation rate savings shown in **FIGURE 4-1** correspond to closure periods in the WOPC scenario. For example, the spikes in 2038, 2048, and 2058 occur when the lock would be closed for 1440 hours for major repairs. Applying a discount rate to the stream of benefits causes the transportation rate savings for each plan to gradually decline. Discounting is done to account for the time value of money by valuing more recent benefits over future benefits

FIGURE 4-1: Incremental System Transportation Rate Savings For Each IHNC Plan (FY 17 Million $)



4.4 Sensitivity Analysis

Since the BCR plays a key role in the decision of best plan, an analysis of how sensitive the metric may be to assumptions is useful. **TABLE 5-5** demonstrates the sensitivity of the BCRs to assumptions on the traffic forecasts. **TABLE 5-5** presents the net benefit and BCR results from the Navigation Investment Model (NIM) when the model assumes a traffic forecast of low, most likely, no growth after 2032, no growth after 2052, and high. For Plan 3, the Tentatively Selected Plan (TSP), the assumption of traffic forecasts causes the BCR for the TSP to range from 2.03 to 8.19 and the net benefits to range from $46.75 million to $327.85 million. The sensitivity test also shows that Plan 5 performs the worst by having the lowest net benefits and BCR. It is also interesting to note that traffic growth causes Plan 2 to fall from one of the best options to the worst performing option.

TABLE 5-5: IHNC Lock With-Project Condition Analysis Assume Elastic/Price Responsive Movement-Level Demand (Millions of FY2017 dollars, Average annual 2.875% discount/amortization rate, 2015-2082 with 2032 base year.)

WITH-PROJECT ALTERNATIVES

ITEM	Plan 2 75' x 900' x 22' Scenario					Plan 3 110' x 900' x 22' Traffic Demand Scenario					Plan 4 75' x 1200' x 22' Traffic Demand Scenario					Plan 5 110' x 1200' x 22' Traffic Demand Scenario				
	Low Forecast	Base Forecast	No-Growth After 2032	No-Growth After 2052	High Forecast	Low Forecast	Base Forecast	No-Growth After 2032	No-Growth After 2052	High Forecast	Low Forecast	Base Forecast	No-Growth After 2032	No-Growth After 2052	High Forecast	Low Forecast	Base Forecast	No-Growth After 2032	No-Growth After 2052	High Forecast
BENEFITS																				
Base Transportation Savings (no service disruptions)	2,879.25	3,365.03	3,133.99	3,298.81	3,986.93	2,876.15	3,363.77	3,131.29	3,296.87	3,996.64	2,875.90	3,363.24	3,130.94	3,296.40	3,995.45	2,876.11	3,363.85	3,131.30	3,296.92	3,997.00
Reduced Surplus frm Scheduled Disruptions *	(28.53)	(29.84)	(27.67)	(28.40)	(38.47)	(28.20)	(27.37)	(27.17)	(27.29)	(29.04)	(28.28)	(27.58)	(27.28)	(27.45)	(29.67)	(28.16)	(27.29)	(27.12)	(27.23)	(28.88)
Reduced Surplus frm Unscheduled Disruptions (i.e., hurricane) *	(6.12)	(21.24)	(20.15)	(20.77)	(38.91)	(5.22)	(19.20)	(18.93)	(19.11)	(30.96)	(5.41)	(19.58)	(19.18)	(19.43)	(31.97)	(5.13)	(19.01)	(18.80)	(18.93)	(30.50)
Base Transportation Savings (with service disruptions)	2,844.83	3,315.80	3,088.01	3,251.48	3,900.06	2,842.96	3,319.03	3,087.02	3,252.30	3,926.98	2,842.45	3,317.91	3,086.31	3,251.35	3,924.14	2,843.06	3,319.38	3,087.21	3,252.59	3,927.95
Land transportation costs Incurred from Unscheduled diversions	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Externality Costs Incurred																				
Externality Cost for Truck Delay	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Externality Cost for Truck Accidents	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Externality Cost for Truck Emissions	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Externality Cost for Non Delay Truck-Accident & Emissions	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Externality Cost for Rail & Barge emissions	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL SYSTEM BENEFITS	**$2,844.83**	**$3,315.80**	**$3,088.01**	**$3,251.48**	**$3,900.06**	**$2,842.96**	**$3,319.03**	**$3,087.02**	**$3,252.30**	**$3,926.98**	**$2,842.45**	**$3,317.91**	**$3,086.31**	**$3,251.35**	**$3,924.14**	**$2,843.06**	**$3,319.38**	**$3,087.21**	**$3,252.59**	**$3,927.95**
WITH-PROJECT BENEFITS (Incre.Sys. Benefits)	91.50	211.96	150.71	197.10	343.81	89.63	215.20	149.71	197.92	370.73	89.12	214.07	149.01	196.97	367.89	89.73	215.55	149.91	198.21	371.70
WOPC Cost Foregone																				
Lock Scheduled Maintenance Federal Costs	2.42	2.42	2.42	2.42	2.42	2.42	2.42	2.42	2.42	2.42	2.42	2.42	2.42	2.42	2.42	2.42	2.42	2.42	2.42	2.42
Lock Random Minor Repair Federal Costs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lock Normal O&M Federal Costs	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Non-lock Scheduled Federal Costs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Non-lock Normal O&M Federal Costs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WITH-PROJECT BENEFITS	**$94.22**	**$214.68**	**$153.43**	**$199.82**	**$346.53**	**$92.35**	**$217.92**	**$152.43**	**$200.64**	**$373.45**	**$91.84**	**$216.79**	**$151.73**	**$199.69**	**$370.61**	**$92.45**	**$218.27**	**$152.63**	**$200.93**	**$374.42**
COSTS **																				
Project Improvement Cost (Federal & IWTF)	43.56	43.56	43.56	43.56	43.56	44.25	44.25	44.25	44.25	44.25	45.21	45.21	45.21	45.21	45.21	46.61	46.61	46.61	46.61	46.61
Scheduled Maintenance Federal Costs	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
Random Minor Federal Costs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Normal O&M Federal Costs	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Non-lock Scheduled Federal Costs	0.65	0.65	0.65	0.65	0.65	0.63	0.63	0.63	0.63	0.63	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71
Non-lock Normal O&M Federal Costs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WITH-PROJECT COSTS	**$44.93**	**$44.93**	**$44.93**	**$44.93**	**$44.93**	**$45.60**	**$45.60**	**$45.60**	**$45.60**	**$45.60**	**$46.65**	**$46.65**	**$46.65**	**$46.65**	**$46.65**	**$48.05**	**$48.05**	**$48.05**	**$48.05**	**$48.05**
NET BENEFITS	**$49.30**	**$169.76**	**$108.51**	**$154.90**	**$301.60**	**$46.75**	**$172.31**	**$106.83**	**$155.04**	**$327.85**	**$45.19**	**$170.14**	**$105.08**	**$153.04**	**$323.96**	**$44.40**	**$170.22**	**$104.58**	**$152.88**	**$326.37**
BENEFIT-COST RATIO (BCR)	**2.10**	**4.78**	**3.42**	**4.45**	**7.71**	**2.03**	**4.78**	**3.34**	**4.40**	**8.19**	**1.97**	**4.65**	**3.25**	**4.28**	**7.94**	**1.92**	**4.54**	**3.18**	**4.18**	**7.79**

Worst performing plan according to the metric

Best performing plan according to metric

4.5 Impact on Transit Time

As shown in **FIGURE 4-2,** all alternatives provide a significant reduction in transit time in comparison to the without project condition (WOPC). However, a closer look at the transit time graph, shown in **FIGURE 4-3**, demonstrates that Plan 2: 900 x 75 ft causes greater spikes in transit time over the period of analysis then Plan 3, Plan 4, and Plan 5. For example, in 2076, a service disruption of 75 hours causes the transit time to spike to nearly 22 hours per tow.

FIGURE 4-2: IHNC Lock Average Vessel Transit Time with Scheduled Maintenance Events (Hours Per Tow)

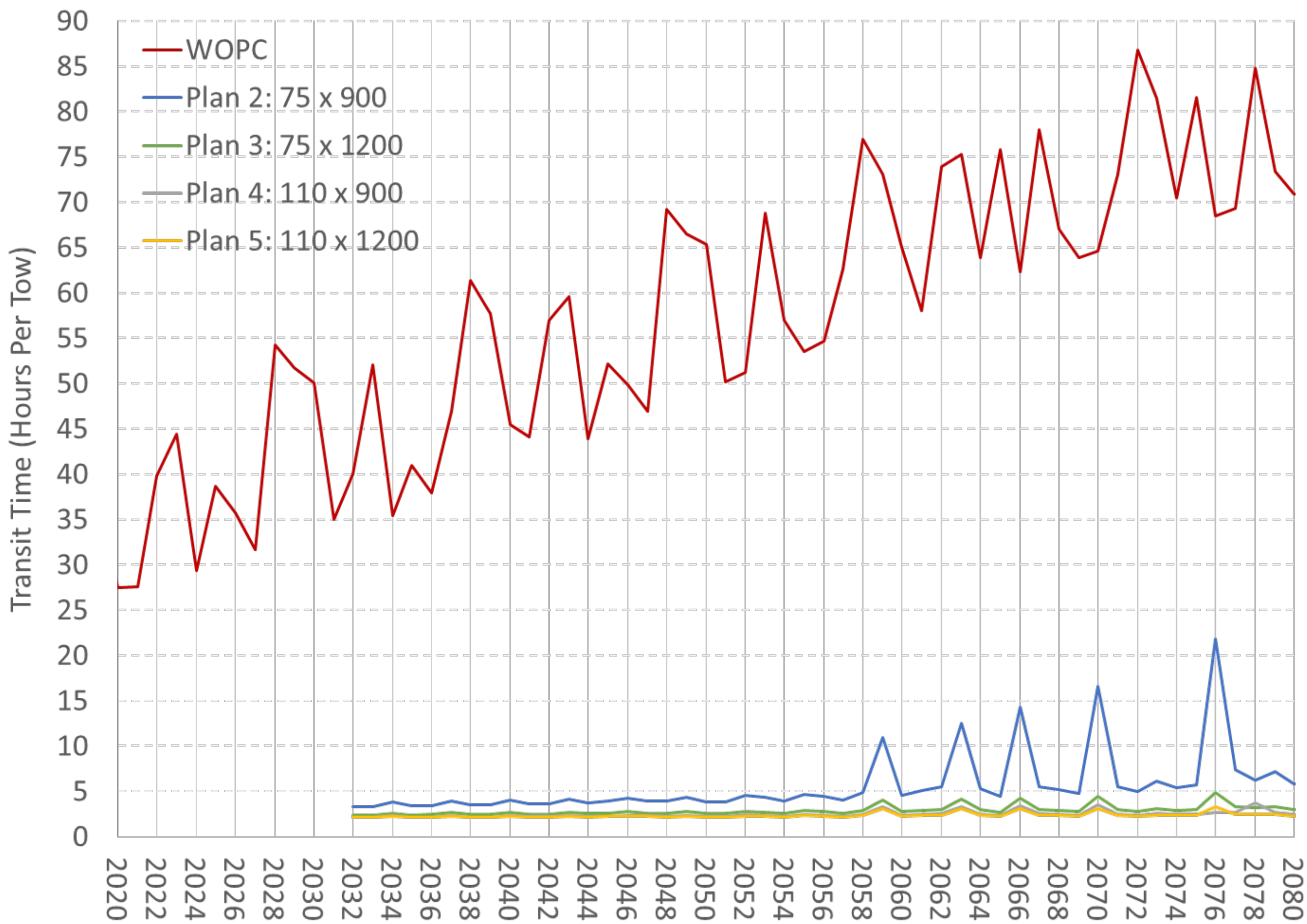
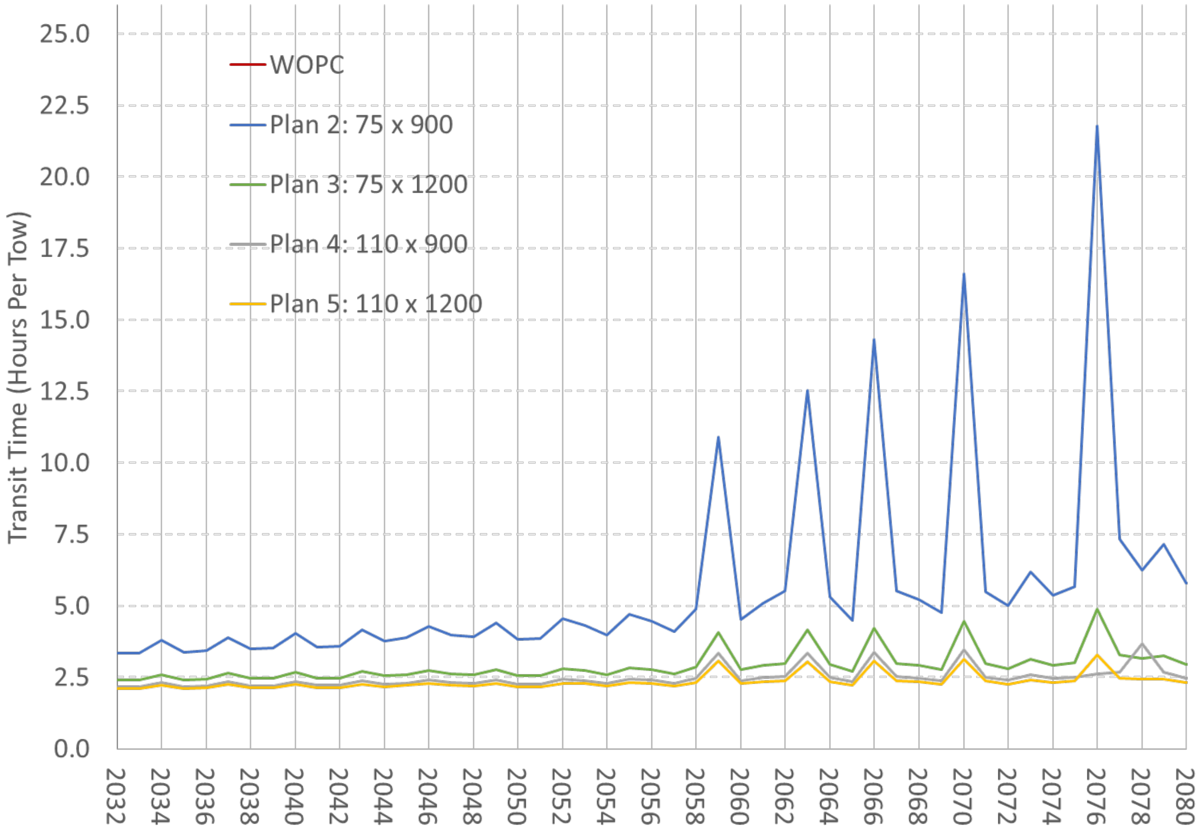


FIGURE 4-3 IHNC Lock Average Vessel Transit Time (with Scheduled Maintenance Events (Hours Per Tow) ZOOMED IN



ATTACHMENT 1: CONSTRUCTION AND MAINTENANCE EVENT DATA

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Inner Harbor Navigation Canal (IHNC) - Lock Replacement, Orleans Parish, Louisiana, General Reevaluation Report

APPENDIX K ECONOMICS ATTACHMENT 1

Construction and Maintenance Event Data

Prepared by:

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September 2016

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1. INTRODUCTION

One of the primary components necessary for evaluating the feasibility of a with-project investment plan is that plan's implementation cost. These costs are identified for each investment plan to be analyzed, as yearly costs for the duration of the construction period, including engineering and design (E&D), construction, supervisory and administration (S&A), mitigation, and real estate costs.

In addition to the with-project condition construction cost, the life-cycle maintenance costs for the without and with-project conditions, and in particular the lock service disruptions they can create, are often critical in the analysis of a lock investment decision. Not only are scheduled maintenance needs applicable, but also service disruption risk from unscheduled repairs. These life-cycle maintenance needs are referred to as the Operations, Maintenance, Repair, Replacement, and Rehabilitation or OMRR&R costs and closures.

In the case of the existing Inner Harbor Navigation Canal (IHNC) Lock study, while requiring regular maintenance, the lock's structural, electrical, and mechanical systems have been determined relatively reliable, and no probabilistic engineering reliability analysis has been performed. Specifically, this means that no engineering reliability probabilities of unsatisfactory performance (PUP) or failure event-trees have been developed to describe service and repair cost risk. Instead a maintenance cost-closure matrix has been created as a proxy for this risk in the without-project condition (WOPC); mimicking a fix-as-fail (FAF) maintenance scenario. Similarly, maintenance cost-closure matrices have been created for each with-project condition (WPC) alternative showing less frequent maintenance events with costs that differ from the WOPC for some events. The assumption that specific events become less frequent from the WOPC) to each WPC may positively impact the benefit-cost ratio (BCR) for each WPC. This is not because the newer components are necessarily more reliable than their older counterparts, but rather that they require less frequent maintenance to maintain their normal operations capability due to more modern technology. For this reason benefits derived from this reduction in required maintenance are not a function of reduced probabilities of component failures (as would be modeled in failure event trees), but rather entirely a function of a reduction in required preventative, scheduled maintenance.

The Gulf region is historically sensitive to seasonal hurricane events, which have the potential to impact lock and system performance. An unscheduled lock closure event has been added to this analysis to serve as a proxy for such an event.

This attachment summarizes the WPC construction costs and the with- and without-project condition OMRR&R data received and then discusses the organization and loading of the data into the Gulf Intracoastal Waterway (GIWW) Navigation Investment Model (NIM). The NIM input can be characterized as:

The with-project construction costs;

The without-project condition scheduled maintenance cost and service disruption assumptions;

The with-project condition scheduled maintenance cost and service disruption assumptions; and

The unscheduled hurricane probabilities and service disruption assumptions.

2. THE WITHOUT-PROJECT CONDITION

The without project condition is the most likely condition expected to exist in the future in the absence of a project, including known changes in law or public policy.

2.1 Without-Project Scheduled Maintenance

The IHNC Lock existing / without-project condition scheduled maintenance was received in workbook "*MVN - IHNC - Cost and Closure Matrix – Revised 3-29.xlsm*" as summarized in ***TABLE A1-0***.

As can be seen, the scheduled OMRR&R data was grouped into no impact to navigation, minor, and major impact to navigation repair work item categories. Multiple scheduled events can occur within a year; there are years where four work items are scheduled (e.g., 2050). The dividing line between minor and major repairs was defined at a repair closure of 175-hours. Repair events with a 175-hour 12-hour shift navigation closure or less were defined as a minor repair event and repair events with navigation closures of 175-hour 24-hour shift or more were defined as major repair events.

The scheduled maintenance data, or OMRR&R, included primarily scheduled maintenance work items, but also included one probabilistic event (hurricane). Additionally, some of the work items were defined as not having impacts to navigation and some of the work items were defined as occurring annually. The seventeen work items in the without-project condition are itemized below by their maintenance / repair level category:

No Impact to Navigation Work Items

- Routine Maintenance (annual $250K)
- Security Maintenance (annual $30K)
- ED Instrumentation (annual $20K)
- A/E Instrumentation (5 year cycle $40K)
- Periodic Inspection (5 year cycle $60K)
- PLC System Upgrades (5 year cycle $500K)

Minor Closures

- Maintenance by Hired Labor Units (annual $500K)
- Rewiring and Machinery Rehabilitation (20 year cycle $750K)
- Rehabilitation of W & E Chamber Guidewall Armoring (12 year cycle $500K)
- Rehabilitation of NW & SW Guidewall Face Timbers (12 year cycle $300K)
- Rehabilitation of NE & SE Guidewall Face Timbers (12 year cycle $100K)

Major Closures

- Dewatering & Monitoring / Major Repairs / Gates (10 year cycle $5M)
- Rehabilitation of E & W Chamber Guidewalls (20 year cycle $4M)
- Rehabilitation of NW & SW Guidewalls (20 year cycle $4M)
- Rehabilitation of NE & SE Guidewalls (20 year cycle $2M)
- Rehabilitation of NE, NW, SE, & SW Dolphins (15 year cycle $1.5M)

Probabilistic Closures

- Hurricane (24-hrs/day 175-hour disruption)

TABLE A1-0: Without-Project Condition Scheduled OMRR&R Assumptions (FY 2016 Dollars)

Fiscal Year	No Impact to Navigation Cost *	Minor Repair Work Items: Service Disrupion 1 Hours	Service Disrupion 1 Pattern	Service Disrupion 2 Hours	Service Disrupion 2 Pattern	Cost	Major Repair work Items: Service Disrupion 3 Hours	Service Disrupion 3 Pattern	Service Disrupion 4 Hours	Service Disrupion 4 Pattern	Cost	TOTAL COST
2015	$ 340,000	150	12hr shifts M-F	-	na	$ 500,000	-	na	-	na	$ -	$ 840,000
2016	$ 360,000	50	12hr shifts M-F	150	12hr shifts M-F	$ 600,000	250	12hr shifts M-F	-	na	$ 1,500,000	$ 2,460,000
2017	$ 300,000	150	12hr shifts M-F	-	na	$ 500,000	400	12hr shifts M-F	-	na	$ 2,000,000	$ 2,800,000
2018	$ 800,000	75	12hr shifts M-F	150	12hr shifts M-F	$ 800,000	1440	24hr shifts Mon-Sun	-	na	$ 5,000,000	$ 6,600,000
2019	$ 300,000	175	12hr shifts M-F	150	12hr shifts M-F	$ 1,200,000	720	12hr shifts M-F	-	na	$ -	$ 1,500,000
2020	$ 340,000	100	12hr shifts M-F	150	12hr shifts M-F	$ 1,000,000	250	12hr shifts M-F	-	na	$ 1,500,000	$ 2,840,000
2021	$ 360,000	150	12hr shifts M-F	-	na	$ 500,000	250	12hr shifts M-F	-	na	$ 1,500,000	$ 2,360,000
2022	$ 300,000	50	12hr shifts M-F	150	12hr shifts M-F	$ 600,000	630	12hr shifts M-F	-	na	$ 1,500,000	$ 2,400,000
2023	$ 800,000	150	12hr shifts M-F	-	na	$ 500,000	720	12hr shifts M-F	-	na	$ 4,000,000	$ 5,300,000
2024	$ 300,000	75	12hr shifts M-F	150	12hr shifts M-F	$ 800,000	-	na	-	na	$ -	$ 1,100,000
2025	$ 340,000	150	12hr shifts M-F	-	na	$ 500,000	400	12hr shifts M-F	-	na	$ 2,000,000	$ 2,840,000
2026	$ 360,000	100	12hr shifts M-F	150	12hr shifts M-F	$ 1,000,000	250	12hr shifts M-F	-	na	$ 1,500,000	$ 2,860,000
2027	$ 300,000	150	12hr shifts M-F	-	na	$ 500,000	-	na	-	na	$ -	$ 800,000
2028	$ 800,000	50	12hr shifts M-F	150	12hr shifts M-F	$ 600,000	1440	24hr shifts Mon-Sun	-	na	$ 5,000,000	$ 6,400,000
2029	$ 300,000	150	12hr shifts M-F	-	na	$ 500,000	720	12hr shifts M-F	-	na	$ -	$ 800,000
2030	$ 340,000	75	12hr shifts M-F	150	12hr shifts M-F	$ 800,000	630	12hr shifts M-F	-	na	$ 1,500,000	$ 2,640,000
2031	$ 360,000	150	12hr shifts M-F	-	na	$ 500,000	-	na	-	na	$ -	$ 860,000
2032	$ 300,000	100	12hr shifts M-F	150	12hr shifts M-F	$ 1,000,000	250	12hr shifts M-F	-	na	$ 1,500,000	$ 2,800,000
2033	$ 800,000	150	12hr shifts M-F	-	na	$ 500,000	720	12hr shifts M-F	-	na	$ 4,000,000	$ 5,300,000
2034	$ 300,000	50	12hr shifts M-F	150	12hr shifts M-F	$ 600,000	-	na	-	na	$ -	$ 900,000
2035	$ 340,000	150	12hr shifts M-F	-	na	$ 500,000	250	12hr shifts M-F	250	12hr shifts M-F	$ 3,000,000	$ 3,840,000
2036	$ 360,000	75	12hr shifts M-F	150	12hr shifts M-F	$ 800,000	-	na	-	na	$ -	$ 1,160,000
2037	$ 300,000	150	12hr shifts M-F	-	na	$ 500,000	400	12hr shifts M-F	-	na	$ 2,000,000	$ 2,800,000
2038	$ 800,000	100	12hr shifts M-F	150	12hr shifts M-F	$ 1,000,000	1440	24hr shifts Mon-Sun	-	na	$ 5,000,000	$ 6,800,000
2039	$ 300,000	175	12hr shifts M-F	150	12hr shifts M-F	$ 1,200,000	720	12hr shifts M-F	-	na	$ -	$ 1,500,000
2040	$ 340,000	50	12hr shifts M-F	150	12hr shifts M-F	$ 600,000	250	12hr shifts M-F	-	na	$ 1,500,000	$ 2,440,000
2041	$ 360,000	175	12hr shifts M-F	150	12hr shifts M-F	$ 1,200,000	-	na	-	na	$ -	$ 1,560,000
2042	$ 300,000	75	12hr shifts M-F	150	12hr shifts M-F	$ 800,000	630	12hr shifts M-F	-	na	$ 1,500,000	$ 2,600,000
2043	$ 800,000	150	12hr shifts M-F	-	na	$ 500,000	720	12hr shifts M-F	-	na	$ 4,000,000	$ 5,300,000
2044	$ 300,000	100	12hr shifts M-F	150	12hr shifts M-F	$ 1,000,000	-	na	-	na	$ -	$ 1,300,000
2045	$ 340,000	150	12hr shifts M-F	-	na	$ 500,000	400	12hr shifts M-F	-	na	$ 2,000,000	$ 2,840,000
2046	$ 360,000	50	12hr shifts M-F	150	12hr shifts M-F	$ 600,000	250	12hr shifts M-F	-	na	$ 1,500,000	$ 2,460,000
2047	$ 300,000	150	12hr shifts M-F	-	na	$ 500,000	-	na	-	na	$ -	$ 800,000
2048	$ 800,000	75	12hr shifts M-F	150	12hr shifts M-F	$ 800,000	1440	24hr shifts Mon-Sun	-	na	$ 5,000,000	$ 6,600,000
2049	$ 300,000	150	12hr shifts M-F	-	na	$ 500,000	250	12hr shifts M-F	720	12hr shifts M-F	$ 1,500,000	$ 2,300,000
2050	$ 340,000	100	12hr shifts M-F	150	12hr shifts M-F	$ 1,000,000	250	12hr shifts M-F	630	12hr shifts M-F	$ 3,000,000	$ 4,340,000
2051	$ 360,000	150	12hr shifts M-F	-	na	$ 500,000	-	na	-	na	$ -	$ 860,000
2052	$ 300,000	50	12hr shifts M-F	150	12hr shifts M-F	$ 600,000	-	na	-	na	$ -	$ 900,000
2053	$ 800,000	175	12hr shifts M-F	150	12hr shifts M-F	$ 1,200,000	720	12hr shifts M-F	-	na	$ 4,000,000	$ 6,000,000
2054	$ 300,000	75	12hr shifts M-F	150	12hr shifts M-F	$ 800,000	250	12hr shifts M-F	-	na	$ 1,500,000	$ 2,600,000
2055	$ 340,000	150	12hr shifts M-F	-	na	$ 500,000	-	na	-	na	$ -	$ 840,000
2056	$ 360,000	100	12hr shifts M-F	150	12hr shifts M-F	$ 1,000,000	-	na	-	na	$ -	$ 1,360,000
2057	$ 300,000	150	12hr shifts M-F	-	na	$ 500,000	400	12hr shifts M-F	-	na	$ 2,000,000	$ 2,800,000
2058	$ 800,000	50	12hr shifts M-F	150	12hr shifts M-F	$ 600,000	1440	24hr shifts Mon-Sun	-	na	$ 5,000,000	$ 6,400,000
2059	$ 300,000	175	12hr shifts M-F	150	12hr shifts M-F	$ 1,200,000	720	12hr shifts M-F	-	na	$ -	$ 1,500,000
2060	$ 340,000	75	12hr shifts M-F	150	12hr shifts M-F	$ 800,000	400	12hr shifts M-F	-	na	$ 2,000,000	$ 3,140,000
2061	$ 360,000	150	12hr shifts M-F	-	na	$ 500,000	-	na	-	na	$ -	$ 860,000
2062	$ 300,000	100	12hr shifts M-F	150	12hr shifts M-F	$ 1,000,000	630	12hr shifts M-F	250	12hr shifts M-F	$ 3,000,000	$ 4,300,000
2063	$ 800,000	150	12hr shifts M-F	-	na	$ 500,000	720	12hr shifts M-F	-	na	$ 4,000,000	$ 5,300,000
2064	$ 300,000	50	12hr shifts M-F	150	12hr shifts M-F	$ 600,000	250	12hr shifts M-F	-	na	$ 1,500,000	$ 2,400,000
2065	$ 340,000	150	12hr shifts M-F	-	na	$ 500,000	250	12hr shifts M-F	630	12hr shifts M-F	$ 3,000,000	$ 3,840,000
2066	$ 360,000	75	12hr shifts M-F	150	12hr shifts M-F	$ 800,000	-	na	-	na	$ -	$ 1,160,000
2067	$ 300,000	150	12hr shifts M-F	-	na	$ 500,000	720	12hr shifts M-F	-	na	$ 4,000,000	$ 4,800,000
2068	$ 800,000	100	12hr shifts M-F	150	12hr shifts M-F	$ 1,000,000	250	12hr shifts M-F	-	na	$ 1,500,000	$ 3,300,000
2069	$ 300,000	150	12hr shifts M-F	-	na	$ 500,000	-	na	-	na	$ -	$ 800,000
2070	$ 340,000	50	12hr shifts M-F	150	12hr shifts M-F	$ 600,000	-	na	-	na	$ -	$ 940,000
2071	$ 360,000	175	12hr shifts M-F	150	12hr shifts M-F	$ 1,200,000	400	12hr shifts M-F	-	na	$ 2,000,000	$ 3,560,000
2072	$ 300,000	75	12hr shifts M-F	150	12hr shifts M-F	$ 800,000	1440	24hr shifts Mon-Sun	-	na	$ 5,000,000	$ 6,100,000
2073	$ 800,000	150	12hr shifts M-F	-	na	$ 500,000	720	12hr shifts M-F	-	na	$ -	$ 1,300,000
2074	$ 300,000	100	12hr shifts M-F	150	12hr shifts M-F	$ 1,000,000	250	12hr shifts M-F	-	na	$ 1,500,000	$ 2,800,000
2075	$ 340,000	150	12hr shifts M-F	-	na	$ 500,000	250	12hr shifts M-F	630	12hr shifts M-F	$ 3,000,000	$ 3,840,000
2076	$ 360,000	50	12hr shifts M-F	150	12hr shifts M-F	$ 600,000	-	na	-	na	$ -	$ 960,000
2077	$ 300,000	75	12hr shifts M-F	150	12hr shifts M-F	$ 800,000	-	na	-	na	$ -	$ 1,100,000
2078	$ 800,000	175	12hr shifts M-F	150	12hr shifts M-F	$ 1,200,000	720	12hr shifts M-F	-	na	$ 4,000,000	$ 6,000,000
2079	$ 300,000	100	12hr shifts M-F	150	12hr shifts M-F	$ 1,000,000	250	12hr shifts M-F	-	na	$ 1,500,000	$ 2,800,000
2080	$ 340,000	150	12hr shifts M-F	-	na	$ 500,000	-	na	-	na	$ -	$ 840,000
2081	$ 360,000	150	12hr shifts M-F	-	na	$ 600,000	-	na	-	na	$ -	$ 960,000

SOURCE: Summarized from "MVN - IHNC - Cost and Closure Matrix - Revised 3-29.xlsm".

* Includes normal O&M.

2.1.1 Annual Maintenance

Three of the six "*No impact to navigation work items*" occur annually throughout the analysis period (i.e., routine maintenance, ED instrumentation, and security maintenance), totaling $300,000 per year. These three "*no impact*" annual cost items were loaded, and handled by the model, slightly different than the cyclical maintenance as will be discussed in section 4.2. The remaining three maintenance actions listed under the "*No impact to navigation work items*", while having no navigation impact, were loaded into the model similarly to the other cyclical maintenance work items containing navigation impacts since they vary by year.

2.1.2 Scheduled Cyclical Maintenance

The eleven work items with navigation impacts were defined with eleven different service disruption definitions / durations. Ten of the service disruption definitions / durations were defined as scheduled events for maintenance work items and are discussed in this section. One of the service disruption definition / durations was defined as unscheduled for the probabilistic hurricane event and is discussed in the next section 2.2. A tonnage-transit curve has been developed for each of these service disruption descriptions for loading into NIM as discussed in the capacity analysis documentation.

2.1.2.1 Scheduled Work Items with Service Disruptions

Since different work items can share the same service disruption definition / duration (however this is not the case in the IHNC Lock without-project condition), the maintenance events will be discussed by their service disruption definition / duration. The ten service disruption definitions / durations identified for the maintenance work items are defined in the sections below.

2.1.2.1.1 1,440-Hour 24-Hour/Day Work Item Event

The tonnage-transit curve simulations for the 1,440-hour 24-hour/day service disruption event assumes a consecutive 60-day closure of the lock. This service disruption event was defined for dewatering & monitoring, major repair, and gate work item event.

2.1.2.1.2 720-Hour 12-Hour/Day Work Item Event

The tonnage-transit curve simulations for the 720-hour 12-hour/day service disruption event assumed 12-hour/day service disruption Monday-Friday over 60 weekdays (84 calendar days). This service disruption event was defined for rehabilitation of west and east chamber guidewalls work item event.

2.1.2.1.3 630-Hour 12-Hour/Day Work Item Event

The tonnage-transit curve simulations for the 630-hour 12-hour/day service disruption event assumed 12-hour/day service disruption Monday-Friday over 52.5 weekdays (72.5 calendar days). This service disruption was defined for rehabilitation of north-west and south-west guidewalls work item event.

2.1.2.1.4 400-Hour 12-Hour/Day Work Item Event

The tonnage-transit curve simulations for the 400-hour 12-hour/day service disruption event assumed 12-hour/day service disruption Monday-Friday over 33.3 weekdays (45.3 calendar days). This service disruption was defined for rehabilitation of the north-east and south-east guidewalls work item event.

2.1.2.1.5 250-Hour 12-Hour/Day Work Item Event

The tonnage-transit curve simulations for the 250-hour 12-hour/day service disruption event assumed 12-hour/day service disruption Monday-Friday over 20.8 weekdays (28.8 calendar days). This service disruption was defined for rehabilitation of north-east, north-west, south-east, and south-west Dolphins work item event.

2.1.2.1.6 175-Hour 12-Hour/Day Work Item Event

The tonnage-transit curve simulations for the 175-hour 12-hour/day service disruption event assumed 12-hour/day service disruption Monday-Friday over 14.6 weekdays (18.6 calendar days). This service disruption was defined for rewiring and machinery rehabilitation work item event.

2.1.2.1.7 150-Hour 12-Hour/Day Work Item Event

The tonnage-transit curve simulations for the 150-hour 12-hour/day service disruption event assumed 12-hour/day service disruption Monday-Friday over 12.5 weekdays (16.5 calendar days). This service disruption was defined for maintenance by hired labor units work item event.

2.1.2.1.8 100-Hour 12-Hour/Day Work Item Event

The tonnage-transit curve simulations for the 100-hour 12-hour/day service disruption event assumed 12-hour/day service disruption Monday-Friday over 8.3 weekdays (10.3 calendar days). This service disruption was defined for rehabilitation of the west and east chamber guidewall armoring work item event.

2.1.2.1.9 75-Hour 12-Hour/Day Work Item Event

The tonnage-transit curve simulations for the 75-hour 12-hour/day service disruption event assumed 12-hour/day service disruption Monday-Friday over 6.3 weekdays (8.3 calendar days). This service disruption was defined for rehabilitation of the north-west and south-west guidewall face timbers work item event.

2.1.2.1.10 50-Hour 12-Hour/Day Work Item Event

The tonnage-transit curve simulations for the 50-hour 12-hour/day service disruption event assumed 12-hour/day service disruption Monday-Friday over 4.2 weekdays (4.2 calendar days). This service disruption was defined for rehabilitation of the north-east and south-east guidewall face timbers work item event.

2.1.2.2 Scheduled Work Items Without Service Disruptions

For the three work items defined as having no navigation impacts, one actually is expected to have intermittent closures of less than 2-hours over a 10-hour period (PLC System Upgrades). This service disruption was not modeled in this analysis (this event was assumed to have no navigation impact).

2.2 Probabilistic Repairs

As previously discussed, eleven work items were defined with navigation impacts and were defined with eleven different service disruption definitions / durations. Ten of the service disruption definitions / durations were defined for scheduled maintenance events, however, the final service disruption definition / durations is for unscheduled repair actions (probabilistic) generated by hurricane events.

The engineering cost-closure workbook contained a hurricane event every five years. This probabilistic 24-hour/day 175-hour event is defined in the engineering maintenance matrix reflects storms of 5-year intensity or higher (top of lock is at a 5-year level of protection). Given this event is probabilistic as opposed to being cyclical, it was removed from the cost-closure matrix and is input to NIM through separate tables for probabilistic events. Per USN Hurricane Havens Handbook for Houston/Galveston (closest listed port to Lake Charles), there were 92 systems of tropical storm strength or higher in the 111-year period 1886 to 1996. Of these, 33 were hurricane-strength with 29 of 92 tropical storms occurring in September. For hurricane-strength storms, however, 11 of 33 occurred in August, and as such August was identified as the most likely month for a hurricane-related drainage events. Post-1996 data has not been added to the online Handbook.

As with the scheduled service disruption events, for NIM a tonnage-transit curve has been developed for the hurricane event. It is possible that a hurricane event that affects IHNC Lock will also result in closure to other nearby GIWW locks. This analysis assessed the closure impact of a hurricane event to IHNC Lock only. It was assumed that neighboring GIWW locks will not be impacted by the hurricane event that was simulated at IHNC lock.

3. The WITH-PROJECT CONDITION ALTERNATIVES

The four alternatives considered in the IHNC Lock GRR entail building a larger concrete U-frame lock north of Claiborne Avenue varying by chamber size:

Alternative #1 - 110' x 900' x 22'

Alternative #2 - 110' x 1200' x 22'

Alternative #3 - 75' x 900' x 22'

Alternative #4 - 75' x 1200' x 22'

Cost and closure data to be considered for the with-project condition alternatives include the construction cost and navigation service disruptions, and the OMRR&R costs and navigation service disruptions.

3.1 With-Project Condition Construction Costs

As previously discussed, the data assumes a with-project on-line year of 2032. Construction costs received for the analysis are summarized by year in **TABLE *A1-1*.**

TABLE A1-1: With-Project Condition Construction Costs by Alternative (FY 2016 Dollars)

Fiscal Year	Alternative #1 110' x 900' x 22'	Alternative #2 110' x 1200' x 22'	Alternative #3 75' x 900' x 22'	Alternative #4 75' x 1200' x 22'
2019	$ 35,433,022	$ 36,326,993	$ 33,798,699	$ 35,190,332
2020	$ 35,433,022	$ 36,326,993	$ 33,798,699	$ 35,190,332
2021	$ 119,141,064	$ 120,602,013	$ 118,080,295	$ 119,038,728
2022	$ 111,893,027	$ 121,925,964	$ 110,105,115	$ 116,494,339
2023	$ 117,124,839	$ 127,831,005	$ 114,994,198	$ 122,074,527
2024	$ 143,069,423	$ 153,710,357	$ 140,880,907	$ 147,957,946
2025	$ 152,410,390	$ 163,012,667	$ 150,187,576	$ 157,262,666
2026	$ 92,486,471	$ 98,203,021	$ 91,234,563	$ 95,017,971
2027	$ 40,510,744	$ 40,360,024	$ 40,377,022	$ 40,369,422
2028	$ 54,126,277	$ 53,902,410	$ 53,927,658	$ 53,916,369
2029	$ 22,118,816	$ 22,060,246	$ 22,066,851	$ 22,063,898
2030	$ 18,578,143	$ 18,519,573	$ 18,526,179	$ 18,523,225
2031	$ 9,783,228	$ 9,749,104	$ 9,752,952	$ 9,751,231
2032	$ -	$ -	$ -	$ -
2033	$ -	$ -	$ -	$ -
2034	$ -	$ -	$ -	$ -
2035	$ -	$ -	$ -	$ -
	$ 952,108,468	$ 1,002,530,370	$ 937,730,713	$ 972,850,987

3.2 With-Project Condition Scheduled Maintenance

As with the IHNC Lock without-project condition, the with-project scheduled maintenance assumptions were also received in workbook "*MVN - IHNC - Cost and Closure Matrix – Revised 3-29.xlsm*". It was assumed in this OMRR&R workbook that the new lock would come on-line in fiscal year 2032 and as such the maintenance data for all four with-project alternatives were identical to the without-project condition up through year 2031. It was assumed that construction work would not impact navigation significantly since a bypass channel is to be built alongside the construction site of the new lock to avoid serious disruptions to navigation traffic. Operations of the canal during construction is assumed to mimic WOPC operations in that tows will lock through the existing IHNC Lock chamber and then move through the bypass channel alongside the new construction site. The OMRR&R is slightly different between alternatives.

Graphics comparing the cyclical maintenance between the with-project condition alternatives and the existing / Without-Project Condition are shown in FIGURE A1- and FIGURE A1-1. FIGURE A1- shows the total maintenance hours by year and FIGURE A1-1 shows the present value of repair costs at a 2.875% discount rate (to help highlight that differences earlier in the analysis period are more important). Note that the maintenance costs are identical at the existing / Without-Project Condition under the With-Project Conditions from 2019-2031. Summaries of the with-project condition OMRR&R costs are shown in **TABLE** ***A1-2*** through **TABLE** ***A1-5***.

FIGURE A1-0: Comparison of Total Annual Maintenance Hours between Alternatives

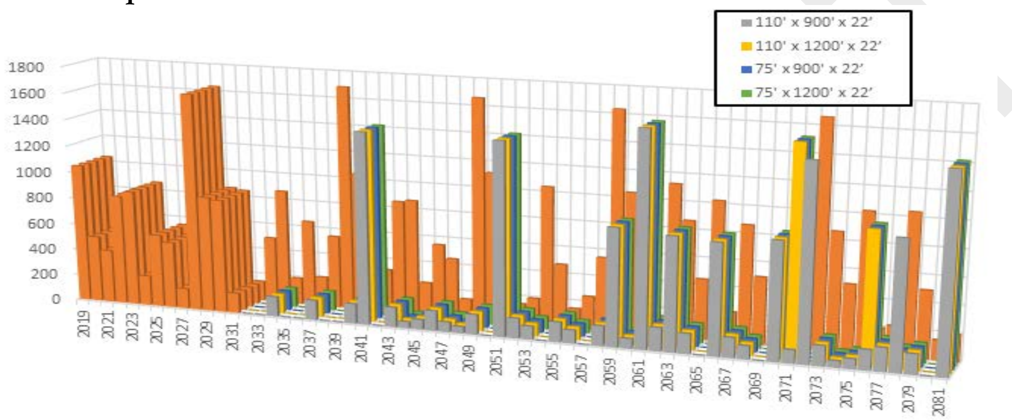
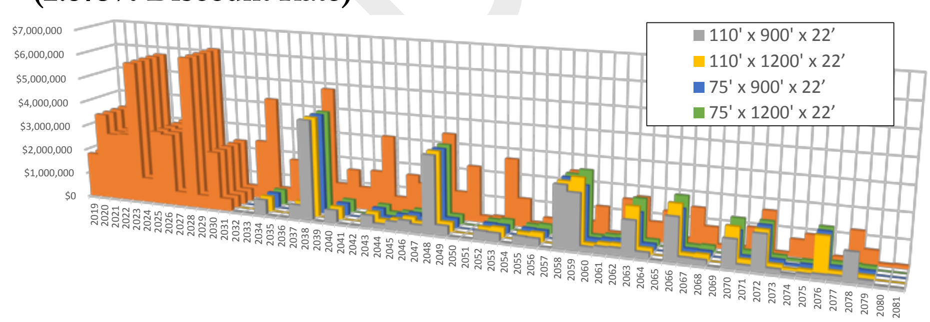


FIGURE A1-1: Present Value of Annual Cyclical Maintenance Costs between Alternatives (2.875% Discount Rate)



As in the without-project condition, the scheduled maintenance data, or Repair, Replacement, and Rehabilitation (OMRR&R), included primarily scheduled maintenance work items, but also included one probabilistic event (hurricane). Additionally, some of the work items were defined as not having impacts to navigation and some of the work items were defined as occurring annually. For the with-project conditions the data included the following fifteen maintenance work items (categorized by maintenance cost category):

No Impact to Navigation Work Items

- Routine Maintenance (annual $250K)
- Security Maintenance (annual $30K)
- ED Instrumentation (annual $20K)

- A/E Instrumentation (5 year cycle $40K)
- Periodic Inspection (5 year cycle $60K)
- PLC System Upgrades (5 year cycle $500K)

Minor Closures

- Maintenance by Hired Labor Units (3 year cycle $675K)
- Rewiring and Machinery Rehabilitation (30 year cycle $750K)
- Rehabilitation of W & E Chamber Guidewall Armoring (25 year cycle $650K)
- Rehabilitation of NW & SW Guidewall Face Timbers (15 year cycle $500K)
- Rehabilitation of NE & SE Guidewall Face Timbers (15 year cycle $250K)

Major Closures

- Dewatering & Monitoring / Major Repairs / Gates (10 year cycle $4M)
- Rehabilitation of E & W Chamber Guidewalls (50 year cycle $4M)
- Rehabilitation of NW & SW Guidewall & Dolphins (35 year cycle $5M)
- Rehabilitation of NE & SE Guidewall & Dolphins (35 year cycle $3M)

Probabilistic Closures

- Hurricane (24-hrs/day 175-hour disruption)

TABLE A1-2: With-Project Alternative #1 110' x 900', Annual OMRR&R Assumptions (FY 2016 Dollars)

Fiscal Year	No Impact to Navigation	Minor Repair Work Items: Service Disrupion 1 Hours	Service Disrupion 1 Pattern	Service Disrupion 2 Hours	Service Disrupion 2 Pattern	Cost	Major Repair work Items: Service Disrupion 3 Hours	Service Disrupion 3 Pattern	Service Disrupion 4 Hours	Service Disrupion 4 Pattern	Cost	TOTAL COST
2032	$ 300,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 300,000
2033	$ 800,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 800,000
2034	$ 300,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 975,000
2035	$ 340,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 340,000
2036	$ 360,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 360,000
2037	$ 300,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 975,000
2038	$ 800,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 800,000
2039	$ 300,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 300,000
2040	$ 340,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 1,015,000
2041	$ 360,000	-	na	-	na	$ -	1440	24hr shifts Mon-Sun	-	na	$ 4,000,000	$ 4,360,000
2042	$ 300,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 300,000
2043	$ 800,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 1,475,000
2044	$ 300,000	50	12hr shifts M-F	-	na	$ 250,000	-	na	-	na	$ -	$ 550,000
2045	$ 340,000	75	12hr shifts M-F	-	na	$ 500,000	-	na	-	na	$ -	$ 840,000
2046	$ 360,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 1,035,000
2047	$ 300,000	75	12hr shifts M-F	-	na	$ 500,000	-	na	-	na	$ -	$ 800,000
2048	$ 800,000	50	12hr shifts M-F	-	na	$ 250,000	-	na	-	na	$ -	$ 1,050,000
2049	$ 300,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 975,000
2050	$ 340,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 340,000
2051	$ 360,000	-	na	-	na	$ -	1440	24hr shifts Mon-Sun	-	na	$ 4,000,000	$ 4,360,000
2052	$ 300,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 975,000
2053	$ 800,000	100	12hr shifts M-F	-	na	$ 650,000	-	na	-	na	$ -	$ 1,450,000
2054	$ 300,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 300,000
2055	$ 340,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 1,015,000
2056	$ 360,000	100	12hr shifts M-F	-	na	$ 650,000	-	na	-	na	$ -	$ 1,010,000
2057	$ 300,000	-	na	-	na	$ -	-	na	-	na	$ 3,500,000	$ 3,800,000
2058	$ 800,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 1,475,000
2059	$ 300,000	50	12hr shifts M-F	-	na	$ 250,000	825	12hr shifts M-F	-	na	$ 5,000,000	$ 5,550,000
2060	$ 340,000	75	12hr shifts M-F	-	na	$ 500,000	-	na	-	na	$ -	$ 840,000
2061	$ 360,000	150	12hr shifts M-F	-	na	$ 675,000	1440	24hr shifts Mon-Sun	-	na	$ 4,000,000	$ 5,035,000
2062	$ 300,000	175	12hr shifts M-F	-	na	$ 750,000	-	na	-	na	$ -	$ 1,050,000
2063	$ 800,000	50	12hr shifts M-F	75	12hr shifts M-F	$ 750,000	720	12hr shifts M-F	-	na	$ 3,000,000	$ 4,550,000
2064	$ 300,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 975,000
2065	$ 340,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 340,000
2066	$ 360,000	-	na	-	na	$ -	825	12hr shifts M-F	-	na	$ 5,000,000	$ 5,360,000
2067	$ 300,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 975,000
2068	$ 800,000	100	12hr shifts M-F	-	na	$ 650,000	-	na	-	na	$ -	$ 1,450,000
2069	$ 300,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 300,000
2070	$ 340,000	150	12hr shifts M-F	-	na	$ 675,000	720	12hr shifts M-F	-	na	$ 3,000,000	$ 4,015,000
2071	$ 360,000	100	12hr shifts M-F	-	na	$ 650,000	-	na	-	na	$ -	$ 1,010,000
2072	$ 300,000	-	na	-	na	$ -	1440	24hr shifts Mon-Sun	-	na	$ 4,000,000	$ 4,300,000
2073	$ 800,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 1,475,000
2074	$ 300,000	50	12hr shifts M-F	-	na	$ 250,000	-	na	-	na	$ -	$ 550,000
2075	$ 340,000	75	12hr shifts M-F	-	na	$ 500,000	-	na	-	na	$ -	$ 840,000
2076	$ 360,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 1,035,000
2077	$ 300,000	175	12hr shifts M-F	-	na	$ 750,000	-	na	-	na	$ -	$ 1,050,000
2078	$ 800,000	50	12hr shifts M-F	75	12hr shifts M-F	$ 750,000	825	12hr shifts M-F	-	na	$ 4,000,000	$ 5,550,000
2079	$ 300,000	-	na	150	12hr shifts M-F	$ 675,000	-	na	-	na	$ -	$ 975,000
2080	$ 340,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 340,000
2081	$ 360,000	-	na	-	na	$ -	1440	24hr shifts Mon-Sun	-	na	$ 4,000,000	$ 4,360,000

TABLE A1-3: With-Project Alternative #2 110' x 1200', Annual OMRR&R Assumptions (FY 2016 Dollars)

Fiscal Year	No Impact to Navigation Cost *	Minor Repair Work Items: Service Disrupion 1 Hours	Service Disrupion 1 Pattern	Service Disrupion 2 Hours	Service Disrupion 2 Pattern	Cost	Major Repair work Items: Service Disrupion 3 Hours	Service Disrupion 3 Pattern	Service Disrupion 4 Hours	Service Disrupion 4 Pattern	Cost	TOTAL COST
2032	$ 300,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 300,000
2033	$ 800,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 800,000
2034	$ 300,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 975,000
2035	$ 340,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 340,000
2036	$ 360,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 360,000
2037	$ 300,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 975,000
2038	$ 800,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 800,000
2039	$ 300,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 300,000
2040	$ 340,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 1,015,000
2041	$ 360,000	-	na	-	na	$ -	1440	12hr shifts M-F	-	na	$ 4,000,000	$ 4,360,000
2042	$ 300,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 300,000
2043	$ 800,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 1,475,000
2044	$ 300,000	50	12hr shifts M-F	-	na	$ 300,000	-	na	-	na	$ -	$ 600,000
2045	$ 340,000	75	12hr shifts M-F	-	na	$ 450,000	-	na	-	na	$ -	$ 790,000
2046	$ 360,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 1,035,000
2047	$ 300,000	75	12hr shifts M-F	-	na	$ 450,000	-	na	-	na	$ -	$ 750,000
2048	$ 800,000	50	12hr shifts M-F	-	na	$ 300,000	-	na	-	na	$ -	$ 1,100,000
2049	$ 300,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 975,000
2050	$ 340,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 340,000
2051	$ 360,000	-	na	-	na	$ -	1440	12hr shifts M-F	-	na	$ 4,000,000	$ 4,360,000
2052	$ 300,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 975,000
2053	$ 800,000	100	12hr shifts M-F	-	na	$ 800,000	-	na	-	na	$ -	$ 1,600,000
2054	$ 300,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 300,000
2055	$ 340,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 1,015,000
2056	$ 360,000	100	12hr shifts M-F	-	na	$ 800,000	-	na	-	na	$ -	$ 1,160,000
2057	$ 300,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 300,000
2058	$ 800,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 1,475,000
2059	$ 300,000	50	12hr shifts M-F	-	na	$ 300,000	825	12hr shifts M-F	-	na	$ 6,000,000	$ 6,600,000
2060	$ 340,000	75	12hr shifts M-F	-	na	$ 450,000	-	na	-	na	$ -	$ 790,000
2061	$ 360,000	150	12hr shifts M-F	-	na	$ 675,000	1440	12hr shifts M-F	-	na	$ 4,000,000	$ 5,035,000
2062	$ 300,000	-	na	175	12hr shifts M-F	$ 750,000	-	na	-	na	$ -	$ 1,050,000
2063	$ 800,000	75	12hr shifts M-F	50	12hr shifts M-F	$ 750,000	720	12hr shifts M-F	-	na	$ 4,000,000	$ 5,550,000
2064	$ 300,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 975,000
2065	$ 340,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 340,000
2066	$ 360,000	-	na	-	na	$ -	825	12hr shifts M-F	-	na	$ 6,000,000	$ 6,360,000
2067	$ 300,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 975,000
2068	$ 800,000	100	12hr shifts M-F	-	na	$ 800,000	-	na	-	na	$ -	$ 1,600,000
2069	$ 300,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 300,000
2070	$ 340,000	150	12hr shifts M-F	-	na	$ 675,000	720	12hr shifts M-F	-	na	$ 4,000,000	$ 5,015,000
2071	$ 360,000	100	12hr shifts M-F	-	na	$ 800,000	1440	12hr shifts M-F	-	na	$ 4,000,000	$ 5,160,000
2072	$ 300,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 300,000
2073	$ 800,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 1,475,000
2074	$ 300,000	50	12hr shifts M-F	-	na	$ 300,000	-	na	-	na	$ -	$ 600,000
2075	$ 340,000	75	12hr shifts M-F	-	na	$ 450,000	-	na	-	na	$ -	$ 790,000
2076	$ 360,000	150	12hr shifts M-F	-	na	$ 675,000	825	12hr shifts M-F	-	na	$ 5,000,000	$ 6,035,000
2077	$ 300,000	175	12hr shifts M-F	-	na	$ 750,000	-	na	-	na	$ -	$ 1,050,000
2078	$ 800,000	75	12hr shifts M-F	50	12hr shifts M-F	$ 750,000	-	na	-	na	$ -	$ 1,550,000
2079	$ 300,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 975,000
2080	$ 340,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 340,000
2081	$ 360,000	-	na	-	na	$ -	1440	12hr shifts M-F	-	na	$ 4,000,000	$ 4,360,000

TABLE A1-4: With-Project Alternative #3 75' x 900', Annual OMRR&R Assumptions (FY 2016 Dollars)

Fiscal Year	No Impact to Navigation Cost *	Minor Repair Work Items: Service Disrupion 1 Hours	Service Disrupion 1 Pattern	Service Disrupion 2 Hours	Service Disrupion 2 Pattern	Cost	Major Repair work Items: Service Disrupion 3 Hours	Service Disrupion 3 Pattern	Service Disrupion 4 Hours	Service Disrupion 4 Pattern	Cost	TOTAL COST
2032	$ 300,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 300,000
2033	$ 800,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 800,000
2034	$ 300,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 975,000
2035	$ 340,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 340,000
2036	$ 360,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 360,000
2037	$ 300,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 975,000
2038	$ 800,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 800,000
2039	$ 300,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 300,000
2040	$ 340,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 1,015,000
2041	$ 360,000	-	na	-	na	$ -	1440	24hr shifts Mon-Sun	-	na	$ 3,000,000	$ 3,360,000
2042	$ 300,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 300,000
2043	$ 800,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 1,475,000
2044	$ 300,000	50	12hr shifts M-F	-	na	$ 250,000	-	na	-	na	$ -	$ 550,000
2045	$ 340,000	75	12hr shifts M-F	-	na	$ 500,000	-	na	-	na	$ -	$ 840,000
2046	$ 360,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 1,035,000
2047	$ 300,000	75	12hr shifts M-F	-	na	$ 500,000	-	na	-	na	$ -	$ 800,000
2048	$ 800,000	50	12hr shifts M-F	-	na	$ 250,000	-	na	-	na	$ -	$ 1,050,000
2049	$ 300,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 975,000
2050	$ 340,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 340,000
2051	$ 360,000	-	na	-	na	$ -	1440	24hr shifts Mon-Sun	-	na	$ 3,000,000	$ 3,360,000
2052	$ 300,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 975,000
2053	$ 800,000	100	12hr shifts M-F	-	na	$ 650,000	-	na	-	na	$ -	$ 1,450,000
2054	$ 300,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 300,000
2055	$ 340,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 1,015,000
2056	$ 360,000	100	12hr shifts M-F	-	na	$ 650,000	-	na	-	na	$ -	$ 1,010,000
2057	$ 300,000	-	na	-	na	$ -	-	na	-	na	$ 3,500,000	$ 3,800,000
2058	$ 800,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 1,475,000
2059	$ 300,000	50	12hr shifts M-F	-	na	$ 250,000	825	12hr shifts M-F	-	na	$ 5,000,000	$ 5,550,000
2060	$ 340,000	75	12hr shifts M-F	-	na	$ 500,000	-	na	-	na	$ -	$ 840,000
2061	$ 360,000	150	12hr shifts M-F	-	na	$ 675,000	1440	24hr shifts Mon-Sun	-	na	$ 3,000,000	$ 4,035,000
2062	$ 300,000	175	12hr shifts M-F	-	na	$ 750,000	-	na	-	na	$ -	$ 1,050,000
2063	$ 800,000	50	12hr shifts M-F	75	12hr shifts M-F	$ 750,000	720	12hr shifts M-F	-	na	$ 3,000,000	$ 4,550,000
2064	$ 300,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 975,000
2065	$ 340,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 340,000
2066	$ 360,000	-	na	-	na	$ -	825	12hr shifts M-F	-	na	$ 5,000,000	$ 5,360,000
2067	$ 300,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 975,000
2068	$ 800,000	100	12hr shifts M-F	-	na	$ 650,000	-	na	-	na	$ -	$ 1,450,000
2069	$ 300,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 300,000
2070	$ 340,000	150	12hr shifts M-F	-	na	$ 675,000	720	12hr shifts M-F	-	na	$ 3,000,000	$ 4,015,000
2071	$ 360,000	100	12hr shifts M-F	-	na	$ 650,000	1440	24hr shifts Mon-Sun	-	na	$ 3,000,000	$ 4,010,000
2072	$ 300,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 300,000
2073	$ 800,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 1,475,000
2074	$ 300,000	50	12hr shifts M-F	-	na	$ 250,000	-	na	-	na	$ -	$ 550,000
2075	$ 340,000	75	12hr shifts M-F	-	na	$ 500,000	-	na	-	na	$ -	$ 840,000
2076	$ 360,000	150	12hr shifts M-F	-	na	$ 675,000	825	12hr shifts M-F	-	na	$ 4,000,000	$ 5,035,000
2077	$ 300,000	175	12hr shifts M-F	-	na	$ 750,000	-	na	-	na	$ -	$ 1,050,000
2078	$ 800,000	50	12hr shifts M-F	75	12hr shifts M-F	$ 750,000	-	na	-	na	$ -	$ 1,550,000
2079	$ 300,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 975,000
2080	$ 340,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 340,000
2081	$ 360,000	-	na	-	na	$ -	1440	24hr shifts Mon-Sun	-	na	$ 3,000,000	$ 3,360,000

TABLE A1-5: With-Project Alternative #4 75' x 1200', Annual OMRR&R Assumptions (FY 2016 Dollars)

Fiscal Year	No Impact to Navigation Cost *	Minor Repair Work Items					Major Repair work Items					TOTAL COST
		Service Disrupion 1		Service Disrupion 2			Service Disrupion 3		Service Disrupion 4			
		Hours	Pattern	Hours	Pattern	Cost	Hours	Pattern	Hours	Pattern	Cost	
2032	$ 300,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 300,000
2033	$ 800,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 800,000
2034	$ 300,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 975,000
2035	$ 340,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 340,000
2036	$ 360,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 360,000
2037	$ 300,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 975,000
2038	$ 800,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 800,000
2039	$ 300,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 300,000
2040	$ 340,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 1,015,000
2041	$ 360,000	-	na	-	na	$ -	1440	24hr shifts Mon-Sun	-	na	$ 3,000,000	$ 3,360,000
2042	$ 300,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 300,000
2043	$ 800,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 1,475,000
2044	$ 300,000	50	12hr shifts M-F	-	na	$ 300,000	-	na	-	na	$ -	$ 600,000
2045	$ 340,000	75	12hr shifts M-F	-	na	$ 450,000	-	na	-	na	$ -	$ 790,000
2046	$ 360,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 1,035,000
2047	$ 300,000	75	12hr shifts M-F	-	na	$ 450,000	-	na	-	na	$ -	$ 750,000
2048	$ 800,000	50	12hr shifts M-F	-	na	$ 300,000	-	na	-	na	$ -	$ 1,100,000
2049	$ 300,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 975,000
2050	$ 340,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 340,000
2051	$ 360,000	-	na	-	na	$ -	1440	24hr shifts Mon-Sun	-	na	$ 3,000,000	$ 3,360,000
2052	$ 300,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 975,000
2053	$ 800,000	100	12hr shifts M-F	-	na	$ 800,000	-	na	-	na	$ -	$ 1,600,000
2054	$ 300,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 300,000
2055	$ 340,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 1,015,000
2056	$ 360,000	100	12hr shifts M-F	-	na	$ 800,000	-	na	-	na	$ -	$ 1,160,000
2057	$ 300,000	-	na	-	na	$ -	-	na	-	na	$ 3,500,000	$ 3,800,000
2058	$ 800,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 1,475,000
2059	$ 300,000	50	12hr shifts M-F	-	na	$ 300,000	825	12hr shifts M-F	-	na	$ 6,000,000	$ 6,600,000
2060	$ 340,000	75	12hr shifts M-F	-	na	$ 450,000	-	na	-	na	$ -	$ 790,000
2061	$ 360,000	150	12hr shifts M-F	-	na	$ 675,000	1440	24hr shifts Mon-Sun	-	na	$ 3,000,000	$ 4,035,000
2062	$ 300,000	175	12hr shifts M-F	-	na	$ 750,000	-	na	-	na	$ -	$ 1,050,000
2063	$ 800,000	50	12hr shifts M-F	75	12hr shifts M-F	$ 750,000	720	12hr shifts M-F	-	na	$ 4,000,000	$ 5,550,000
2064	$ 300,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 975,000
2065	$ 340,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 340,000
2066	$ 360,000	-	na	-	na	$ -	825	12hr shifts M-F	-	na	$ 6,000,000	$ 6,360,000
2067	$ 300,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 975,000
2068	$ 800,000	100	12hr shifts M-F	-	na	$ 800,000	-	na	-	na	$ -	$ 1,600,000
2069	$ 300,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 300,000
2070	$ 340,000	150	12hr shifts M-F	-	na	$ 675,000	720	12hr shifts M-F	-	na	$ 4,000,000	$ 5,015,000
2071	$ 360,000	100	12hr shifts M-F	-	na	$ 800,000	1440	24hr shifts Mon-Sun	-	na	$ 3,000,000	$ 4,160,000
2072	$ 300,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 300,000
2073	$ 800,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 1,475,000
2074	$ 300,000	50	12hr shifts M-F	-	na	$ 300,000	-	na	-	na	$ -	$ 600,000
2075	$ 340,000	75	12hr shifts M-F	-	na	$ 450,000	-	na	-	na	$ -	$ 790,000
2076	$ 360,000	150	12hr shifts M-F	-	na	$ 675,000	825	12hr shifts M-F	-	na	$ 5,000,000	$ 6,035,000
2077	$ 300,000	175	12hr shifts M-F	-	na	$ 750,000	-	na	-	na	$ -	$ 1,050,000
2078	$ 800,000	50	12hr shifts M-F	75	12hr shifts M-F	$ 750,000	-	na	-	na	$ -	$ 1,550,000
2079	$ 300,000	150	12hr shifts M-F	-	na	$ 675,000	-	na	-	na	$ -	$ 975,000
2080	$ 340,000	-	na	-	na	$ -	-	na	-	na	$ -	$ 340,000
2081	$ 360,000	-	na	-	na	$ -	1440	24hr shifts Mon-Sun	-	na	$ 3,000,000	$ 3,360,000

3.2.1 Annual Maintenance

As under the existing (without-project condition) three of the six "*No impact to navigation work items*" occur annually throughout the analysis period (i.e., routine maintenance, ED instrumentation, and security maintenance). Unlike the existing (without-project condition) the minor closure Maintenance by Hired Labor Units work item is now on a 3-year cycle. The aforementioned three "*no impact*" annual cost items were loaded, and handled by the model, slightly different than the cyclical maintenance as will be discussed in section 4.2. The remaining three maintenance actions listed under the "*No impact to navigation work items*", while having no navigation impact, were loaded into the model similarly to the other cyclical maintenance work items containing navigation impacts.

3.2.2 Scheduled Cyclical Maintenance

The ten work items with navigation impacts were defined with nine different service disruption definitions / durations. Nine of the service disruption definitions / durations were defined as scheduled events for maintenance work items and are discussed in this section. As under the existing (without-project condition), one of the service disruption definition / durations was defined as unscheduled for the probabilistic hurricane event and is discussed in the next section 3.3. A tonnage-transit curve has been developed for each of these service disruption descriptions for loading into NIM as discussed in the capacity analysis documentation.

3.2.2.1 Scheduled Work Items with Service Disruptions

Since different work items can share the same service disruption definition / duration, the maintenance events will be discussed by their service disruption definition / duration. The nine service disruption definitions / durations identified for the maintenance work items are defined in the sections below.

3.2.2.1.1 1,440-Hour 24-Hour/Day Work Item Event

The tonnage-transit curve simulations for the 1,440-hour 24-hour/day service disruption event assumes a consecutive 60-day closure of the lock. This service disruption event was defined for dewatering & monitoring, major repair, and gate work item event.

3.2.2.1.2 825-Hour 12-Hour/Day Event

The tonnage-transit curve simulations for the 825-hour 12-hour/day service disruption event assumed 12-hour/day service disruption Monday-Friday over 68.8 weekdays (94.8 calendar days). This service disruption event was defined for both the Rehabilitation of Chamber Guidewall (W & E) and Rehabilitation of Guidewall & Dolphin (NW & SW) work item events.

3.2.2.1.3 720-Hour 12-Hour/Day Event

The tonnage-transit curve simulations for the 720-hour 12-hour/day service disruption event assumed 12-hour/day service disruption Monday-Friday over 60 weekdays (84 calendar days). This service disruption event was defined for the Rehabilitation of Guidewall & Dolphin (NE & SE) work item event.

3.2.2.1.4 175-Hour 12-Hour/Day Event

The tonnage-transit curve simulations for the 175-hour 12-hour/day service disruption event assumed 12-hour/day service disruption Monday-Friday over 14.6 weekdays (18.6 calendar days). This service disruption was defined for the Rewiring and Machinery Rehabilitation work item event.

3.2.2.1.5 150-Hour 12-Hour/Day Event

The tonnage-transit curve simulations for the 150-hour 12-hour/day service disruption event assumed 12-hour/day service disruption Monday-Friday over 12.5 weekdays (16.5 calendar days). This service disruption was defined for the Maintenance by Hired Labor Units work item event.

3.2.2.1.6 100-Hour 12-Hour/Day Event

The tonnage-transit curve simulations for the 100-hour 12-hour/day service disruption event assumed 12-hour/day service disruption Monday-Friday over 8.3 weekdays (10.3 calendar days). This service disruption was defined for the Rehabilitation of Chamber Guidewall Armoring (W & E) work item event.

3.2.2.1.7 75-Hour 12-Hour/Day Event

The tonnage-transit curve simulations for the 75-hour 12-hour/day service disruption event assumed 12-hour/day service disruption Monday-Friday over 6.3 weekdays (8.3 calendar days). This service disruption was defined for the Rehabilitation of Guidewall Face Timber (NW & SW) work item event.

3.2.2.1.8 50-Hour 12-Hour/Day Event

The tonnage-transit curve simulations for the 50-hour 12-hour/day service disruption event assumed 12-hour/day service disruption Monday-Friday over 4.2 weekdays (4.2 calendar days). This service disruption was defined for the Rehabilitation of Guidewall Face Timber (NE & SE) work item event.

3.2.2.2 Scheduled Work Items without Service Disruptions

For the three work items defined as having no navigation impacts, one actually is expected to have intermittent closures of less than 2-hours over a 10-hour period (PLC System Upgrades). This service disruption was not modeled in this analysis (this event was assumed to have no navigation impact).

3.3 Probabilistic Repairs

As previously discussed, for the with-project conditions, ten work items were defined with navigation impacts and were defined with nine different service disruption definitions / durations. Eight of the service disruption definitions / durations were defined for scheduled maintenance events, however, the final service disruption definition / durations is for unscheduled repair actions (probabilistic) generated by hurricane events as described in Section 2.2.

The engineering cost-closure workbook contained a hurricane event every five years. This probabilistic 24-hour/day 175-hour event that is defined in the engineering maintenance matrix reflects storms of 5-year intensity or higher (top of lock is at a 5-year level of protection). Per USN Hurricane Havens Handbook for Houston/Galveston (closest listed port to Lake Charles), there were 92 systems of tropical storm strength or higher in the 111-year period 1886 to 1996. Of these, 33 were hurricane-strength with 29 of 92 tropical storms occurring in September. For hurricane-strength storms, however, 11 of 33 occurred in August, and as such August was identified as the most likely month for a hurricane-related drainage event. Post-1996 data has not been added to the online Handbook. As with the scheduled service disruption events, for NIM a tonnage-transit curve has been developed for the hurricane event.

4. NAVIGATION INVESTMENT MODEL TABLES

NIM input, output, and execution data is stored in Microsoft Sequel (SQL) Server 2012 R2 database tables. The following sections briefly describe these NIM input tables: investments to consider, maintenance characteristics, and reliability characteristics.

4.1 Investments to Consider

The NIM model analyzes "*alternatives*" which are packaged into "*Runs*" and "*Investment Plans*" for analysis assuming specified analysis settings and parameters. An alternative has an implementation period, an implementation cost, possible post implementation system, reliability and demand changes, and possibly an implementation service disruption. An alternative can be the replacement of a single component (e.g., main chamber miter gates), a new lock (which essentially replaces multiple components), or a combination of investments across multiple navigation projects. An alternative can be defined as a single investment or as a package of multiple investments across multiple sites. Each of the alternatives in this study represent a new lock being constructed. The definition of an alternative is handled in the following database tables:

Alternative – The Alternative table contains the basic information on the alternative (e.g., implementation duration, post implementation network version, and post implementation movement set). As discussed in section 3, four alternatives are considered in the IHNC Lock GRR. The IHNC Lock with-project conditions are for a new lock just north of the existing lock. Until the with-project condition is complete, NIM operates under network version 1 where the existing lock node is activated and the new lock node is effectively inactive. Upon implementation of an alternative in the WPC, the existing lock is inactivated while the new lock node is activated. Each WPC alternative was designated with a separate network version ID since shipping plan will vary between alternatives since fewer trip vessels are needed when switching to an alternative of higher capacity. Each with-project condition network version requires calibration of the shipping plans, as does the existing / without-project condition. There is no change in movement demand at IHNC Lock post-implementation of an alternative, and as such there is only one "*movementSetID*" for each alternative. Moreover, the same "*movementSetID*" is used across all four alternatives.

AlternativeComponent – The AlternativeComponent table contains the changes to the probabilistic reliability of components from implementation of the alternative. As discussed in section ___ there are no reliability issues at the existing or new IHNC Lock facilities, however, the hurricane event is entered into NIM as a component since it is probabilistic (a constant 20% probability of occurring in any given year).

AlternativeCost – The AlternativeCost table contains the implementation costs associated with a non-component-level alternative (i.e., data from Table 2).

AlternativeDetail – The AlternativeDetail table contains details of the tonnage-transit time curve set used when an alternative is implemented. By specifying a unique tonnage-transit curve set for each year of implementation, curves can be created with a construction service disruption sequence. The tonnage-transit time curve family used after an alternative is implemented managed under the ALternativeLock table. The AlternativeDetail table was not used for the IHNC Lock analysis since there are no construction service disruptions.

AlternativeLock – The AlternativeLock table contains information on the change in the tonnage-transit time curve family ID after an alternative is implemented. Given that the new IHNC Lock location will be located at a different node within the network than the existing / without-project condition lock, the existing lock must also be deactivated from the network upon implementation of an alternative in this table.

AlternativeClosurePlanRule – The AlternativeClosurePlanRule table contains information on changes in scheduled closures that occur after the implementation of an alternative by chamber, closure type, and year (not by lock project).

AlternativeClosurePlanRuleXRef – The AlternativeClosurePlanRuleXRef table works in conjunction with the AlternativeClosurePlanRule tables and is used to identify which rule to apply to which lock project.

AlternativeMaintenanceCategory – The AlternativeMaintenanceCategory table contains information on how implementing an alternative modifies the maintenance plan at a lock (i.e., a absolute or relative adjustment to a maintenance category ID. This table was not needed for the IHNC Lock analysis.

ComponentScheduledReplacement – The ComponentScheduledReplacement table contains information on the annual impact of scheduled replacement of components. This table was not needed for the IHNC Lock analysis.

InvestmentPlan – The InvestmentPlan table is used to define one or more investments into a plan, and to specify the analysis parameters such as the planning period, base year, and discount rate. Additional investment plan specification is include in the InvestmentPlanRunXRef and the InvestmentPlanForecastXRef tables.

InvestmentPlanRunXRef – The InvestmentPlanRunXRef table defines which component RUNs are to be included in the investment plan. This table was not needed for the IHNC Lock study since there are no cases of multiple alternatives being implemented for the same investment plan.

InvestmentPlanForecastXRef – The InvestmentPlanForecastXRef stores whether or not a specific IP and forecast has been analyzed at when the results were created. This table was not used in this study since there are no cases of multiple forecast scenarios being implemented within the same investment plan.

4.2 Maintenance Characteristics Tables

The cyclical maintenance needs of the components and chambers (which can shift as investments are implemented) are handled in the following database tables:

ClosureTypes – The ClosureTypes table defines the 62 cyclical scheduled maintenance events discussed in sections 2.1.2.1 and 2.1.2.2 for the Without-Project Condition, and sections 3.2.2.1 and 3.2.2.2 for the With-Project Condition Alternatives.

GeneralCost – The GeneralCost table holds the fixed annual O&M project costs, including fixed cyclical costs. As discussed, three of the five maintenance actions listed under the IHNC Lock "*No impact to navigation work items*" were constant each year of the analysis period. Information on maintenance items that do not impact navigation and have costs that are constant each year of the analysis period, and associated with nodes, but not with particular components (e.g., normal O&M), are stored in the GeneralCost table.

ScheduledClosure – The ScheduledClosure table holds the cyclical scheduled closures for each lock project.

InitialClosurePlan – The InitialClosurePlan table specify the start year for each "*closurePlanNumber*" referenced in the ScheduledClosure table.

ScheduledClosureType – The ScheduledClosureType table defines a closure type which can then be related to the AlternativeClosurePlanRule table.

4.3 Reliability Characteristics Tables

Lock service disruption events not only occur from scheduled maintenance events, but can also occur from probabilistically driven events (risk). These unscheduled service disruption events are typically generated by unreliable lock components, and as such the NIM tables and field names are biased toward modeling lock parts. The structure for modeling of unreliable components, however, is applicable for any probabilistic event. In the case of the IHNC Lock study, the lock's structural, electrical, and mechanical systems have been determined relatively reliable, however, in the Gulf region hurricane events can impact IHNC Lock performance. Probabilistic events are described through a probability of unsatisfactory performance (PUP) and event-tree. While PUPs and event-trees can change through time from continued degradation and from failure and repair reliability adjustment, in the case of a hurricane event a flat PUP and a single branch event-tree was used. The hurricane probability and its lock service disruption consequence can be loaded and modeled in NIM through the following reliability tables:

Component – The Component table is used to itemize the components analyzed in an analysis by lock, chamber, the component's initial state, and specifies the year when risk is to start.

ComponentName – the ComponentName table simply allows the specification of a component name. This is done in a separate table to make the database more relational and efficient (e.g., valves can exist at multiple lock projects and multiple chambers at a given lock project).

ComponentState – the ComponentState table itemizes the various states a component can experience at a given lock project and chamber. NIM has the capability to branch to a different PUP function and event-tree from any of the second-level branches in the model's simulation of the unscheduled events. For a hurricane event where the repair from the event does not change either the future PUP or the future repair costs, only one "*stateID*" is needed and defined.

HazardFunction – The HazardFunction table holds the probabilities of unsatisfactory performance (PUP) by component age. The hurricane event is specified with an annual 20% probability of occurrence.

ComponentBranchProbability – The ComponentBranchProbability table holds the probabilities for the first layer of branching (failure level) of the reliability event-tree.

ComponentRiskDetail – The ComponentRiskDetail table holds the probabilities for the second layer of branching (fix level) of the reliability event-tree. At this level of branching the branch probability and post-repair reliability is defined.

ComponentRepairDetail – The ComponentRepairDetail table contains the repair protocol; service disruption specification and repair cost for each year of the repair (e.g., emergency repair in year 1, replacement in year 2). For the hurricane repair, the repair cost can be $1,500,000 or $5,000,000 depending on the severity of the hurricane event. Both possibilities result in a "*175-hour, 24-hour/day closure*" event.

ATTACHMENT 2: CAPACITY ANALYSIS

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US Army Corps of Engineers

Inner Harbor Navigation Canal (IHNC) - Lock Replacement, Orleans Parish, Louisiana, General Reevaluation Report

APPENDIX K ECONOMICS ATTACHMENT 2 CAPACITY ANALYSIS

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1. INTRODUCTION

This attachment documents the data sources, procedures, analytical methods and results of the Tonnage-Transit Time (Capacity) analysis for the Inner Harbor Navigation Canal (IHNC) Lock General Reevaluation Report study. While the IHNC Lock system analysis included nine lock projects in the region, the capacities and tonnage-transit time relationships for these other projects were obtained from the 2014 Calcasieu Lock Study.

1.1 Geographic Scope

For the IHNC Lock system analysis capacity curves were needed for 6 locks on the Gulf Intracoastal Waterway, 2 on the Port Allen route, and 1 lock on the Old River. All of these locks are located in the New Orleans district. FIGURE A2-0: IHNC Lock Study Projects**FIGURE A2-** shows the location of locks on the Gulf Intracoastal Waterway and Old River.

FIGURE A2-0: IHNC Lock Study Projects

1.2 Project Setting

The Intracoastal Waterway (IWW) traces the U.S. coast along the Gulf of Mexico from Apalachee Bay near St. Marks, Florida, to the Mexican border at Brownsville, Texas. Mile 0.0 of the IWW intersects the Mississippi River at mile 98.2 above Head of Passes (AHP), the location of Harvey lock, and extends eastwardly for approximately 376 miles and westwardly for approximately 690 miles. In addition to the mainstem, the IWW includes a major alternate channel, 64 miles long, which connects Morgan City, Louisiana to Port Allen, Louisiana at Mississippi River mile 227.6 AHP, and a parallel mainstem channel, 9.0 miles long, which joins the Mississippi River at mile 88.0 AHP, the location of Algiers lock, to the mainstem at IWW West mile 6.2. Project dimensions for the mainstem channel and the alternate route are 12 feet deep and 125 feet wide, except for the 150 foot width between the Mississippi River and Mobile Bay portion of the IWW East. Numerous side channels and tributaries intersect both the eastern and western mainstem channels providing access to inland areas and coastal harbors.

Within the study area, there are nine primary navigation locks. On the IWW mainstem west: Algiers, Harvey, Bayou Boeuf, Leland Bowman, and Calcasieu, with Port Allen and Bayou Sorrel on the IWW Morgan City Port Allen Alternate Route. On the Inner Harbor Navigation Canal (IHNC), which intersects the Mississippi River at mile 93 AHP there is the IHNC lock, connecting the eastern and western sections of the IWW. On Old River, there is the Old River lock near mile 304 AHP on the Mississippi River, which links the Atchafalaya and Mississippi Rivers. West of Calcasieu lock, the western most lock identified above, there are four additional navigation structures. These include the East and West Brazos River Floodgates located at IWW West mile 404.1, and the East and West Colorado River locks located at IWW West mile 444.8. There are no navigation structures on the IWW east of the IHNC lock. **TABLE A2-0** describes the physical characteristics and locations of the nine primary locks.

TABLE A2-0: System Physical Description of Lock Projects

Waterway/Lock	GIWW Mile	Miss. River Mile	Length (Feet)	Width (Feet)	Sill Depth (Feet)	Lift (Feet)	Year Opened
GIWW East							
IHNC	0	92.6	640	75	31.5	17	1923
GIWW West							
Algiers	0	88.0	760	75	13	18	1956
Harvey	0	98.2	425	75	12	20	1935
Bayou Boeuf	93.3	n.a.	1156	75	13	11	1954
Leland Bowman	162.7	n.a.	1200	110	15	5	1985
Calcasieu	238.9	n.a.	1206	75	13	4	1950
GIWW Alt. Route M.C. - P.A.							
Port Allen	64.1	227.6	1202	84	14	45	1961
Bayou Sorrel	36.7	n.a.	797	56	14	21	1952
Atchafalaya-Mississippi River Link (Old River)							
Old River	n.a.	304	1200	75	11	35	1963

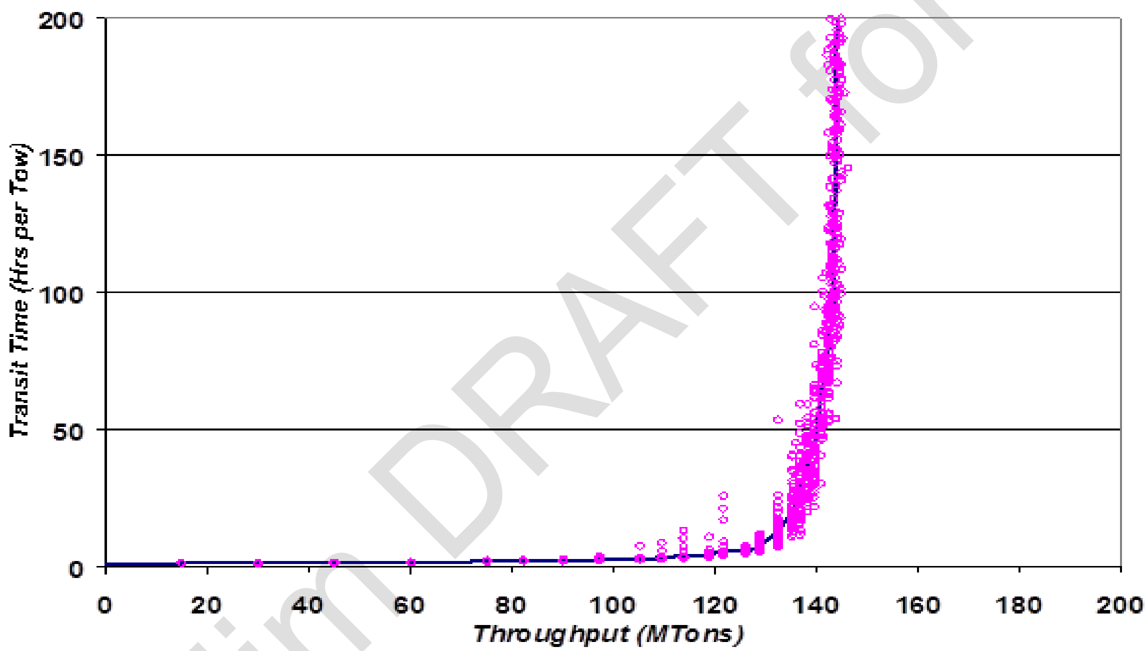
The Intracoastal Waterway is a middle-aged system compared to other inland waterway segments within the United States. As ***TABLE A2-*** shows, with the exception of Port Allen, Old River and Leland Bowman, most of the primary locks are over 40 years old. However, the IWW continues to be a critical part of our nation's infrastructure and confers wide-ranging benefits on national and state economies. The waterway is not only important to American commerce, it supports a variety of other public purposes, including flood control, waterside commercial development, and water-based recreational activities.

1.3 Capacity Analysis

1.3.1 Model Runs

The Waterways Analysis Model (WAM) was used to make traffic-transit time estimates in this study (see Section 2). The WAM is a discrete event computer simulation model and with each simulation iteration the model produces estimates of how the modeled system performs. Many output statistics are generated during each run. The most important of these are the total amount of traffic served and the time needed to serve it. If many simulation iterations are made at several different traffic levels, the performance of a system over its full range of utilization can be presumed as shown in **FIGURE A2-** FIGURE A2-. Each circle in the figure represents one run. A WAM curve, or tonnage-transit curve, is usually defined by the average of 50 runs at 27 different traffic levels. For curves representing more restrictive activity, more runs may be required at each point in order to produce a smoother curve. The analysis of IHNC Lock incorporated a minimum of 250 runs at each of the 27 points to produce well-behaved curves.

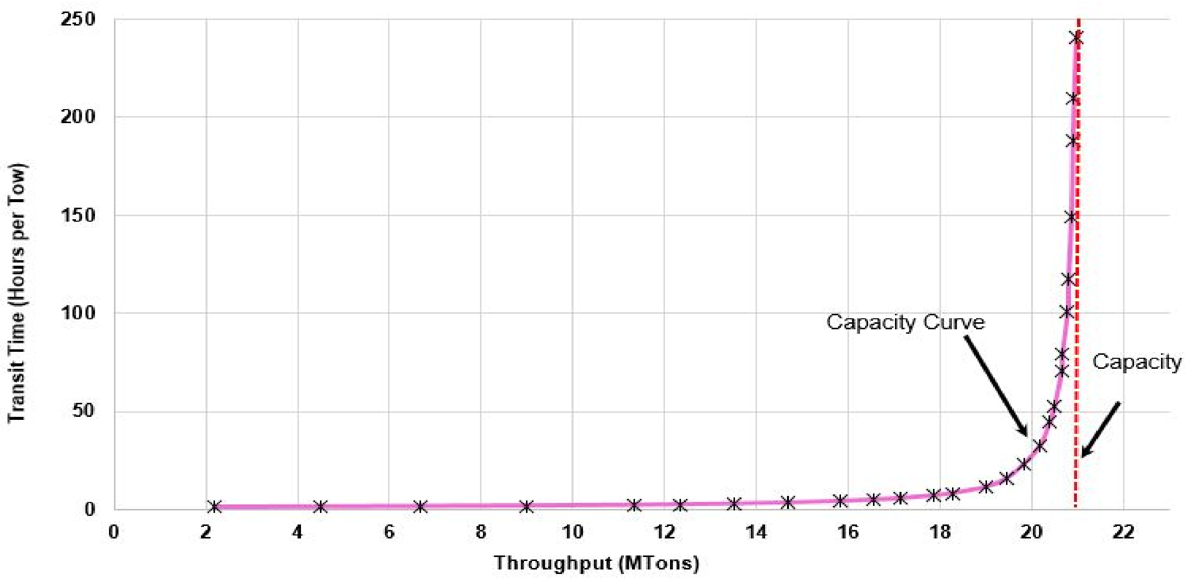
FIGURE A2-1: WAM Simulation Iterations



1.3.2 Tonnage-Transit Curves

A capacity curve defines the relationship between project throughput and transit time. ***FIGURE A2-2*** is typical of many capacity curves in this analysis. At most locks, transit times remain very low until demand reaches about 80% of capacity. As traffic levels increase from that level, transit times increase rapidly. Throughput is measured as annual tons served, and transit time includes both the time needed to "process" the vessel and the time the vessel is "delayed". A vessel's process time begins when either the lock operator signals a waiting tow that the lock is ready for processing, or the tow is at the arrival point and the lock is idle. Process time ends when the lock is free to serve another vessel. Delay occurs when a vessel arrives at a lock and cannot be served immediately. Capacity is defined as the level of tonnage where the capacity curve reaches its vertical asymptote. At this point, additional demand results in increased delay but no increase in throughput.

FIGURE A2-2: Typical Capacity Curve and Capacity



1.3.3 Service Disruption Tonnage-Transit Curves

Every capacity curve represents the relationship between tonnage and transit time for a given, very specific, set of circumstances. Many factors are considered when developing capacity curves. Number of chambers, interference characteristics between the chambers, fleet size and loadings, processing times (by direction, chamber, and flotilla size), arrival and inter-arrival patterns, service policies, etc., all have an effect on the shape of the curve, and the ultimate capacity of the project.

Chamber downtime, or more generally service disruption, is also factor. In some cases (e.g., Calcasieu Lock) a service disruption may only impact certain vessels. For purposes of this IHNC Lock analysis, downtime is defined as time when all traffic is unable to use a lock chamber. Downtime can occur because the chamber itself is unavailable (e.g., maintenance), or for reasons that are beyond the control of the lock operator (e.g., weather, bridge curfews, etc.). When a chamber is “down”, processing stops and vessels must either use another chamber, if available, another route, if available, or wait until the downtime ends.

Downtime is a major consideration in the IHNC Lock study given maintenance need differences between the existing (without-project condition) and the with-project conditions and the influence of bridge curfews in the area which choke off vessel transits. As a result, a series of tonnage-transit curves are needed for a given project alternative in addition to the normal / full operations tonnage-transit curve. Each one of these curves represent the annual tonnage-transit relationship to be expected if that particular service disruption event occurs. Hence, for the IHNC Lock, an additional 11 curves were developed for the existing condition and an additional 9 curves were developed for each of the four with-project condition alternatives.

1.3.4 Relevant Range

While capacity is useful to demonstrate relative differences between alternatives, only the relevant range of a curve is used during an economic analysis. Relevant range is lock specific and depends on current and projected future traffic levels. The lower bound of a range is defined as the minimum expected demand, measured in tons, throughout the period of analysis. Conversely, the upper bound is set at the maximum expected tonnage. The capacity of a curve may lie above the relevant range, below the relevant range, or within the relevant range. The relevant range for the IHNC Lock is projected at between 15 and 36 million tons annually based on historic tonnage levels and forecasted traffic demands.

2. MODEL DESCRIPTION

Tonnage-transit time (capacity) curves for all nine lock projects in the IHNC Lock system analysis were developed using the Waterway Analysis Model (WAM). All nine lock projects had been analyzed in an earlier analysis of the Calcasieu Lock, which was completed in 2014, however, for this analysis the IHNC Lock capacity analysis needed to be updated and simulated with expanded granularity.

The WAM is a discrete event computer simulation model developed by the Corps of Engineers for use in simulating tow movements on the inland waterways system. It was developed as part of the U. S. Army Corps of Engineers Inland Navigation Systems Analysis Program (INSA) for the Office of the Chief of Engineers by CACI, Inc. WAM was written in the mid 1970's and has been continually modified and improved since the early 1980's. WAM has been used in navigation studies on the Ohio River and its tributaries for the last 30 years. The version of WAM used in this study received a HQ Planning Model "approval for use" certification 09 September 2016.

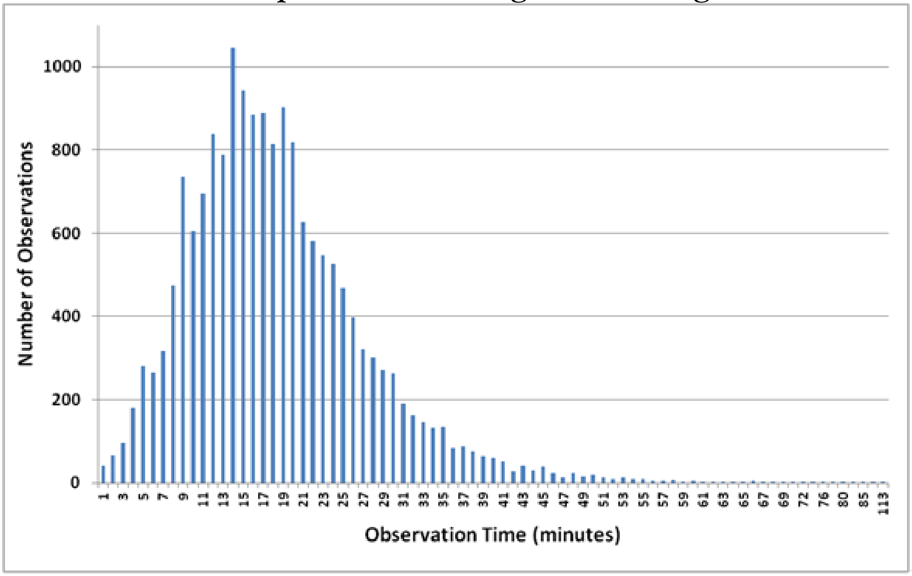
As a simulation model, the WAM incorporates the concept of variability into the modeling process. Instead of an action taking a fixed amount of time to accomplish, say 15 minutes every time, it may take any value between 5 and 30 minutes. Instead of every vessel arriving 60 minutes after the previous vessel, a vessel may arrive anywhere between a couple minutes and several hours after the previous vessel. This type of modeling is well suited for real world events, since real world events seldom take exactly the same amount of time every time they occur.

The interactions between the variability of the arrivals and the variability of the processing times causes times when the lock is idle and times when the lock is busy, with vessels waiting to process. The model monitors and accumulates many statistics as it executes. These statistics are written to files so the results of the model run can be reviewed and analyzed at will.

2.1 Processing Time Components

FIGURE A2-3 shows a histogram of an actual component time data set used in this study. Notice the shape of the figure. Although it can be as low as 1 minute, there is less than a 4% chance that the value will be less than 6 minutes. On the other hand, 92% of the values are between 6 and 35, inclusive. The chance of the value being greater than 36 minutes is about the same as it being less than 6 minutes. Over 80 data sets like ***FIGURE A2-3*** were used in this study.

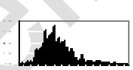
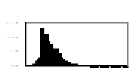
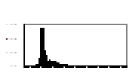
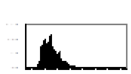
FIGURE A2-3: Component Processing Time Histogram



2.2 WAM Lockage Process

WAM is a highly detailed lock simulation model. A detailed model explanation is beyond the scope of this Attachment. Fundamentally however, the model is easy to describe. Vessels arrive at the lock where they either begin processing, or are made to wait because the facility is busy or "down". When the lock is ready to process the vessel, the vessel goes through 4 distinct processes if the lock is in standard locking mode and 1 process if the lock is in open pass mode. ***TABLE A2-1*** shows a simple representation of a standard lockage.

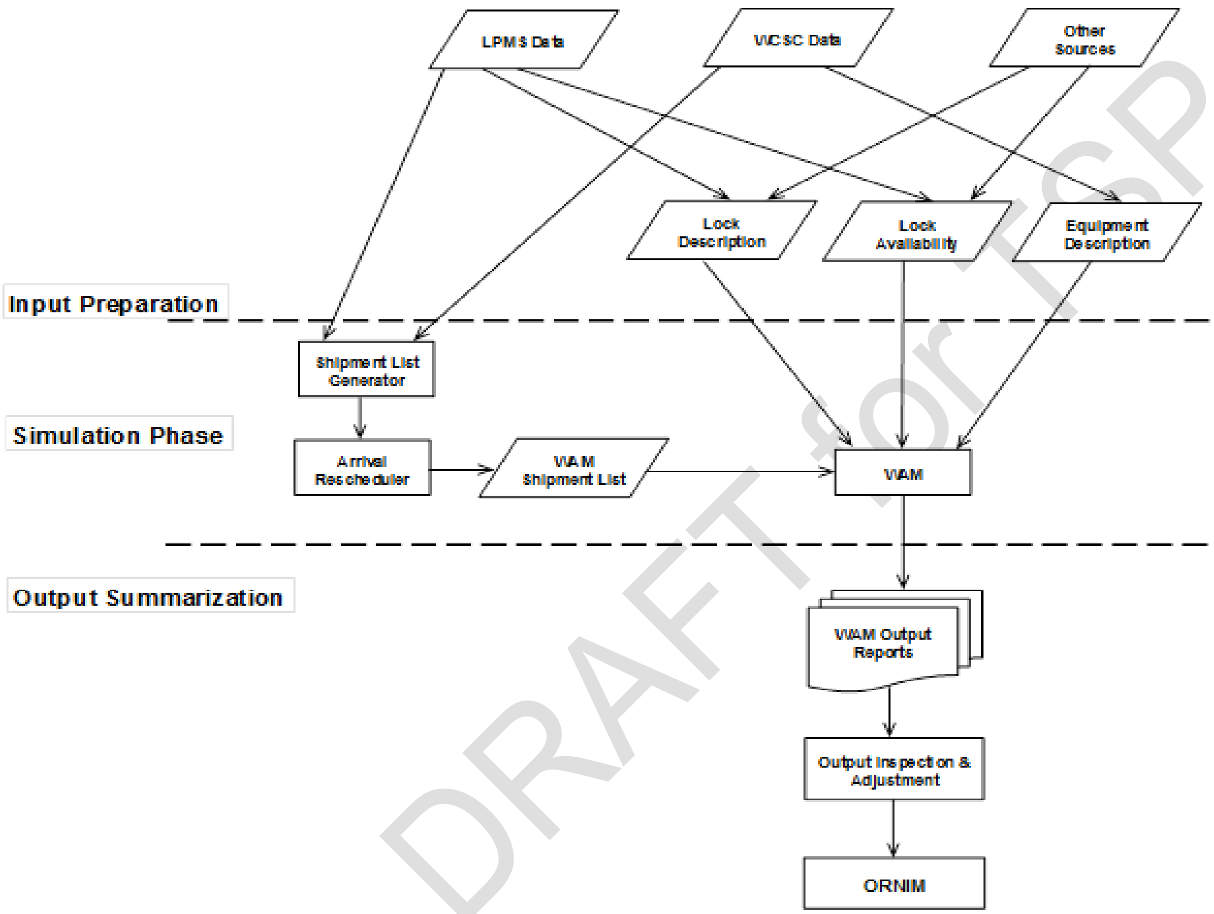
TABLE A2-1: WAM Lockage

Description	Wam Component	LPMS Time
Arrival	Input to WAM from Shipment list	Arrival
Delay	Determined by WAM based on Conditions at Lock	Start of Lockage
Approach	 Approach Distribution Fit From Data	Bow Over Sill
Entry	 Entry Distribution Fit From Data	End of Entry
Chambering	 Chambering Distribution Fit From Data	Start of Exit
Exit	 Exit Distribution Fit From Data	End of Lockage

2.3 WAM Modeling Process

WAM modeling consists of 3 basic steps: 1) input preparation, 2) system simulation, and 3) output review and summarization. ***FIGURE A2-4*** provides a general overview of the modeling process.

FIGURE A2-4: Component Processing Time Histogram



2.4 Input Preparation

The WAM simulation module "simulates" tow movement through navigation locks based on the model configuration. Many factors are included when configuring a WAM simulation. The most important features are listed below.

the lock

- o number of chambers
- o chamber sizes
- o processing times
- o interference characteristics (multi-chamber locks only)
- o drainage status and rules (Calcasieu Lock only)
- o downtime
- o service policy

the fleet using the lock

- o towboat types and sizes

- barge types and sizes
- tow sizes/barges per tow
- empty movements
- recreation and other craft

the fleet arrival pattern

- monthly variations
- daily variations
- hourly variations
- recreation craft arrival variations

2.4.1 Lock Data

2.4.1.1 Processing Times, Sample Set Development

As stated earlier, standard lockages are simulated in the WAM by four sequential periods of time. They are in order of occurrence, the approach, entry, chambering and exit. A vessel's total processing time equals the sum of the approach, entry, chambering and exit times. Processing time is added to the delay time, if any, to get total transit time for the vessel. Transit time is shown as the ordinate on capacity curve charts.

The Corps Lock Performance Monitoring System serves as the data source for processing times used by WAM. Processing time data is retrieved from the LPMS system and grouped into these components.

Long Approach (Fly and Exchange)

Short Approach (Turnback)

Chamber Entry

Chambering

Long Exit (Fly and Exchange)

Short Exit (Turnback)

Chamber Turnback

Approaches and exits are grouped based on whether they are long or short. This is done because there is a large difference in these times, and the differentiation gives the model the ability to identify the most efficient lockage policy.

2.4.1.1.1 Sample Set Development, Overview

LPMS Data was imported into a series of SQL Server tables, and from there queried into workbooks to select specific lock component times. Component times were grouped based on lock number, component type (i.e. long approach), chamber number (main or auxiliary), vessel direction (upstream or downstream), and number of cuts (1, 2 …or 5). LPMS summary data for the selected criteria was then displayed. Summary data included the locks' components' mean times, total observations, minimum and maximum value, and standard deviation for each year of the selected data sets.

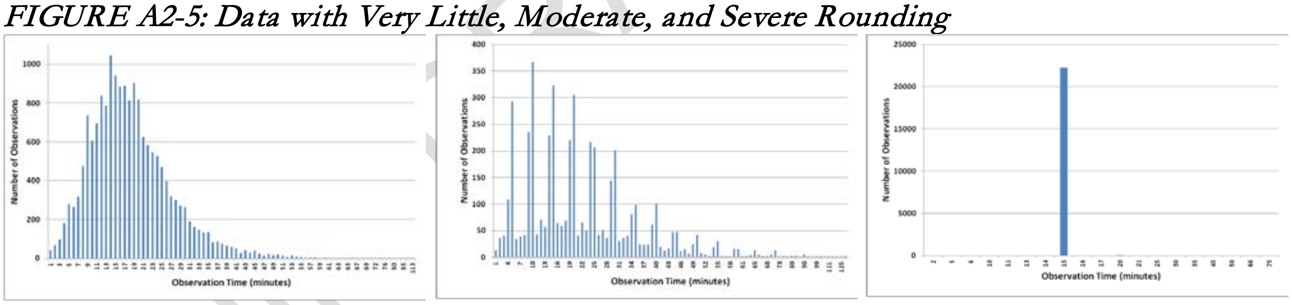
2.4.1.1.2 Sample Set Development, Sample Set Size and Data Years

The first activity associated with developing valid component processing time sample sets was to analyze data from years 2011-2015 and compare each year's data separately to determine whether the data sets for each year were sufficiently valid when compared with the base year 2015. Visual and calculated comparisons were made to insure that something had not happened to make data from other years invalid. The visual comparison consisted of viewing various histograms of the selected data set in different single and multi-year scenarios. The skewness of each year's frequency distribution and general 'spread' of observations was considered and compared to the base year. The calculated comparison consisted of analyzing the LPMS summary data in various single and multi-year scenarios for each selected year or group of years. Each year(s) means, standard deviations, number of observations, and highest and lowest observations were compared with the base year. If insufficient sample sizes existed after combining all 2011-2016 data, which occurred in some of the double cuts and straight multi component data sets, data from another project was added to the insufficient sample size.

2.4.1.1.3 Sample Set Development, Rounding

Lock component data sets had various degrees of rounding from very little rounding to moderate rounding, and to extreme rounding, as shown in ***FIGURE A2-5***. Rounding occurs when lock operators record the LPMS tow processing times in increments of 5 minutes (e.g., 5, 10, 15, …25) instead of the nearest minute. Moderate (subtle) rounding occurs when there are several times recorded in increments of 5 minutes in the data set while extreme (severe) rounding occurs when the times are recorded in only one or a few increments of 5 minutes or when nearly all occurrences are given the same time. Although some of the data sets contained some moderate and extreme rounding, all of the lock component data sets were used in this study due to each lock project having different lock dimensions. That is, there were no locks that could be a proxy for another lock. Processing times will tend to vary according to the lock's unique length and width.

FIGURE A2-5: Data with Very Little, Moderate, and Severe Rounding



2.4.1.1.4 Sample Set Development, Outliers

For purposes of this study, outliers are data that do not belong in the data set. They are considered invalid, and are not included in the final data set. Outliers can take the form of very low values, or very high values.

Low outliers were determined by first setting a lower threshold for each component type based on the number of occurrences of the lowest observation. If the lowest observation occurred several times in the data set, the time remained in the data set. Conversely, if the observation occurred only a few times in the data set, the observation was removed as an outlier and became the threshold value. The threshold was determined by looking at the process, and determining the shortest process time possible. For example, a single cut chambering time begins when the vessel is tied off in the chamber and ends when the gates are fully open and the vessel can begin its exit. During this period, one set of gates is closed, the chamber was filled or emptied, and the other gates are opened. If the upper and lower pools were approximately equal, the filling or emptying process would be very short, essentially zero. This leaves the minimum process time as the time it takes to close one set of gates and open the other

There were no specific rules for removing high outliers. Less emphasis was placed on higher component observation times than the lower observation times. “High Outliers” were removed only when they were considered extreme, and were unique to each selected data set. Examples of extreme outlier(s) would include an obvious typographical error such as the observation time of 999 minutes or high observation time(s) that contain large ‘gaps’ or differences in data values. An example of a large ‘gap’ in data would be a 100 minute time and the next highest values in the data set 30 minutes. In this case, the 100 minute time is over 3 times as large as the next largest value.

2.4.1.1.5 Processing Times, Distribution Fitting

Valid sample sets (i.e., samples with outliers removed) were analyzed using a commercial software product called Decision Suite - @Risk by Palisade. @ Risk provides automated probability distribution fitting capabilities that analyzes the sample set, fits 20 distribution types to the set, determines which distribution type best represents the set, and displays the parameters that describe the distribution. *TABLE A2-2* shows the distribution types considered by @Risk, and the parameters that define the distributions.

TABLE A2-2: WAM Probability Distribution Types

Distribution Type	Parameter 1	Parameter 2	Parameter 3	Parameter 4
Beta	Low EndPt	Hi EndPt	Shape #1	Shape #2
Chi-Square	Degrees Freedom	Location		
Constant	Value			
Erlang	Mean[1]	Shape	Location	
Exponential	Scale	Location		
Gamma	Mean[1]	Shape	Location	
Inverse Gaussian	Scale	Shape	Location	
Inverted Weibull	Scale	Shape	Location	
Johnson SB	Low EndPt	Hi EndPt	Shape #1	Shape #2
Lognormal	Mean[1]	Std Dev	Location	
Log-LaPlace	Scale	Shape	Location	
Log-Logistic	Scale	Shape	Location	
Normal	Mean	Std Dev		
Pareto	Scale	Location		
Pearson Type 5	(1/Scale)*Shape	Shape	Location	
Pearson Type 6	Scale	Shape #1	Shape #2	Location
Random Walk	Scale	Shape	Location	
Rayleigh	Scale	2	Location	
Uniform	Lower Limit	Upper Limit		
Weibull	Scale	Shape	Location	

1. An adjusted mean equal to sample mean minus location

2.4.1.2 Downtime

Locks experience periods of time when traffic is unable to transit through the facility. These periods are referred to as downtime events. Downtimes happen for a variety of reasons and can last from a few minutes to over a month. Some downtimes are scheduled ahead of time while others occur without warning. This study addresses downtime by segregating these events into two groups, random minor downtimes and major maintenance downtimes.

The Corps LPMS data is the main data source for downtimes. LPMS data includes fields for vessel stalls. These stall events are used to determine how often and for what duration lock chambers are unable to serve traffic.

2.4.1.2.1 Random Minor Downtime

Random minor downtimes are short duration, less than 1 day, unscheduled chamber closures. They are caused by various things such as the weather, mechanical breakdowns, river conditions, lock conditions, and other circumstances. LPMS categorizes the causes of downtime into 5 major groups, and then further subdivides each major group into subgroups, for a total of 19 different causes of downtime. These categories and sub-categories are shown in *TABLE A2-3*. Data was developed for each downtime subgroup by determining the number of events expected each year, and the total annual amount of downtime.

TABLE A2-3: LPMS Downtime Types

Weather
Fog
Rain
Sleet or Hail
Snow
Wind
Surface Conditions
Ice
River Currents/Outdrafts
Flood
Tow Conditions
Interference by Other Vessel
Tow Malfunction
Tow Staff Ocuppied w Other Duties
Lock Conditions
Debris
Lock Hardware Malfunction
Lock Staff Occupied w Other Duties
Test and Maintain Lock
Others
Tow Detained by Coast Guard
Collision or Accident
Bridge Delay
Other

Downtime files are developed by creating the events for each subgroup, and combining the events into one file. Each event in the downtime file is created keeping in mind the time of year that the event subgroup usually occurred, and in accordance with the distribution of event durations for that subgroup.

2.4.2 Vessels

The WAM allows each vessel to be classified based on several attributes. For the purposes of this analysis, the most important attributes are the length, width and carrying capacity. These attributes are used by WAM to determine the number of cuts needed to process a vessel, and the tonnage carried by that vessel. The WAM determines the number of cuts by comparing the lock chamber size with the number and size of the vessels in a shipment.

Vessels are grouped into one of three types in this study. Tows are commercial towboats pushing one or more barges. Light-boats are commercial towboats without barges. Recreation craft are non-commercial, usually small, vessels. Commercial-passenger vessels, government vessels, and other vessel types are counted and included in the Light-boats group.

2.4.2.1 Towboats

Towboats were categorized into eight groups based on horsepower. ***TABLE A2-4*** lists the towboat types, horsepowers and dimensions used in this study.

TABLE A2-4: Towboat Dimensions by Horsepower Class

Horsepower Class	Length (feet)	Width (feet)
< 1,000	82	24
1,000 to 1,499	98	29
1,500 to 1,899	115	30
1,900 to 2,299	131	31
2,300 to 3,099	141	35
3,100 to 4,199	151	40
4,200 to 5,499	162	42
> 5,500	185	53

2.4.2.2 Barge Types

Tow size is a key input determinant when estimating lock capacity. Tow size is determined by the type and number of barges being pushed, and the towboat type. This study models 12 barge types typical. ***TABLE A2-5*** shows the barge types and their dimensions.

TABLE A2-5: IHNC Lock Barge Data

Barge Type	Length (Feet)	Width (Feet)
Sand Flat	135	27
Regular	175	26
Stumbo	195	26
Jumbo	195	35
Covered Jumbo	195	35
Super Jumbo	245	35
Giant Jumbo	260	52
Jumbo Tanker	195	35
147 Tanker	147	52
175 Tanker	175	54
264 Tanker	264	50
297 Tanker	297	54

2.4.3 Shipment List

The shipment list file contains a stream of vessel demands input to the WAM during program execution. It is generated based on historic LPMS and WCSC data, and may contain several thousand records. Every record represents a vessel that must be processed through the lock. The records contain information regarding the arrival time, direction, vessel type (tow, recreational craft, or Light-boat), commodity type and tonnage (if applicable), towboat type (if applicable), and type and number of barges (if applicable). When taken in total, a shipment list closely matches the overall characteristics of the actual 2015 fleet utilizing IHNC Lock.

2.4.3.1 LPMS Summary Program

The LPMS Summary Program was developed in conjunction with the shipment list generator program. The program summarizes the fleet through a lock project by predominate barge type and commodity in each tow. For example, if a tow has 4 jumbo hopper barges and 3 jumbo tankers, then the tow is counted as a 7-barge jumbo hopper barge tow. While most tows on the GIWW are configured homogeneously, some tows are a mix of barge types and commodities. The summary program assumes homogeneous tows.

The LPMS Summary Program reads an entire year of raw LPMS data and creates several tables that describe the fleet. Some of the most important ways that data is summarized include; the number of barges by barge type and direction, the total tonnage of each commodity carried in each barge type by direction, the number of empty barges by barge type and direction, the distribution of barges per tow by barge type and direction, the distribution of tows by month of year, day of week and hour of day. These summary tables are used by the shipment list generator to generate tows that reflect historical tow size distributions that arrive based on historical temporal distributions.

2.4.3.2 WCSC Summary File

The Waterborne Commerce Statistics Center (WCSC) input files are created using 2014 WCSC raw data for IHNC Lock. WCSC barge data is recorded by the shipping companies and collected at the Navigation Data Center. There are two WCSC input files created for each lock project to include a ".lst" file and a summary file. These files are used by WAM's shipment generator to create shipment lists. The WCSC input files describe the origin destination (O-D) pairs by barge type and commodity for barges traveling both in the upstream and downstream direction. Each lock project has its own unique O-D matrix which describes the number of loaded barges, the 9 MVD commodity groupings the barge carries, the average loading, and the total tonnage for each of the 12 barge types used in this study.

2.4.3.3 Shipment List Generator

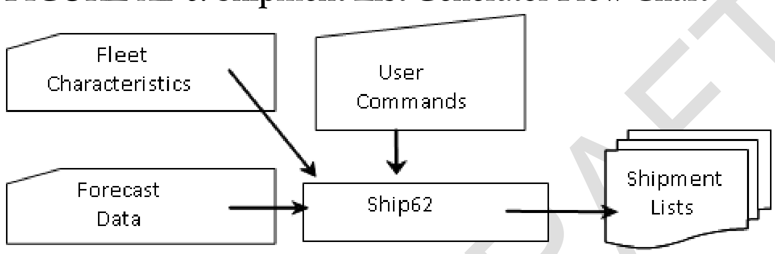
Shipment lists are generated by the WAM Shipment Generator (Ship62), which was developed in the 1995. The ultimate objective of Ship62 is to produce shipment lists that closely reflect historic fleet characteristics. Fleet characteristics can be described in two ways. First, the fleet can be described by its physical characteristics, the most important of which are listed in ***TABLE A2-6***. Second, the fleet can be described temporally, that is, how arrivals are distributed on a monthly, daily and hourly basis.

TABLE A2-6: Shipment List Statistics of Interest

Number of Tows
Tons per Tow
Number of Barges
Number of Loaded Barges
Number of Empty Barges
Percent Empty Barges
Tons per Loaded Barge
Barges per Tow
Number of Recreation Craft
Number of Light Boats

Ship62 has three basic inputs: 1) the fleet characteristics summary files; 2) the forecast file and, 3) a control file containing user defined instructions. The fleet summary files are created by two standalone programs, LPMS Summary and WCSC Summary, described above. Although Ship62 has the ability to read forecasted demand flows to capture flow shifts, this feature was not used during this study. The user defined instructions file contains input and output file name information, a random number seed, and an escalation factor that determines the how many shipments are created in the shipment list. ***FIGURE A2-6*** is a simplified shipment list generator flow chart.

FIGURE A2-6: Shipment List Generator Flow Chart



The Ship62 stochastically generates shipment lists, using target fleet distributions derived from LPMS and WCSC data. Performance statistics (e.g. transit time for a given annual tonnage) out of the WAM are sensitive to the arrival patterns in the shipment list, which are variable due to the generator's stochastic generation method. Therefore, 50 shipment lists are generated and run through the WAM to estimate average tow transit time for any given tonnage level.

2.4.3.4 Shipment List Calibration

The shipment list generator uses two data sources to develop shipment lists, the LPMS data and the WCSC data. These data sources each have their own strengths and weaknesses. For example, LPMS is a better data source for barge counts, tow and other vessel counts, and is the only source for empty barge and lock specific processing time information. On the other hand, WCSC is a better data source for tonnage moved per barge, and commodity type information. These two data sources, therefore, are used together to create shipment lists that reflect the actual fleet at a lock.

Before shipment lists can be used for WAM production runs, they must first be calibrated to insure that they truly reflect the fleet observed at the lock of interest. Shipment lists are calibrated by manually adjusting the LPMS summary data file until the generated fleet matches the observed fleet. The statistics most often adjusted are the number of empty barges, by barge type, and barges per tow percentages for each barge type.

2.4.4 Tow Arrival Rescheduling

The shipment list generator creates shipment lists that are valid for normal lock operation conditions. Shipment list arrival times reflect the actual 2014 arrival pattern for IHNC Lock.

During normal lock operations, tow arrivals vary by month of year, day of week and hour of day. At most locks in this study, there is very little variation in the rate of tow arrivals by month, day, or hour. When long, disruptive closures occur however, tow arrival patterns change dramatically. Since the locks analyzed in this report are single chamber locks, lock closures stop all traffic through the lock. When relatively long duration closures occur, historic data shows the number of arrivals decrease significantly during the closure. Tow arrival rescheduling mimics this decrease in arrivals by rescheduling arrivals around the closure(s) of interest.

2.5 Input Files

Simu01 – this is the shipment list that drives the simulation.

Simu03 – this is the network file that serves many purposes. This file feeds the timing data and distributions into the model as well as other information about fleets and lock dimensions.

Simu10 – this is the downtime file. This file is used to make specified chambers either operational or un-operational (down). The file included in the package puts chamber 2 into an un-operational state for the duration of the entire simulation. Chamber 1 remains operational throughout the simulation, except for when a downtime is specified in this file. IHNC Lock is a single chamber project. That's why chamber 2 is modeled as closed.

Simu50 – this is the file that controls the simulation.

2.6 Output Files

Simu13 – This is a simulation trace file that provides details about the entire lockage process.

Simu60 – this is the main WAM output report.

Simu84 – this file is a playback of the "rules" files. It is explained in the Model Documentation and can be used to verify that the intended input is read correctly.

Simu89 – this is a simulation by simulation summary of the results of each simulation. The PCXIN has spreadsheet procedures that use the data in this file. This file was not used for this effort and is output by default.

2.7 Model Execution

As stated in Section 2.1 WAM was developed in the 1970's. Although WAM has been continually modified and enhanced since that time, it retains the original input-output mechanisms of the era, ASCII files.

2.7.1 Making a WAM Run

In its most simple form, WAM requires four fundamental input files to fully define the system and conditions which are to be simulated. These four files are: the shipment list, the network file, the downtime file, and the run control file.

The shipment list, which is created by the Shipment List Generator described in Section 2.2.3.3, contains the list of vessels seeking to use the lock. The network file describes the operational characteristics of the lock including chamber size, processing time distributions, service policy, open pass schedule, chamber packing criteria, and towboat and barge dimensions. The downtime file contains a list of downtime events which control when a chamber is able to serve traffic and when is it unavailable. The run control file contains information that controls how much simulated time WAM will execute, the type of and extent of WAM output, and the random number seed passed to the model.

In addition to the input files, five supporting programs are used while running WAM. These five programs are: the WAM executable, the shipment list generator, a shipment list sorting program, an arrival rescheduling program, and a downtime file warm-up program. It is beyond the scope of this report to describe each of these programs in detail. Suffice it say, a great deal of file manipulation and program execution is required to make one WAM run.

2.7.2 Making a WAM Curve

It generally requires 1,350 executions of the WAM to create one capacity curve. More executions may be necessary in order to create well-behaved curves, for instance this study used 6,750 executions to make the curves for IHNC Lock. Every one of these model executions, called runs, is made with a set of four fundamental input files that are slightly different from all other runs. Obviously, it would be difficult if not impossible to manually create these input files, run WAM, and gather the relevant information from the output files. Therefore, an automated graphical user interface known as the WAMBPP was developed to facilitate the process of creating input files, executing WAM, gathering pertinent data from the output files, and appending this data into various SQL Server tables.

2.8 Output Review and Adjustment

WAM possesses the ability to produce vast quantities of output data. A user can trace every event of the modeling process if so desired. WAM gives the user full control over the amount and type of output produced.

Only two pieces of WAM output data are used when creating capacity curves, the tonnage processed during a run, and the average transit time for all tows that processed during the run. These two pieces of information, when averaged over the number of runs made at a traffic level, define a point on a capacity curve. The curve is created by connecting these average points over the range defined by the 27 traffic levels made for each curve.

2.8.1 Outlier Removal

Periodically, WAM will produce a run where either the tonnage processed or transit time is unreasonable. These runs are known as outliers. Although outlier runs are rare, their impact on a curve can be very large.

At its most basic mathematical level, a capacity curve is defined by a set of x, y values in a 2 dimensional space. Therefore, outliers have two ways of appearing. Either a tonnage value is out of bounds or the transit time is out of bounds. Therefore, we search for outliers using two different set of bounds, one for tonnage, one for transit time.

Through years of experience and examination of data, we've found that tonnage is seldom the outlier. Tonnage varies very little from run-to-run. This makes sense. It all comes down to how many tows are in queue at the end of the year. A typical lock on the GIWW serves 10,000 or more tows per year. If there are 20 or 200 tows in queue at the end of the year, it makes little difference. Therefore, the tonnage bounds were set at plus or minus 3% of the average tonnage.

Transit time on the other hand is highly variable. Once traffic starts entering the “elbow” of a capacity curve, transit times can easily vary by 100% from run-to-run. Experience has shown that transit time outliers are always high outliers. Therefore, no low boundary was set. The upper bound was set at 300% of the average transit time.

Using these rules, the Summary Data tables in each lock’s databases were searched for outliers. Outliers identified by the search were deleted from the table.

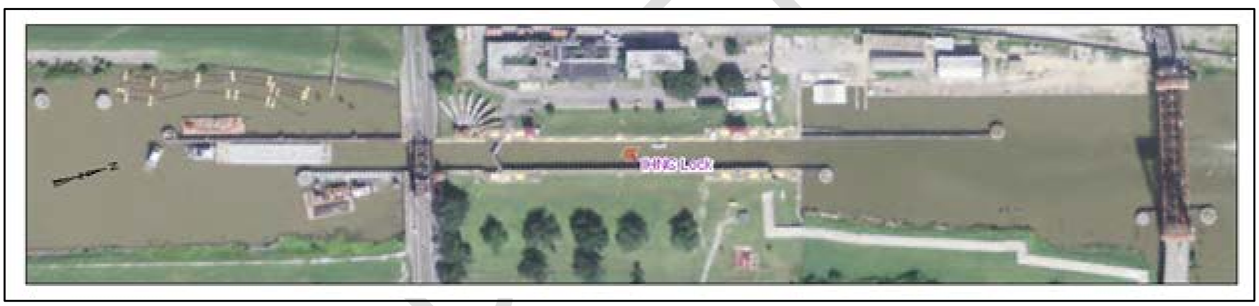
3. IHNC LOCK WITHOUT-PROJECT CONDITION CAPACITY ANALYSIS

As discussed, the IHNC Lock system analysis included nine lock projects in the region, however, this capacity analysis was focused on the IHNC Lock. The capacities and tonnage-transit time relationships for the other eight projects were obtained from the capacity analysis work performed in the 2014 Calcasieu Lock Final Feasibility Study and are summarized in Section 5. While a capacity analysis was performed for the IHNC Lock in this Calcasieu report, a more detailed and granular simulation was needed for this analysis and capacities for the with-project alternatives were needed. A detailed discussion of the existing / without-project condition IHNC Lock capacity analysis follows.

3.1 Background

Inner Harbor Navigation Canal (IHNC) Lock (***FIGURE A2-7***) is located on between river miles 6-7 on the Gulf Intracoastal Waterway East within the City of New Orleans and consists of a single 640' x 75' main chamber with a lift of 17 feet at normal pool and a depth over the sill of 31.5 feet. The canal originally connected only Lake Pontchartrain with the Mississippi River (mile 92.6), but during World War II rerouted the GIWW so that the IHNC Lock connected the eastern and western sections of the GIWW, creating a more direct route to locations on the eastern gulf coast.

FIGURE A2-7: IHNC Lock



The section of canal of interest in this analysis connects the Mississippi River to the south with the now closed Mississippi River Gulf Outlet (MR-GO) to the north, approximately 2.1 miles. Less than 5% of IHNC Lock traffic is in common with Lake Pontchartrain (753,797/15,967,412 over 2011-2014 WCS). Processing of traffic through this reach of the canal and through IHNC Lock is unique. For multi-cut tows, except during high water events on the Mississippi River, tows will break and make outside the canal area and employ "trip vessels" to shuttle their cuts through the canal and the IHNC Lock. This is done to increase the efficiency of transiting the constrained canal and as a result, for the most part, flotilla arrive at IHNC Lock as single cut powered flotilla. The project has no tow-haulage equipment, and when tows break and make on the walls, a helper-boat is required.

When vessels arrive in the LPMS arrival area they call into the lock to get assigned their arrival time and their queue position. The lockmaster will notify the vessel 2-hours prior to the expected lock transit so that the flotilla can acquire any needed trip vessels. These trip vessels work IHNC Lock as well as Algiers and Harvey Locks.

- Going north (up-bound) the 1st powered cut will queue on the wall, the 2nd powered cut will queue at the dolphins (mooring cells), and the 3rd and greater powered cuts will queue in the Mississippi River. The flotilla will then re-make north of the Florida Avenue Bridge.

- Going south (down-bound) the 1st powered cut will queue on the wall, the 2nd powered cut will queue along the bank of the canal, usually on the northern side, while the 3rd and greater cuts will queue further back in the canal and GIWW-East as necessary.

The lockmaster will re-order the queue and multi-vessel cut as needed to maximize throughput. In 2010-2014, 40% of lockage cuts were re-queued, and 13% of lockage cuts were multi-vessel lockage cuts.

A major inefficiency at the project comes from three bridges (two low-lift bridges and one mid-rise bridge) in the canal area and their Monday-Friday rush-hour curfews (***TABLE A2-7***), in which the bridges are left in their lowered positions. While approximately 70% of vessels can pass under the mid-rise Claiborne Avenue Bridge while it's in its lowered position, during the curfew periods, due to the low-lift bridges, all vessel traffic is effectively stopped. The bridges are major commuter routes for those living on the east side of the canal and cause some interference during non-curfew periods.

TABLE A2-7: Bridge Curfew History, non-Holiday Monday - Friday

Period		Morning Curfew		Evening Curfew	
		Start	**End**	**Start**	**End**
1994 to June 2001					
	St. Claude Ave. Bridge	6:45 am	8:15 am	4:30 pm	6:30 pm
	Claiborne Ave. Bridge	6:45 am	8:15 am	4:30 pm	6:30 pm
	Florida Ave. Bridge	6:30 am	8:30 am	4:30 pm	6:30 pm
June 2001 to December 2003					
	St. Claude Ave. Bridge	6:45 am	8:30 am	4:45 pm	6:45 pm
	Claiborne Ave. Bridge	6:45 am	8:30 am	4:45 pm	6:45 pm
	Florida Ave. Bridge	6:45 am	8:30 am	4:45 pm	6:45 pm
December 2003 to present					
	St. Claude Ave. Bridge	6:30 am	8:30 am	3:30 pm	5:45 pm
	Claiborne Ave. Bridge	6:30 am	8:30 am	3:30 pm	5:45 pm
	Florida Ave. Bridge	6:30 am	8:30 am	3:30 pm	5:45 pm

Source: Port of New Orleans.

During non-curfew periods vessels radio the bridge as they approach and the bridge operator must first wait for a sufficient break in vehicular traffic flow, lower the traffic barriers, and then raise the bridge to a safe height for navigation to pass. At St. Claude Avenue Bridge this non-curfew interference has been estimated by the District to cause an average incremental delay of approximately 3 minutes per lockage. For the most part, given the distance between the project and the other two bridges, there is sufficient time to coordinate the bridge opening. This occurs because the vessels are not allowed to signal the bridges for opening until the lock chamber gates are open and the flotilla is untied.

As shown in ***FIGURE A2-7*** and ***FIGURE A2-8*** one bridge, the low-lift St. Claude Avenue Bridge, actually crosses the project's lower approach area. The mid-rise St. Claude Avenue Bridge is just north (up-bound) of the project and is also visible in ***FIGURE A2-7***. The low-lift Florida Avenue vehicular/railroad Bridge is a little over a mile north (up-bound) of the project.

FIGURE A2-8: IHNC Lock Lower Approach Area

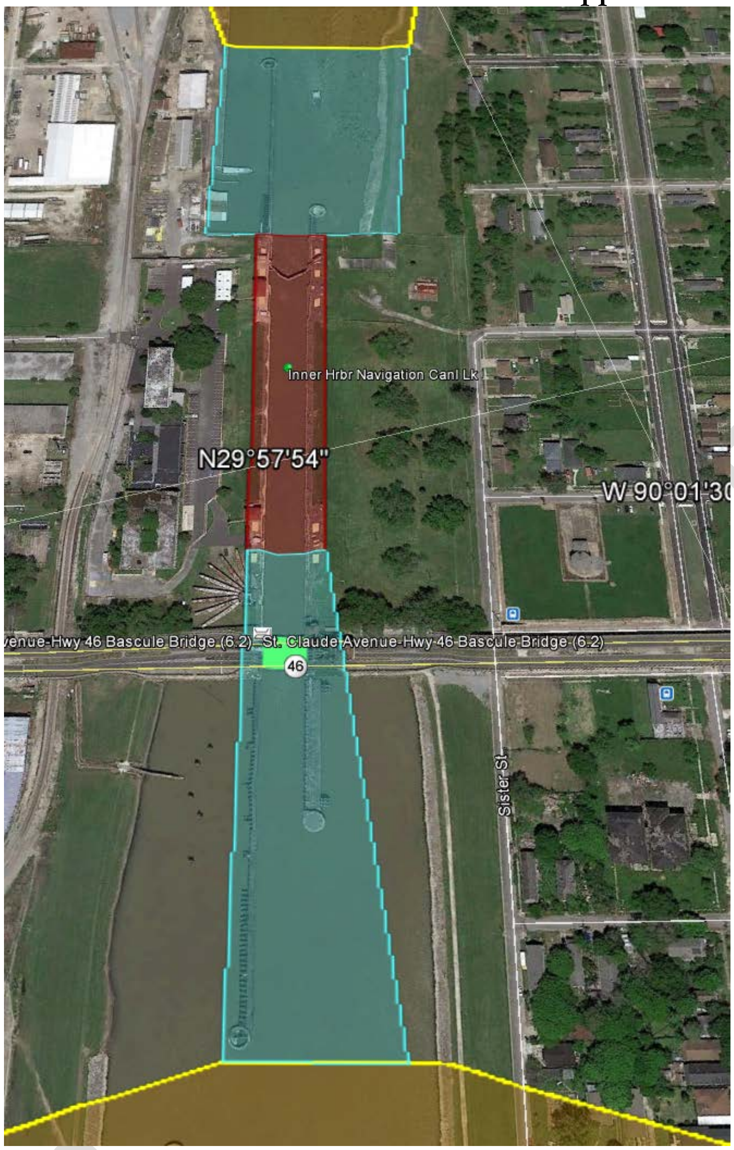
Recent traffic levels have been around 15-16 million tons annually with delays around 10-15 hours per tow. In 2014 (LPMS), IHNC Lock processed 15.8 million tons of commodities (16.0% was petroleum), 6,024 tows with 14,407 barges, 202 recreation craft, and 2301 light-boats. Average tow size was 2.4 barges per tow carrying 2,623 tons. Average processing time from 2010-2014 was 32 minutes per tow with an average delay of 14.1 hours per tow.

3.2 Existing Condition Input Data

The primary existing condition data source is the Corps of Engineers Lock Performance Monitoring System (LPMS) data. Additionally the IHNC Lock Lockmaster was also interviewed.

LPMS Automatic Identification System (AIS) was introduced at the project around 2008 and as a result the approach points were changed. The south-side approach point of the project is now located at the southern end of the guidewall making the project's south-side approach area from the southern end of the guidewall to the south-side sill of the lock chamber. Similarly the north-side approach point is now located at the northern end of the guidewall making the project's north-side approach area from the northern end of the guidewall to the north-side sill of the lock chamber. The arrival time of flotilla is now based on their call-in time as they enter the arrival area. ***FIGURE A2-9*** shows the IHNC Lock AIS arrival and approach areas.

FIGURE A2-9: IHNC Lock AIS Arrival and Approach Areas



The south-side arrival area extends from the south-side end of the guidewall out into the Mississippi River in both directions. West of the canal's southern entrance, the south-side arrival area extends westward down the Mississippi to the Crescent City Connection Bridge #1. Vessels cannot call the lockmaster and request a spot in the processing queue prior to traveling beneath this bridge. The eastern edge of the south-side approach area extends eastward down the Mississippi from east of the canal entrance until the confluence of the Mississippi with the GIWW (close to Algiers Lock).

The project's north-side arrival area extends westward from the north-side end of the guidewall to the end of the canal (i.e., where the canal meets Lake Pontchartrain), and extends eastward down the GIWW East from the end of the north-side of the guidewall until the GIWW splits in to two waterways shortly after the Paris Road Bridge. Arrival areas are outlined in yellow and shaded orange in ***FIGURE A2-9*** above.

The approach areas are shaded in light blue. The lock chamber is shaded red in ***FIGURE A2-9*** above.

3.2.1 Processing Times

Lock Performance Monitoring System data from 2009 through 2015 served as the data source for defining detailed component processing time distributions. The development of processing time distributions is ideally completed using as large a sample set as possible. In order to select the period from which the timing data is pulled, analysts will typically look at historic times on a year by year basis and select the largest sample set consistent with the times recorded in the most recent complete record year. Over time, recorded lock component processing times can change. These changes can be the result of the implementation of a different measuring system (such as AIS), significant changes in fleet characteristics (such as horsepower or speed changes), or lock performance through improvements or degradation of systems.

Six component processing time sample sets (long [fly or exchange] approach, short [turnback] approach, entry, chambering, long [fly or exchange] exit, and short [turnback] exit) were developed by direction, and lockage type (i.e., single-cut, double-cut, etc.). These sample sets were then analyzed with Palisade @RISK software to determine which WAM distribution type (***TABLE A2-2***) fits the data the best. These historical processing times are analyzed to assess how efficiently the lock is performing by determining the without-project-condition (WOPC) capacity.

Initially, any component time that either falls within a curfew period, or that begins before and ends after a curfew period, were filtered out of the component time distributions, whether or not they are in fact impacted by the bridge curfews. These observations were considered corrupted by delay time and as a result would not reflect a pure uninhibited component time. The delays and impacts on the component times from bridge curfews are explicitly simulated in WAM as a chamber closure, allowing modification of traffic levels in the simulation and allowing modification of the curfew assumptions.

The IHNC Lock Lockmaster noted that fill / spill takes 3 minutes on average and the gate open / close takes 1.5 minutes. Summary statistics for the various component processing times distributions can be seen in **TABLE A2-8.**

TABLE A2-8: Summary Statistics for 2009-2015 IHNC Lock Component Processing Times

Summary Statistics for 2009-2015 IHNC Processing Times							
		Upbound			Downbound		
	Lock Component	Sample Size after Removing Outliers	Mean LPMS time (min)	Number of Outliers Removed	Sample Size after Removing Outliers	Mean LPMS time (min)	Number of Outliers Removed
1-cut	Long Approach	2250	11.5	0	2071	11.0	0
	Short Approach	4144	8.5	2	3563	5.3	1
	Entry	9829	7.0	3	9455	7.2	3
	Chambering	9830	11.1	2	9452	12.0	6
	Long Exit	2519	5.4	2	2453	8.4	3
	Short Exit	3939	5.5	1	3407	8.4	6
2-cut	Long Approach	1492	11.2	1	1072	9.3	4
	Short Approach	3584	7.8	2	2971	5.0	3
	Entry	8138	6.5	0	6686	6.5	1
	Chambering	7233	53.7	6	6035	56.5	2
	Long Exit	1573	5.4	0	1267	8.2	1
	Short Exit	3609	5.3	0	2902	8.1	1

After removing observations impacted by the bridge curfews, the component processing time distributions for IHNC lock are then fitted to a specific probability density curve using the Palisade @Risk software. Palisade's @Risk has a feature to automatically fit a distribution to one or more probability density curves that are each of a different probability distribution type (e.g., Gamma or

Weibull Distribution) selected in the program. The selected distribution types to which component processing times are fitted can then be compared with one another to determine the "best fitting" distribution type.

@Risk uses maximum likelihood estimators to make an initial attempt at estimating the best probability distribution type to fit to the sample distribution. Maximum likelihood estimation is a technique to estimate the model parameters, i.e., the parameters (e.g., mean, shape, and location parameters) of the probability density function that allow the sample distribution to be fitted to a specific probability distribution. Maximum likelihood estimation selects the model parameter values that will maximize the likelihood or probability of simulating the observed sample distribution with a fitted probability density function of a specific distribution type.

First, outlier observations must be identified and removed before fitting distributions. Timing observations were removed from a distribution if they had a processing time that has a very low frequency (e.g., one or two observations) and if their duration was substantially longer than the next largest processing time. Observations were also removed as outliers if they did not seem reasonable based on knowledge of the lock project's operations and knowledge of processing times in general from other projects. It was never the case in this IHNC lock capacity analysis that processing times were removed for being too short since a duration of 1 minute is feasible for any component processing time (e.g., turnback approach or open pass chambering). There were only 2 open-pass lockage types out of 92,188 cut-based lockages (as opposed to flotilla-based lockages, in which the lockage type will by default be the lockage type of the flotilla's first cut) records that occurred from 2004 until April of 2016 in the LPMS database.

Outliers for this analysis were always processing times that were considered an anomaly for being too long. Once outliers have been removed, the remaining filtered distribution can be fitted to a known probability distribution type.

The criteria for comparing and choosing the best-fitting probability distribution selected in @Risk is a multi-stage process that requires the user to exercise discretion. The first stage requires identification of the distribution that seems to have a shape similar to the sample's actual probability density function. If this condition is met, then the best fitted distribution is selected on the basis of which distribution has the lowest Akaike information criterion (AIC). AIC is a score that rewards goodness-of-fit (i.e., how well the model explains the actual sample probability distribution of a component's processing times) while penalizing overfitting (i.e., unnecessarily adding parameters to the model that explain the sample distribution well but not out-of-sample observations for the same processing time component, since the model is mistakenly treating some of the idiosyncrasies in the sample data as explainable that in fact cannot be explained by the model). Overfitting almost always increases goodness-of-fit and goodness-of-fit is not the only necessary criteria in determining the best-fitting distribution.

When @Risk fits the various distributions it calculates a set of parameters that correspond to the probability density function that describes the fitted density curve. Some or all of these parameters are then input into WAM to simulate the project's capacity in the WOPC and four alternative WPCs.

For example, exponential distributions, which were one of the most common distribution types to which a sample distribution was fitted, require a scale and location parameter. These parameters were also required inputs for describing other commonly fitted distribution types such as gamma distributions, log-logistic distributions, and Weibull distributions.

The location parameter produced by @Risk is a measure of the minimum value in the fitted distribution. Regardless of the location parameter value generated, it was assumed for input in to WAM that the location parameter was never less than 1 since the minimum component processing time duration that can be recorded in LPMS is 1 minute. When a location parameter is the minimum value of the distribution than it is specifically called a shift parameter. Shift parameters are often applied to processing time distribution due to their having a lower bound.

The scale parameter measures how spread out a distribution is. Increasing the scale parameter for a probability density function will widen its corresponding curve and flatten the curve's peak (i.e., lengthen its tails). The scale parameter for a standard normal probability distribution is equal to its standard deviation. A scale parameter of one will result in the probability density function remaining unchanged. A scale parameter of greater than one horizontally stretches out a probability density function in both directions; whereas as a scale parameter that is a fraction will compress the probability density curve's width.

Another parameter needed for some distribution types is the shape parameter, which is any parameter that is not a scale or location parameter and affects the shape of the probability density curve. The shape can be estimated in terms of the skewness and (or) kurtosis of the distribution.

FIGURE A2-10 below shows the 2009 – 2015 sample distribution of upbound single-cut long approach times at IHNC lock, fitted to a probability density function that is an exponential distribution type. The blue bar-graph in the figure is the sample distribution whereas the red curve is the fitted distribution.

As can be seen, the probability of observing a certain time for an upbound single-cut long approach decreases at a decelerating rate as the approach time increases. Therefore, there is a higher probability of observing a very low approach time relative to a high time since the most frequently observed times in the sample are less than two minutes. Moreover, the difference in probability or likelihood of observing a 1 - 3 minute approach time versus a 4 - 6 minute approach time is far greater than the difference in the probability of observing a 40 - 42 minute approach time versus a 43 - 45 minute approach time. This makes sense given that there are fewer observations at the high approach times and therefore the probability of observing a high approach time is quite low.

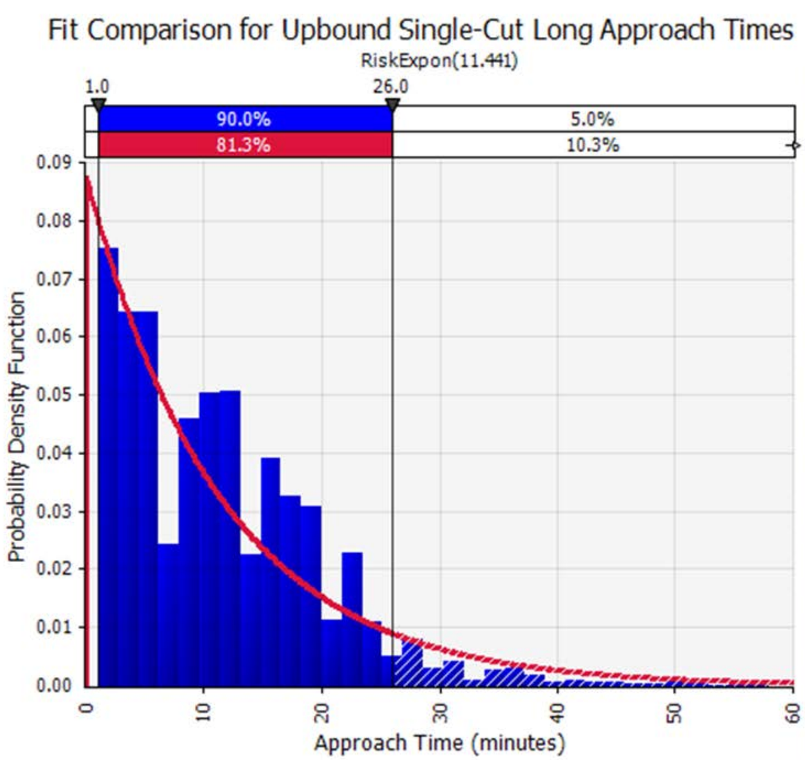
Although long approaches consists of fly and exchange approach types, ***FIGURE A2-10*** and ***FIGURE A2-11*** show that a time range of one to two minutes is the most likely time range to be observed for an upbound long approach and downbound long approach respectively. The reason for this is that the times for fly approaches can be very low for some lockages. This is because the approach area at IHNC lock is fairly short since it extends from the gates of the lock out to the end of the guidewall on either side of the project; whereas at many projects the approach area extends well beyond the ends of the guidewall.

The downbound approach times, both long and short, are on average shorter than the upbound approach times. Furthermore, relative to the upbound approach times, the downbound approach times distribution have a higher concentration of approach time observations concentrated at low approach times. Also in comparison with upbound approach times, the downbound approach time distributions have a smaller share of their distribution concentrated around high approach times. One reason for these timing differences is that upbound approaches traverse the project's south-side approach area, which is more than 200 feet longer than the north-side approach area because the guidewall extends further out from the gate on the south-side compared to the north-side. Also the south-side approach area lies beneath the St. Claude Bridge. Since the St. Claude requires raising for all navigation, this inevitably results in additional approach time for upbound tows from having to wait while the bridge is raised.

The difference in upbound versus downbound approach times is far more pronounced for short approaches compared with long approaches. This is likely because downbound turnback approaches can wait to approach just outside the north-side lock gates. On the south-side tows cannot wait just beyond the south-side sill since this usually requires waiting beneath St. Claude, which is prohibited when the bridge is lowered. Upbound turnback approaches must wait in the segment of the approach area just south of St. Claude. Therefore upbound turnback approaches have slightly shorter times than upbound long approaches since they can wait just south of the bridge instead of having to wait at the very end of the guidewall. As a result, upbound turnback approaches are on average slightly faster than upbound long approaches, but they do not have the same advantage as a downbound turnback approach of being able to start their approach from just beyond the north-side sill. Moreover, it is possible that the wait at St. Claude's is shorter on average for long upbound approaches relative to short upbound approaches because St. Claude's cannot be raised before the tows start-of-lockage time. Since a long approach begins further away from St. Claude (i.e., end of guidewall), it is easier to coordinate so that the bridge is already rising or raised once the tow reaches it, therefore minimizing the bridge wait. This coordination is not possible with an upbound turnback approach since the vessel is already at the bridge when it begins its approach, and therefore its approach time will include the time it takes to raise the bridge from beginning to end. The small difference between upbound long approaches versus downbound long approaches may also be explained by this coordination resulting in the bridge wait being fairly short for many upbound long approaches.

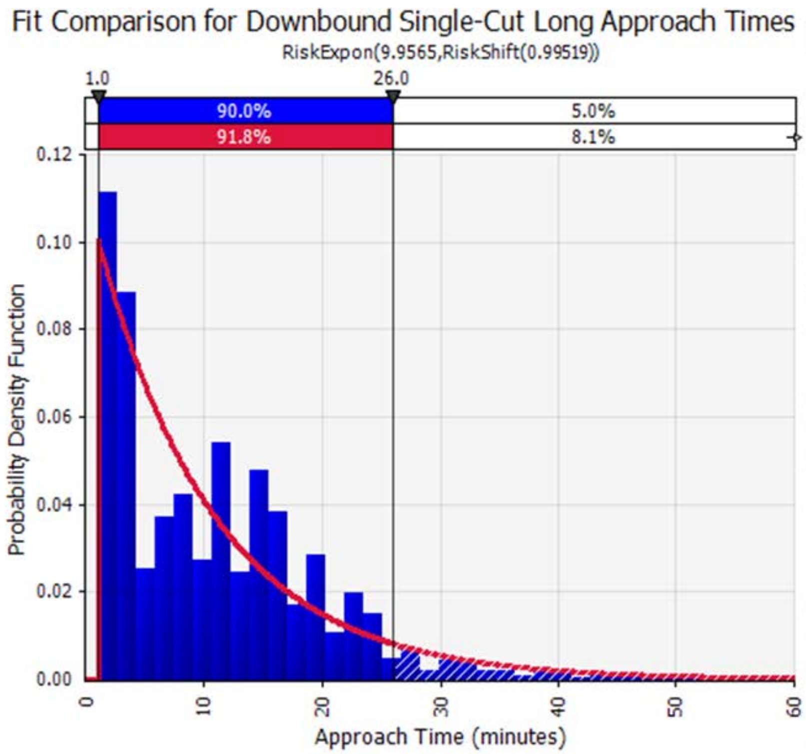
The time distributions for short approaches in **FIGURE A2-12** and **FIGURE A2-13***,* which correspond to turnback approach types, have lower means than the long approach time distribution of the same respective direction. Short approaches also have times that are more likely than long approaches to have short durations.

FIGURE A2-10: Upbound Single-Cut Long Approach Times Distribution Fitted to Exponential Distribution



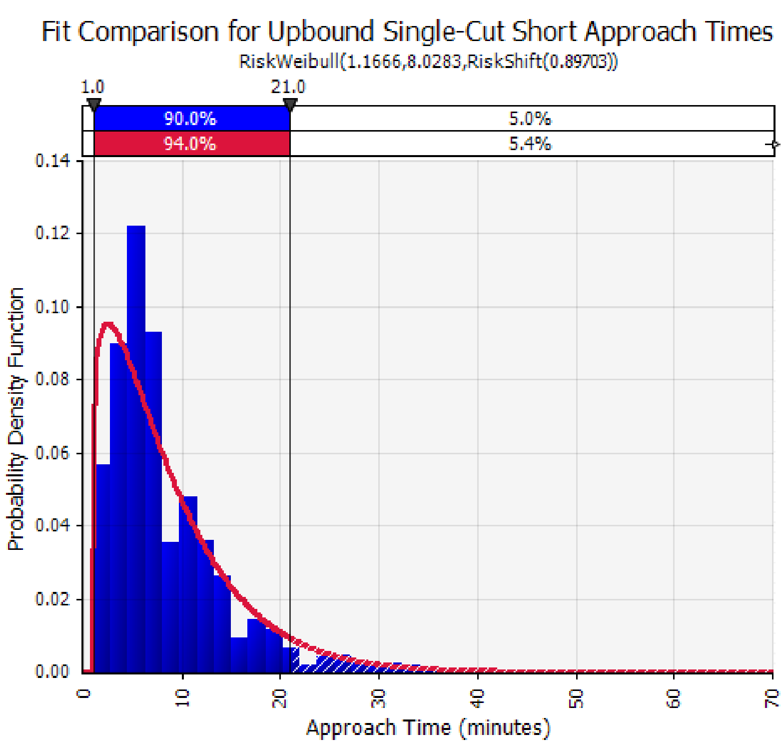
Statistics	Input	Expon
Minimum	1.000	0.000
Maximum	58.000	+∞
Mean	11.441	11.441
Mode	≈1.000	0.000
Median	10.000	7.930
Std Dev	8.514	11.441
Skewness	1.2185	2.0000
Kurtosis	5.3984	9.0000
Left X	1.0	1.0
Left P	5.0%	8.4%
Right X	26.0	26.0
Right P	95.0%	89.7%
Dif. X	25.000	25.000
Dif. P	90.0%	81.3%
1%	1.000	0.115
5%	1.000	0.587
10%	2.000	1.205
15%	3.000	1.859
20%	4.000	2.553
25%	5.000	3.291
30%	6.000	4.081
35%	6.000	4.929
40%	8.000	5.844
45%	9.000	6.840

FIGURE A2-11: Downbound Single-Cut Long Approach Time Distribution Fitted to Exponential Distribution



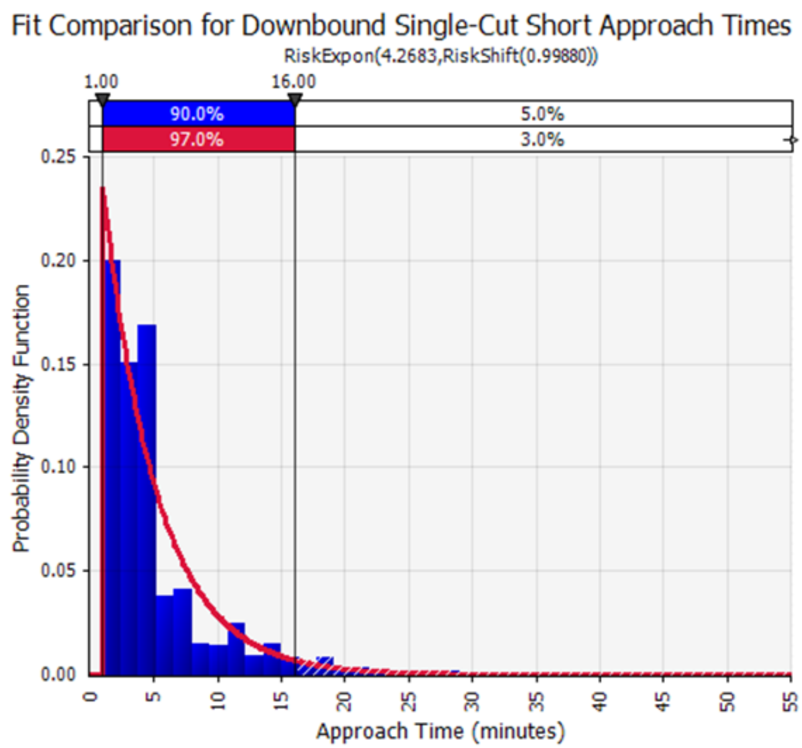
Statistics	Input	Expon
Minimum	1.000	0.995
Maximum	54.000	+∞
Mean	10.957	10.952
Mode	≈1.000	0.995
Median	10.000	7.897
Std Dev	8.723	9.957
Skewness	1.1589	2.0000
Kurtosis	4.7501	9.0000
Left X	1.0	1.0
Left P	5.0%	0.0%
Right X	26.0	26.0
Right P	95.0%	91.9%
Dif. X	25.000	25.000
Dif. P	90.0%	91.8%
1%	1.000	1.095
5%	1.000	1.506
10%	2.000	2.044
15%	2.000	2.613
20%	3.000	3.217
25%	3.000	3.859
30%	4.000	4.546
35%	5.000	5.284
40%	7.000	6.081
45%	9.000	6.948

FIGURE A2-12: Upbound Single-Cut Short Approach Times Distribution Fitted to Weibull Distribution



Statistics	Input	Weibull
Minimum	1.000	0.897
Maximum	64.000	+∞
Mean	8.525	8.506
Mode	≈1.000	2.411
Median	7.000	6.761
Std Dev	6.611	6.543
Skewness	2.3177	1.5874
Kurtosis	11.9821	6.5682
Left X	1.0	1.0
Left P	5.0%	0.6%
Right X	21.0	21.0
Right P	95.0%	94.6%
Dif. X	20.000	20.000
Dif. P	90.0%	94.0%
1%	1.000	1.053
5%	1.000	1.526
10%	3.000	2.063
15%	3.000	2.588
20%	4.000	3.116
25%	4.000	3.656
30%	5.000	4.215
35%	5.000	4.797
40%	6.000	5.411
45%	6.000	6.063

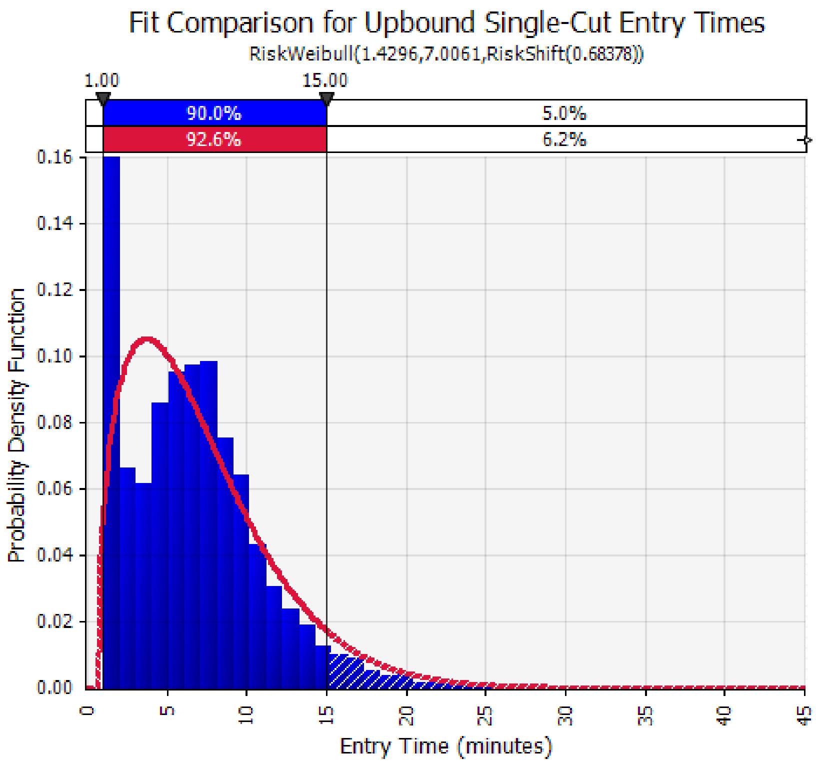
FIGURE A2-13: Downbound Single-Cut Short Approach Times Distribution Fitted to Exponential Distribution



Statistics	Input	Expon
Minimum	1.000	0.999
Maximum	50.000	+∞
Mean	5.268	5.267
Mode	≈1.000	0.999
Median	4.000	3.957
Std Dev	5.171	4.268
Skewness	2.8605	2.0000
Kurtosis	14.7902	9.0000
Left X	1.00	1.00
Left P	5.0%	0.0%
Right X	16.00	16.00
Right P	95.0%	97.0%
Dif. X	15.000	15.000
Dif. P	90.0%	97.0%
1%	1.000	1.042
5%	1.000	1.218
10%	1.000	1.449
15%	2.000	1.692
20%	2.000	1.951
25%	2.000	2.227
30%	3.000	2.521
35%	3.000	2.838
40%	3.000	3.179
45%	3.000	3.551

FIGURE A2-14 and ***FIGURE A2-15*** below reflect that the entry times distributions are fairly similar between upbound and downbound entries. This makes sense because the entry processing component time is the difference between the vessel's LPMS recorded bow-over-sill time (BOS) and its end-of-entry time (EOE), i.e., the time elapsed from when the vessel's bow traverses the sill of the lock chamber until the time when the vessel has fully entered the chamber and stopped moving to allow for gate closing. This process entails the same distance by both directions, with no expected obstructions. Therefore times should not vary by direction.

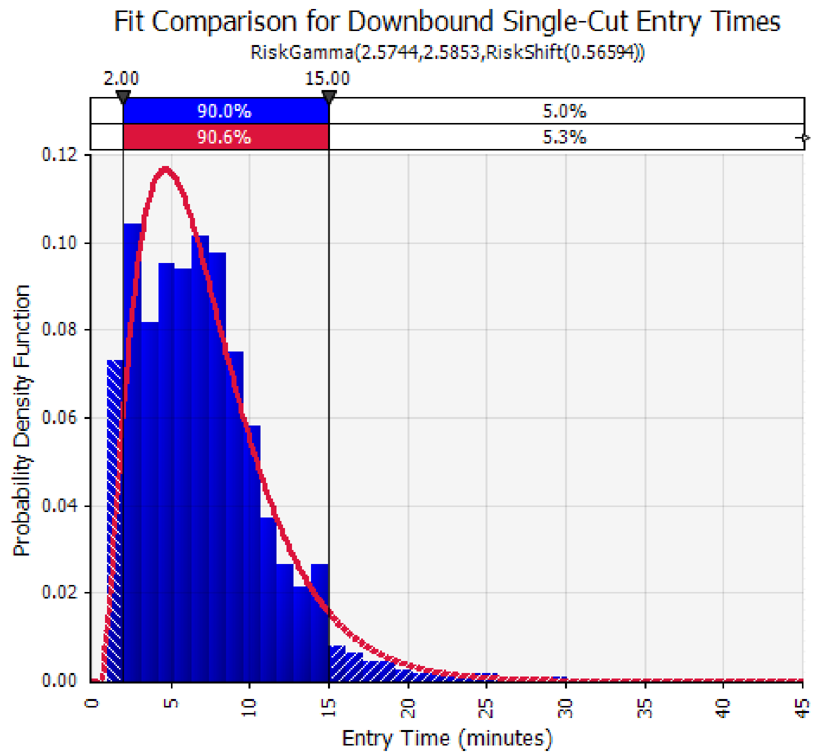
FIGURE A2-14: Upbound Single-Cut Entry Times Distribution Fitted to Weibull Distribution



Statistics

	Input	Weibull
Minimum	1.000	0.684
Maximum	41.000	+∞
Mean	7.080	7.049
Mode	≈1.000	3.705
Median	7.000	6.105
Std Dev	4.371	4.518
Skewness	1.1589	1.1591
Kurtosis	5.9833	4.6936
Left X	1.00	1.00
Left P	5.0%	1.2%
Right X	15.00	15.00
Right P	95.0%	93.8%
Dif. X	14.000	14.000
Dif. P	90.0%	92.6%
1%	1.000	0.964
5%	1.000	1.561
10%	2.000	2.135
15%	2.000	2.649
20%	3.000	3.137
25%	4.000	3.615
30%	5.000	4.090
35%	5.000	4.571
40%	6.000	5.063
45%	6.000	5.573

FIGURE A2-15: Downbound Single-Cut Entry Times Distribution Fitted to Gamma Distribution

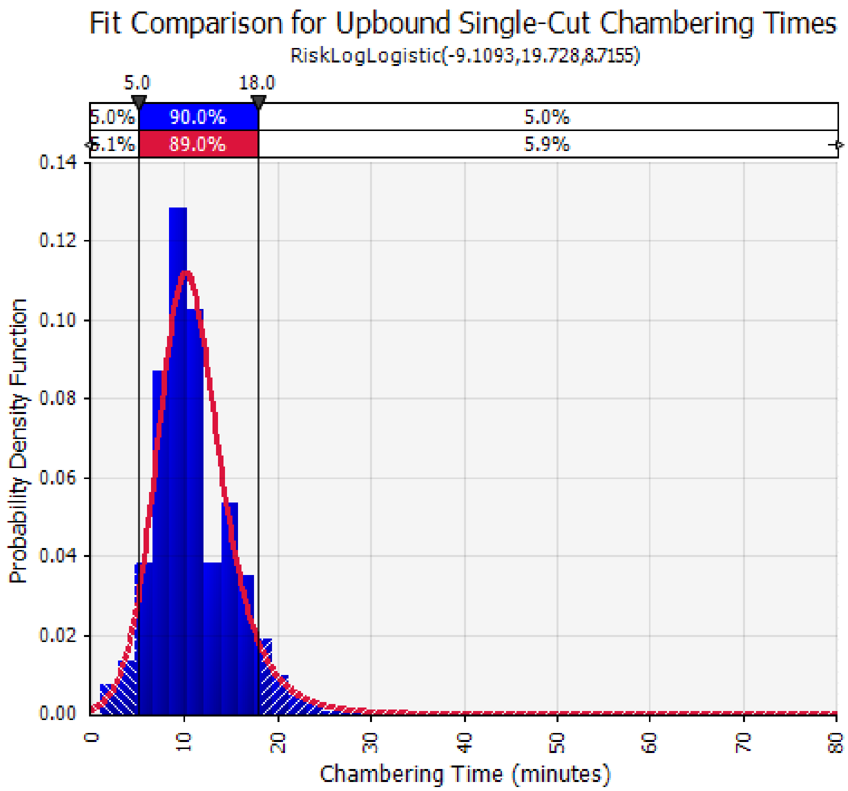


Statistics	Input	Gamma
Minimum	1.000	0.566
Maximum	43.000	+∞
Mean	7.222	7.222
Mode	≈1.000	4.636
Median	7.000	6.382
Std Dev	4.248	4.148
Skewness	1.7693	1.2465
Kurtosis	9.3863	5.3306
Left X	2.00	2.00
Left P	5.0%	4.1%
Right X	15.00	15.00
Right P	95.0%	94.7%
Dif. X	13.000	13.000
Dif. P	90.0%	90.6%
1%	1.000	1.339
5%	2.000	2.137
10%	3.000	2.758
15%	3.000	3.269
20%	4.000	3.732
25%	4.000	4.171
30%	5.000	4.601
35%	5.000	5.031
40%	6.000	5.466
45%	6.000	5.915

FIGURE A2-16 and **FIGURE A2-17** below show the upbound single-cut chambering times distribution and downbound single-cut chambering times distribution respectively. Skewness measures how asymmetric a distribution is around its mean. A normal distribution thus has a skewness of zero since it is perfectly symmetric. Given that both distributions have a lower bound of zero, they will inevitably have positive skewness. A distribution is considered to be skewed left if its skewness measure is negative, imply a left tail that is relatively longer than the right tail; while positive skewness corresponds to a distribution with a relatively longer right tail.

As can be seen in **FIGURE A2-16** and **FIGURE A2-17**, both distributions are skewed to the right. The downbound distribution though is more skewed to the right than the upbound distribution and has a larger mean. This is likely because downbound chambering times can be inflated from downbound vessels occasionally being delayed in exiting the lock as they must wait for the St. Claude Avenue Bridge to first be raised. The sample (unfitted) upbound chambering distribution actually has a higher kurtosis than the downbound times, meaning in this case its probability distribution has a higher peak and a right tail that is thinner and shorter than that of the downbound times, i.e., upbound chambering times that are substantially higher than the mean have a lower probability of occurring than in the case of downbound chamberings. A standard normal distribution has a kurtosis of three.

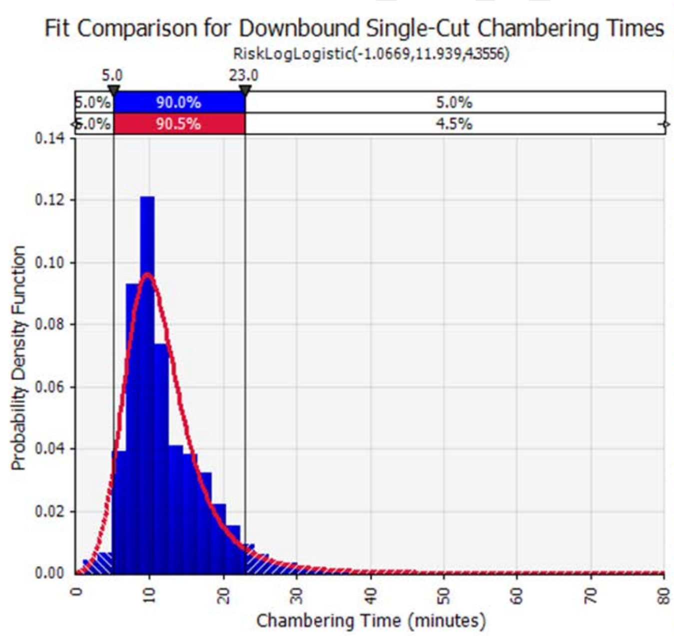
FIGURE A2-16: Upbound Single-Cut Chambering Times Distribution Fitted to Log-Logistic Distribution



Statistics

	Input	LogLogistic
Minimum	1.000	-9.109
Maximum	73.000	+∞
Mean	11.066	11.052
Mode	≈1.000	10.104
Median	10.000	10.619
Std Dev	4.388	4.309
Skewness	1.5462	1.1018
Kurtosis	14.0022	7.4800
Left X	5.0	5.0
Left P	5.0%	5.1%
Right X	18.0	18.0
Right P	95.0%	94.1%
Dif. X	13.000	13.000
Dif. P	90.0%	89.0%
1%	1.000	2.535
5%	5.000	4.963
10%	6.000	6.223
15%	7.000	7.058
20%	8.000	7.718
25%	8.000	8.282
30%	9.000	8.791
35%	9.000	9.266
40%	10.000	9.722
45%	10.000	10.170

FIGURE A2-17: Downbound Single-Cut Chambering Times Distribution Fitted to Log-Logistic Distribution

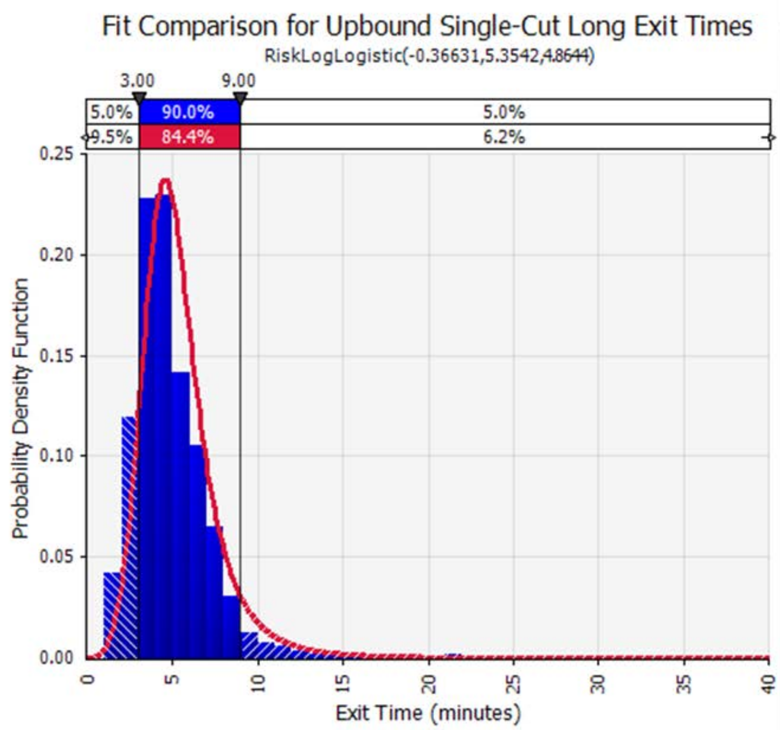


Statistics

	Input	LogLogistic
Minimum	1.000	-1.067
Maximum	77.000	+∞
Mean	12.055	11.974
Mode	≈5.000	9.657
Median	10.000	10.872
Std Dev	5.808	6.104
Skewness	1.7593	3.3631
Kurtosis	9.7546	89.4520
Left X	5.0	5.0
Left P	5.0%	5.0%
Right X	23.0	23.0
Right P	95.0%	95.5%
Dif. X	18.000	18.000
Dif. P	90.0%	90.5%
1%	3.000	3.090
5%	5.000	5.006
10%	7.000	6.142
15%	7.000	6.950
20%	8.000	7.618
25%	8.000	8.210
30%	9.000	8.762
35%	9.000	9.290
40%	10.000	9.811
45%	10.000	10.335

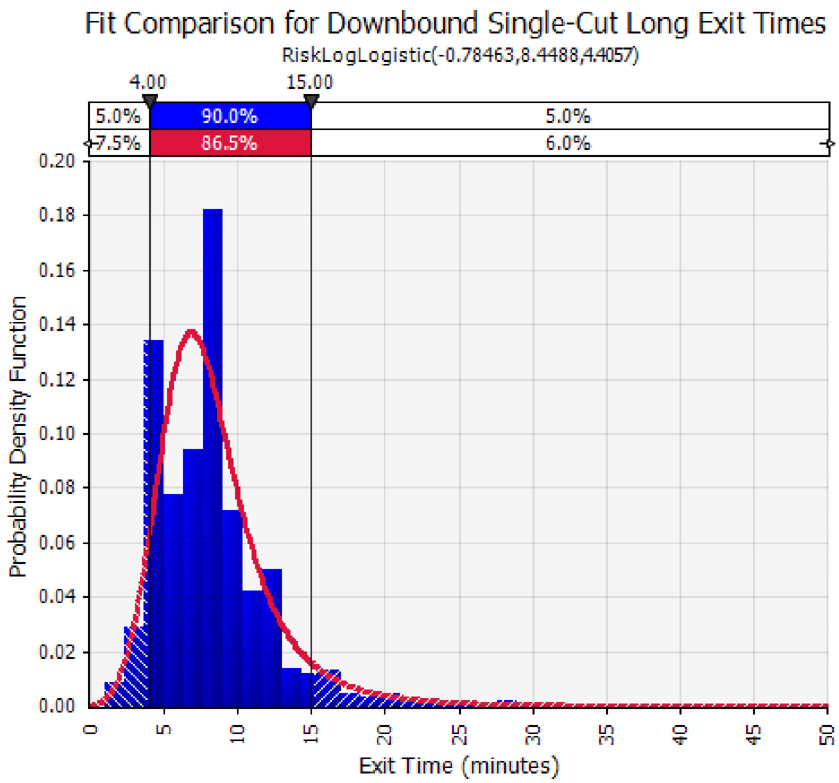
FIGURE A2-18 and ***FIGURE A2-19*** show that downbound exit times are almost three minutes longer on average than upbound times, for single-cut flotilla lockages. Despite this, upbound exit time observations are more concentrated at values that are just a few minutes or less above the mean, resulting in a relatively thinner and shorter right tail for the upbound distribution. This is consistent with the fact that the downbound distribution has more variance on average. Downbound exit times seem to typically be longer because the south-side guidewall is relatively longer and therefore exiting on the south-side takes more time since a greater distance must be traveled to complete the exit. The greater variance for downbound times may also be attributable to St. Claude, since some vessels will have very short exit times if they are not impacted by St. Claude while others may have very long times if they are delayed by the bridge. The potential large variance in delay time from waiting for St. Claude's translates in to substantial variation in downbound exit times.

FIGURE A2-18: Upbound Single-Cut Long Exit Times Distribution Fitted to Log-Logistic Distribution



Statistics	Input	LogLogistic
Minimum	1.000	-0.366
Maximum	35.000	+∞
Mean	5.392	5.379
Mode	≈2.000	4.548
Median	5.000	4.988
Std Dev	2.475	2.347
Skewness	3.1755	2.6237
Kurtosis	25.9402	34.4766
Left X	3.00	3.00
Left P	5.0%	9.5%
Right X	9.00	9.00
Right P	95.0%	93.8%
Dif. X	6.000	6.000
Dif. P	90.0%	84.4%
1%	2.000	1.716
5%	3.000	2.557
10%	3.000	3.042
15%	3.000	3.382
20%	4.000	3.660
25%	4.000	3.905
30%	4.000	4.132
35%	4.000	4.348
40%	5.000	4.560
45%	5.000	4.772

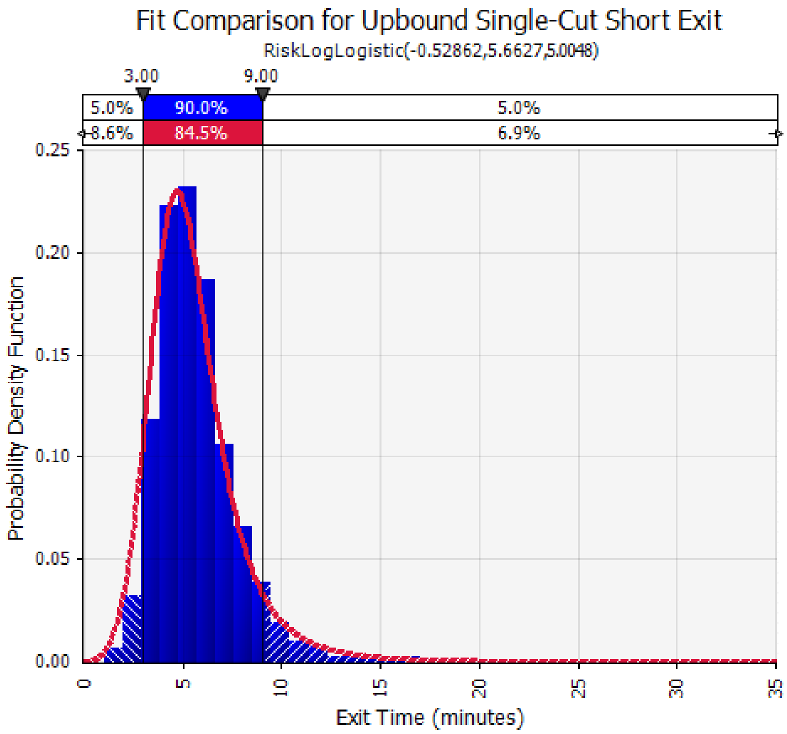
FIGURE A2-19: Downbound Single-Cut Long Exit Times Distribution Fitted to Log-Logistic Distribution



Statistics	Input	LogLogistic
Minimum	1.000	-0.785
Maximum	45.000	+∞
Mean	8.385	8.425
Mode	≈3.000	6.823
Median	8.000	7.664
Std Dev	4.150	4.249
Skewness	2.3505	3.2686
Kurtosis	14.7099	77.6549
Left X	4.00	4.00
Left P	5.0%	7.5%
Right X	15.00	15.00
Right P	95.0%	94.0%
Dif. X	11.000	11.000
Dif. P	90.0%	86.5%
1%	2.000	2.193
5%	4.000	3.546
10%	4.000	4.346
15%	5.000	4.914
20%	5.000	5.383
25%	6.000	5.800
30%	6.000	6.186
35%	7.000	6.557
40%	7.000	6.921
45%	7.000	7.288

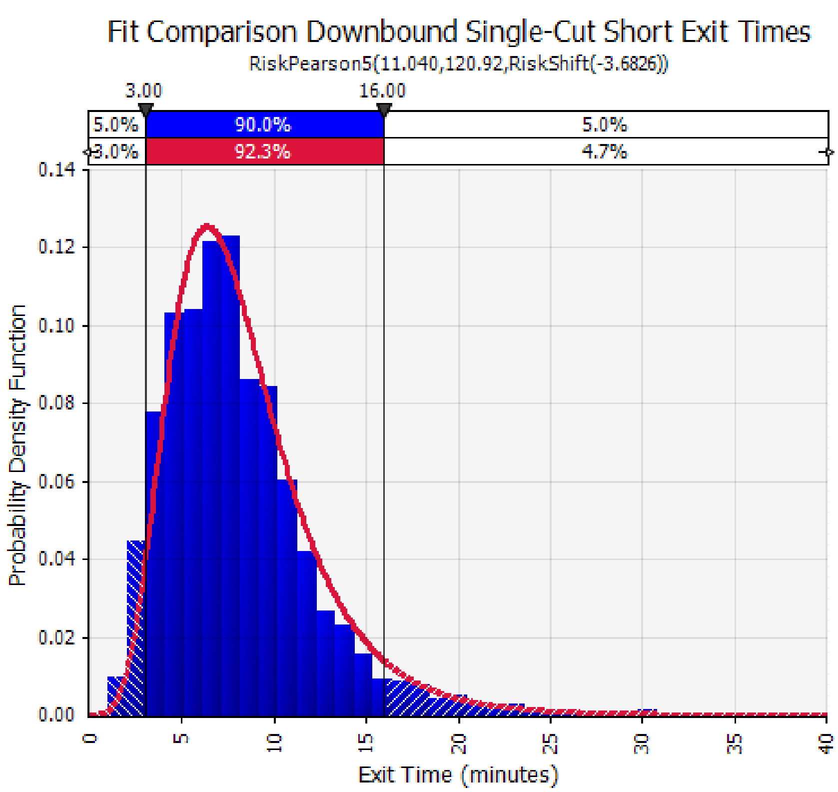
Although the downbound single-cut short exit time distribution was fitted to a different distribution type then that of the single-cut long exits in the same direction (), the means for the short exit time distributions are very similar to their corresponding long exit time distribution of the same direction. The reason for this similarity is that a turnback exit, i.e., short exit, on average should not have a duration that differs greatly from a fly or exchange exit since a turnback exit does not entail a shorter distance traveled than the other exit types.

FIGURE A2-20: Upbound Single-Cut Short Exit Times Distribution Fitted to Log-Logistic Distribution



Statistics	Input	LogLogistic
Minimum	1.000	-0.529
Maximum	34.000	+∞
Mean	5.537	5.524
Mode	≈2.000	4.694
Median	5.000	5.134
Std Dev	2.490	2.390
Skewness	2.8326	2.4807
Kurtosis	22.0950	29.4079
Left X	3.00	3.00
Left P	5.0%	8.6%
Right X	9.00	9.00
Right P	95.0%	93.1%
Dif. X	6.000	6.000
Dif. P	90.0%	84.5%
1%	2.000	1.732
5%	3.000	2.616
10%	3.000	3.122
15%	4.000	3.475
20%	4.000	3.764
25%	4.000	4.018
30%	4.000	4.252
35%	4.000	4.475
40%	5.000	4.693
45%	5.000	4.912

FIGURE A2-21: Downbound Single-Cut Short Exit Times Distribution Fitted to Pearson Type 5 Distribution



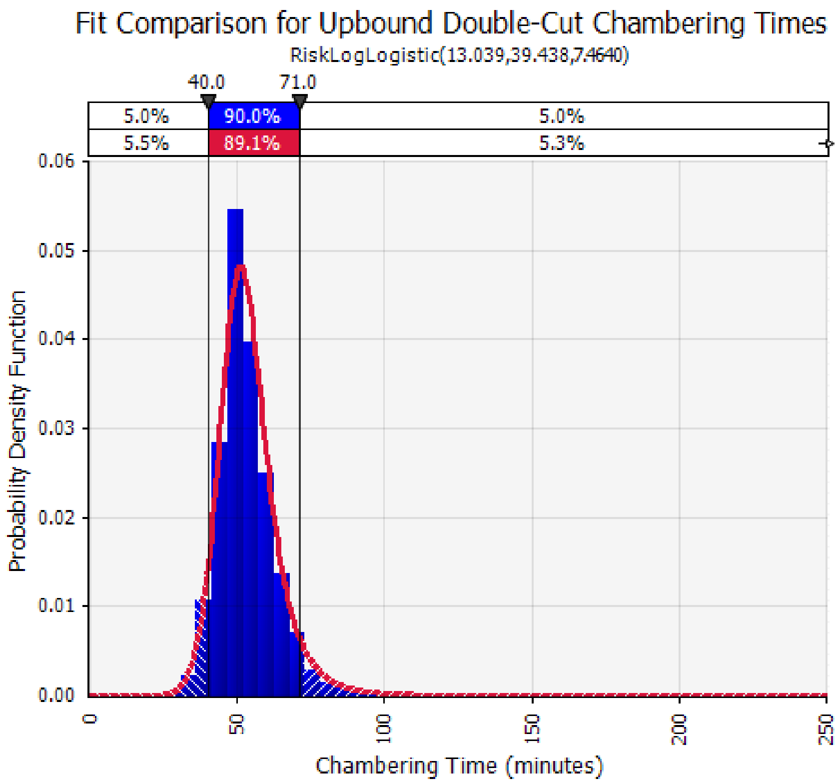
Statistics	Input	Pearson5
Minimum	1.000	-3.683
Maximum	37.000	+∞
Mean	8.368	8.361
Mode	≈3.000	6.361
Median	8.000	7.609
Std Dev	4.086	4.006
Skewness	1.7287	1.4959
Kurtosis	8.7201	7.6854
Left X	3.00	3.00
Left P	5.0%	3.0%
Right X	16.00	16.00
Right P	95.0%	95.3%
Dif. X	13.000	13.000
Dif. P	90.0%	92.3%
1%	3.000	2.304
5%	3.000	3.425
10%	4.000	4.142
15%	5.000	4.681
20%	5.000	5.146
25%	6.000	5.574
30%	6.000	5.981
35%	7.000	6.381
40%	7.000	6.780
45%	7.000	7.188

The probability distributions of component processing times for double-cut distributions are in most cases similar to that of their single-cut counterpart, with the exception of the chambering times distributions. The duration of a multi-cut chambering time is the difference between the end-of-entry time of its first cut and the start-of-exit time of its last cut. This means a double-cut chambering time encompasses the chambering time and exit time of the first cut; as well as the turnback chambering time, approach time, entry time, and chambering time of the second cut.

The means, and in some cases the standard deviations are fairly similar for the single-cut and double-cut distributions for the same processing component time of the same direction (with the exception of chambering times). In fact, in most cases the mean of the double-cut distributions for all component processing times, other than chambering times, is slightly less than the distributions of its single-cut counterpart. Interestingly, the probability density curve for the single-cut chambering time distributions seems to start falling (i.e., nearing a flat slope of zero) and reaching times with miniscule probabilities at a chambering time that is fairly close to the time at which its corresponding double-cut distribution of the same direction has its own probability density curve start increasing. In other words, the upbound single-cut chambering time distribution has a very low probability of experiencing a time greater than 30 minutes whereas its corresponding double-cut distribution is very unlikely to observe a time less than 30 minutes (**FIGURE A2-22**). Both distributions are log-logistic, and have similar kurtosis and skewness, yet there is much greater variance for double-cut lockages. This makes sense, given that there could be some variance in how long it takes to turn back the chamber and variance in the approach time of the second cut, both of which are components of a double-cut chambering time. The mean time for upbound double-cut chamberings is nearly 54 minutes compared with approximately 11 minutes for single-cuts. This large difference is because a double-cut chambering entails not just twice as much time waiting for the chamber to fill and spill, but also the additional time for the turning back of the chamber and the approach and entry of the second cut.

Similarly, the downbound single-cut chambering time distribution has a very low probability of experiencing a chambering time greater than 35 minutes while it is very unlikely that a downbound double-cut chambering time of less than 35 minutes will be observed.

FIGURE A2-22: Upbound Double-Cut Chambering Times Distribution Fitted to Log-Logistic Distribution



Statistics

	Input	LogLogistic
Minimum	15.00	13.039
Maximum	216.00	+∞
Mean	54.35	53.666
Mode	≈40.00	51.078
Median	52.00	52.477
Std Dev	14.16	10.243
Skewness	5.0157	1.3384
Kurtosis	44.1040	9.2604
Left X	40.0	40.0
Left P	5.0%	5.5%
Right X	71.0	71.0
Right P	95.0%	94.7%
Dif. X	31.00	31.000
Dif. P	90.0%	89.1%
1%	36.00	34.347
5%	40.00	39.621
10%	43.00	42.420
15%	45.00	44.299
20%	46.00	45.792
25%	47.00	47.079
30%	48.00	48.245
35%	49.00	49.338
40%	50.00	50.392
45%	51.00	51.431

3.2.2 Non-Curfew Random Minor Downtimes

Locks experience periods of time when traffic is unable to transit through the facility. These periods are referred to as downtime. This study addresses downtime by segregating these events into two groups, random minor and major maintenance. This section discusses random minor downtimes.

Random minor downtimes are short duration, less than 1 day, unscheduled chamber closures. They are caused by various things such as the weather, mechanical breakdowns, river conditions, lock conditions, and other circumstances. For the IHNC Lock analysis random minor downtime files were developed based on 2010 through 2014 LPMS data and are summarized in ***TABLE A2-9***.

TABLE A2-9: IHNC Lock Historic LPMS Random Minor Stalls and WAM Downtime

Disruption Description	Number of Occurrences	Average Duration (Minutes)	Minimum Duration (Minutes)	Max of Duration (Minutes)
Bridge or other structure (i.e. railway, pontoon, swing etc.)	80	112.64	4.00	803.00
Collision or Accident	3	83.00	26.00	128.00
Environmental (i.e. fish, animals, oil spills, etc.)	2	458.50	94.00	823.00
Fog	29	272.28	20.00	903.00
Lightning	5	64.00	40.00	124.00
Lock hardware or equipment malfunction	9	203.22	61.00	565.00

Maintaining lock or lock equipment	6	92.50	34.00	309.00
Other	7	64.43	9.00	120.00
Repairing lock or lock hardware	7	272.43	40.00	841.00
Wind	2	257.50	74.00	441.00

Source: Lock Performance Monitoring System (LPMS).

3.2.3 Fleet

The fleet is the sum total of all vessels that use the lock. This includes commercial tows, Light-boats, and recreation craft. The fleet is fed to WAM as an external event file known as the WAM shipment list. The shipment list is generated based on historic LPMS and WCSC data, and may contain several thousand records. Each record, which represents a shipment, has a unique arrival time and vessel description. When taken in total, a WAM shipment list closely matches the overall characteristics of the actual fleet.

A typical shipment can be characterized three ways; by type of vessel, by size of vessel, and by time of arrival. WAM simulates three types of vessels, tows, recreation craft, and Light-boats / other vessels. The size of the vessel is dependent on vessel type, and for tows, the number and type barges. Arrival times are based on historic arrival patterns, with each vessel type having its own arrival pattern. The actual arrival time in any one given WAM shipment list is variable.

The shipment list drives what happens at the lock during the simulation. Therefore, a great deal of effort is expended to ensure that the "what and when" of the WAM fleet closely match the "what and when" of the actual fleet.

3.2.3.1 Vessel Types

Vessels are grouped into one three types in this study. Tows are commercial towboats pushing one or more barges. Light-boats are commercial towboats without barges. Recreation craft are non-commercial, usually small, vessels. Commercial-passenger vessels, government vessels, and other vessel types are counted and included in the Light-boats group. ***TABLE A2-10*** shows the number of vessels, by vessel type, for the 2014 Inner Harbor fleet.

TABLE A2-10: IHNC Lock Number of Vessels by Type

Tows	5,864
Recreational	189
Other	395

Source: Lock Performance Monitoring System (LPMS)

3.2.3.2 Towboat Types

Towboats were categorized into 8 groups based on horsepower. ***TABLE A2-11*** lists the towboat types, horsepower, prevalence, and dimensions used in this study.

TABLE A2-11: IHNC Lock Towboat Types, Horsepower, and Dimension Assumptions

Horsepower Class	Percent of Population	Length (feet)	Width (feet)
< 1,000	74.9	82	24
1,000 to 1,499	3.5	98	29
1,500 to 1,899	19.2	115	30
1,900 to 2,299	1.4	131	31
2,300 to 3,099	0.3	141	35

3,100 to 4,199	0.7	151	40
4,200 to 5,499	0.0	162	42
> 5,500	0.0	185	53

Source: Lock Performance Monitoring System (LPMS)

3.2.3.3 Barge Types

Tow size is a key input determinant when estimating lock capacity. Tow size is determined by the type and number of barges being pushed. This study models 12 barge types which are typical on the inland navigation system. ***TABLE A2-12*** shows the barge types, barge dimensions, number of barges, percent loaded, and barges per tow in the 2014 Inner Harbor fleet.

TABLE A2-12: IHNC Lock Barge Data

Barge Type	Length (Feet)	Width (Feet)	Percent Loaded	Barges Per Tow
Sand Flat	135	27	41.8	1.6
Regular	175	26	60.3	1.5
Stumbo	195	26	0.0	-
Jumbo	195	35	56.7	3.5
Covered Jumbo	195	35	62.7	5.3
Super Jumbo	245	35	46.8	2.7
Giant Jumbo	260	52	71.9	4.9
Jumbo Tanker	195	35	0.0	-
147 Tanker	147	52	58.8	1.3
175 Tanker	175	54	72.2	1.2
264 Tanker	264	50	79.7	1.4
297 Tanker	297	54	55.0	1.7
Total			57.2	2.5

Source: Lock Performance Monitoring System (LPMS)

3.3 WAM Existing Condition Calibration and Validation

WAM validation involves first a validation of the shipment list generator and calibration of the shipment list that is fed into the WAM simulation. After the shipment list is calibrated, the next step is to validate the WAM simulation itself. The validation process for the IHNC Lock existing condition consisted of three steps: 1) calibration of the shipment list; 2) verification of the processing times by lockage type; and 3) validation of the delay times.

3.3.1 Shipment List Calibration

After the input data is prepared, the next step in running WAM is running the shipment list generator and calibrating shipment lists. Calibration is a process that fine tunes the input files so that generated shipment lists closely match the real world fleet. Calibration is necessary for two reasons. First, WAM uses two data sources to create the shipment lists, and the data sources are not perfectly compatible. Second, the shipment list generator generates tows that have only one barge type instead of two or more barge types in a single tow. For a full explanation of how the shipment list generator works, see Section 2.4.3.3. A detailed description of the calibration process can be found in Section 2.4.3.4.

TABLE A2-13 shows the statistics used when calibrating the shipment list. The target values for tons / loaded barge were taken directly from WCSC data. The target values for number of tows, number of loaded barges, and number of empty barges were taken directly from LPMS data. The other remaining values were calculated based on the values taken directly from WCSC and LPMS. The values shown in the WAM Runs column are the averages of ten different WAM shipment lists. Calibration is considered complete when the WAM Runs are within 3% of the Target values for all statistics.

TABLE A2-13: IHNC Lock Shipment List Calibration

IHNC	2014 Base Year		
	Target	WAM Runs	% Difference
Tonnage (thousands)	17,835	17,845	0.06%
Tows	6,024	5,960	-1.07%
Tons per Tow	2,961	2,994	1.14%
Barges	14,540	14,438	-0.70%
Loaded Barges	8,314	8,313	-0.01%
Empty Barges	6,226	6,125	-1.62%
Percent Empty	42.8%	42.4%	-0.40%
Tons per Loaded Barge	2,145	2,147	0.07%
Barges per Tow	2.41	2.42	0.37%

Source: Lock Performance Monitoring System (LPMS) and Waterborne Commerce Statistics (WCS) data. Fields are calculated from aggregated metrics and may not match source data exactly.

3.3.2 Processing Time & Delay Validation

After the shipment list is calibrated, the next step is to validate the WAM simulation itself. Validation ensures that WAM results reasonably reproduce actual base year processing and delay times. Target processing and delay times, taken directly from LPMS, were used to validate WAM. Fifty WAM runs were made at base year traffic levels with the FIFO lockage policy. The average processing and delay times for those runs is then compared to actual data.

TABLE A2-14 displays historic LPMS data to which the WAM runs were compared. This is notable because beginning in 2010, IHNC Lock operators began altering how data was input at the project. Instead of waiting until tows had the necessary assist vessels in place to transit the lock, operators began recording data from the time the tow arrived, regardless of if it was technically ready to transit per operating policy. This introduces a random variable to the lockage process that WAM is not capable of modeling well, and which the equilibrium modeling accounted for separately. ***TABLE A2-15*** shows the results of the WAM validation runs, and **TABLE A2-16** shows how well the results tracked with historic averages given the different policies. The validation comparison displays WAM's capability of modeling the pre-2010 policy quite well and also demonstrates the issues with modeling the random availability and acquisition of trip vessels. Given this, and the fact that the equilibrium model was setup to account for the operating policy separately, WAM was validated against data from 2000-2009.

TABLE A2-16 shows how well WAM reproduces the target processing and delay times. WAM reproduces processing times at IHNC Lock from 2000-2009 within 10%, but estimates delay times within 4%. Given the variability in operating policy and fluctuations in head differential, this was considered valid for use in this study.

TABLE A2-14: IHNC Lock Historic Timing - Validation

Year	Process Time (min)	Delay (Hours)	Tons
2000	58	5.22	16,781,304
2001	42	4.12	16,364,432
2002	44	5.32	17,543,776
2003	44	4.62	17,265,557
2004	47	8.42	18,609,207

2005	47	7.83	16,280,776
2006	47	8.13	16,579,598
2007	46	7.00	17,232,992
2008	50	8.42	12,586,987
2009	51	7.65	14,058,206
2010	52	10.67	16,123,416
2011	50	12.52	14,974,780
2012	51	14.12	15,444,250
2013	54	12.80	15,646,284
2014	51	24.83	15,728,281
2015	50	17.73	15,188,938
Average (All Years)	49.00	9.96	16,025,549
Average (2000-2009)	47.60	6.67	16,330,284
Average (2010-2015)	51.33	15.44	15,517,658

Source: Lock Performance Monitoring System

TABLE A2-15: WAM Validation Run Output

	Tonnage	Process Time (Minutes)	Delay (Hours)
WAM Validation	16,204,157.00	58.5	6.2

TABLE A2-16: Validation of WAM Simulation to LPMS Statistics

Year	Process Time	Delay (Hours)	Process Time	Process Time Difference	Delay (Hours)	Delay Difference
Average (All Years)	49.00	597.69	58.5	9%	6.2	23%
Average (2000-2009)	47.60	400.30	58.5	10%	6.2	4%
Average (2010-2015)	51.33	926.67	58.5	7%	6.2	43%

3.4 Existing / Without-Project Condition Capacity Analysis

Capacity is a useful number when making simple comparisons between locks. However, navigation economic studies do not use the capacity number. Instead, the economic analysis uses capacity curves, or tonnage-transit curves. The tonnage-transit curves are used because they define the relationship between tonnages processed and expected transit time over a range of tonnage levels. This way, the economic model can determine expected transit time for any given tonnage between zero and capacity.

3.4.1 Identification of Optimal Lockage Policy

After input preparation, shipment list calibration, and processing and delay time validation, the next step is to determine the most efficient lockage policy. This is done to satisfy Corps regulation ER-1105-2-100 section II, E-9.c.a which states in part "*Assume that all reasonably expected non-structural practices …. Including … lockage policies are implemented at the appropriate time.*" Two lockage policies are typically evaluated:

First-In First-Out (FIFO); and

6-up / 6-down service policy.

Often to determine the best or "*optimal*" lockage policy, simulation runs are made at high project utilization levels for each lockage policy. The 'optimal' lockage policy is the policy that results in the highest tonnage level with the lowest transit time at maximum lock utilization. With a 6-up / 6-down service policy in WAM, FIFO is practiced until the n-up / n-down policy becomes optimal. The n-up / n-down policy is typically optimal at high utilization levels as it minimizes chamber turn-back operations.

For the analysis of the IHNC Lock without-project (existing) condition, a 6-up / 6-down lockage policy was assumed.

3.4.2 Without-Project Condition Capacity Results

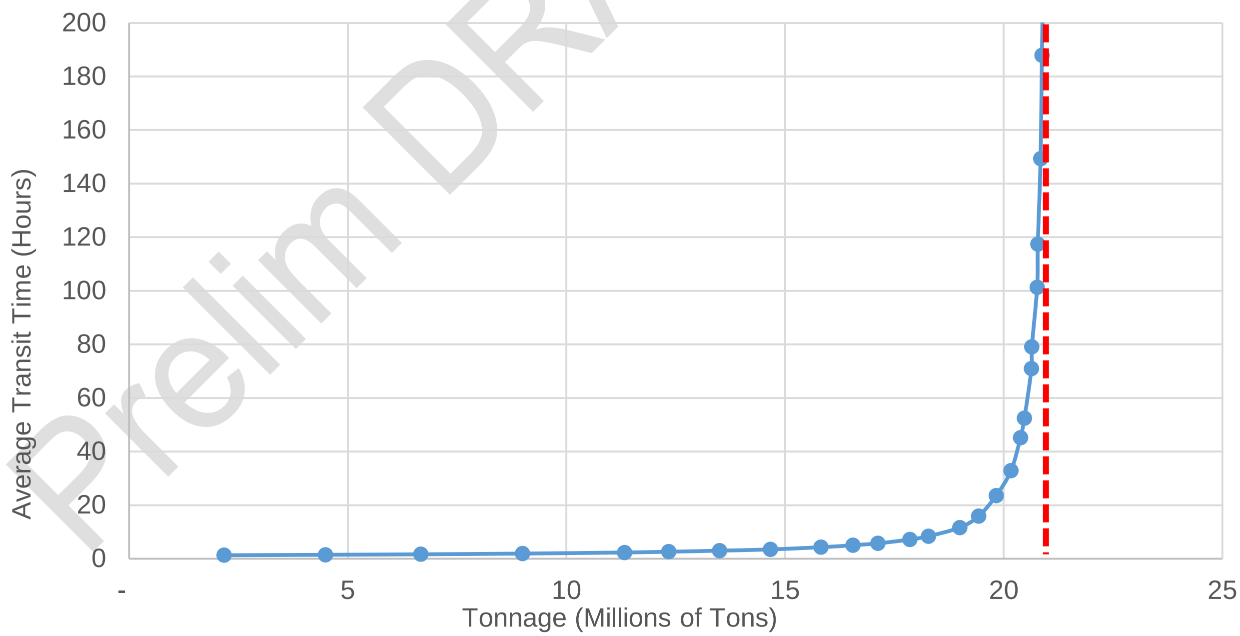
For the economic analysis, a full-operations and eleven service disruption curves were developed.

3.4.2.1 Full-Operations Tonnage-Transit Curves

FIGURE A2-23 shows the capacity curve and other information for IHNC Lock Without-Project Condition, Full Operation scenario. This capacity curve is used to represent a year where only random downtime occurs as well as downtimes for bridge curfews provided in ***TABLE A2-7***. The curve is developed by running WAM at 27 different traffic levels, 250 different runs per level. Therefore, 6,750 WAM runs were made to create one curve. The curve connects the averages at each tonnage level.

FIGURE A2-23 also shows a vertical dashed line where the curve goes asymptotic. This value is the capacity shown in **Error! Reference source not found.** as 20,886,988 tons. The capacity is the tonnage that corresponds with a transit time of 200 hours. The 200 hour transit time is an arbitrary value. In this reach of the curve, the difference in tonnage between 100 hours and 300 hours is typically very small.

FIGURE A2-23: IHNC Lock Existing / Without-Project Tonnage-Transit Curve



3.4.2.2 Service Disruption Tonnage-Transit Curves

For the economic analysis of the without-project condition eleven service disruption curves were also needed and developed. The service disruption events are summarized below.

3.4.2.2.1 1,440-Hour 24-Hour/Day Work Item Event

The tonnage-transit curve simulations for the 1,440-hour 24-hour/day service disruption event assumes a consecutive 60-day closure of the lock. This service disruption event was defined for dewatering & monitoring, major repair, and gate work item event.

3.4.2.2.2 720-Hour 12-Hour/Day Work Item Event

The tonnage-transit curve simulations for the 720-hour 12-hour/day service disruption event assumed 12-hour/day service disruption Monday-Friday over 60 weekdays (82 calendar days). This service disruption event was defined for rehabilitation of west and east chamber guidewalls work item event.

3.4.2.2.3 630-Hour 12-Hour/Day Work Item Event

The tonnage-transit curve simulations for the 630-hour 12-hour/day service disruption event assumed 12-hour/day service disruption Monday-Friday over 52.5 weekdays (72.5 calendar days). This service disruption was defined for rehabilitation of north-west and south-west guidewalls work item event.

3.4.2.2.4 400-Hour 12-Hour/Day Work Item Event

The tonnage-transit curve simulations for the 400-hour 12-hour/day service disruption event assumed 12-hour/day service disruption Monday-Friday over 33.3 weekdays (45.3 calendar days). This service disruption was defined for rehabilitation of the north-east and south-east guidewalls work item event.

3.4.2.2.5 250-Hour 12-Hour/Day Work Item Event

The tonnage-transit curve simulations for the 250-hour 12-hour/day service disruption event assumed 12-hour/day service disruption Monday-Friday over 20.8 weekdays (28.8 calendar days). This service disruption was defined for rehabilitation of north-east, north-west, south-east, and south-west Dolphins work item event.

3.4.2.2.6 175-Hour 24-Hour/Day Event

The tonnage-transit curve simulations for the 175-hour 24-hour/day service disruption event assumed 24-hour/day service disruption for 7.29 days straight. This service disruption was defined for unscheduled hurricane events.

3.4.2.2.7 175-Hour 12-Hour/Day Work Item Event

The tonnage-transit curve simulations for the 175-hour 12-hour/day service disruption event assumed 12-hour/day service disruption Monday-Friday over 14.6 weekdays (18.6 calendar days). This service disruption was defined for rewiring and machinery rehabilitation work item event.

3.4.2.2.8 150-Hour 12-Hour/Day Work Item Event

The tonnage-transit curve simulations for the 150-hour 12-hour/day service disruption event assumed 12-hour/day service disruption Monday-Friday over 12.5 weekdays (16.5 calendar days). This service disruption was defined for maintenance by hired labor units work item event.

3.4.2.2.9 100-Hour 12-Hour/Day Work Item Event

The tonnage-transit curve simulations for the 100-hour 12-hour/day service disruption event assumed 12-hour/day service disruption Monday-Friday over 8.3 weekdays (10.3 calendar days). This service disruption was defined for rehabilitation of the west and east chamber guidewall armoring work item event.

3.4.2.2.10 75-Hour 12-Hour/Day Work Item Event

The tonnage-transit curve simulations for the 75-hour 12-hour/day service disruption event assumed 12-hour/day service disruption Monday-Friday over 6.3 weekdays (8.3 calendar days). This service disruption was defined for rehabilitation of the north-west and south-west guidewall face timbers work item event.

3.4.2.2.11 50-Hour 12-Hour/Day Work Item Event

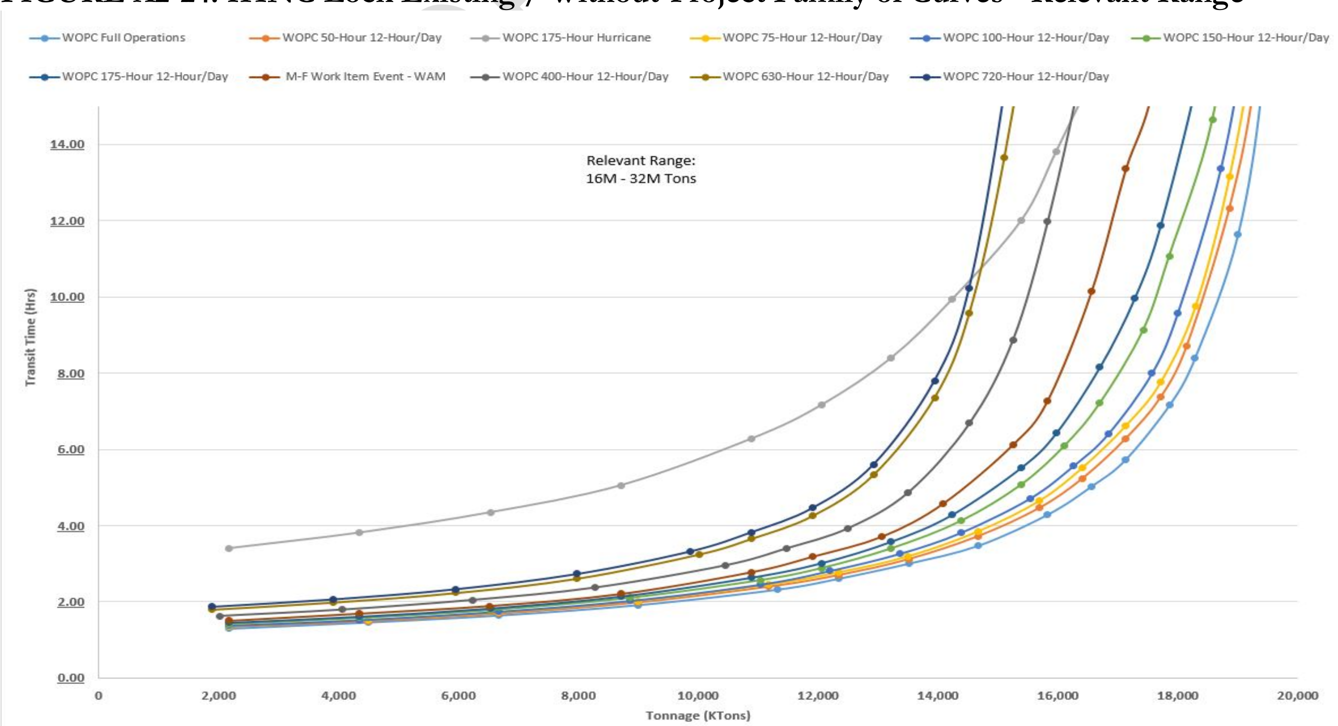
The tonnage-transit curve simulations for the 50-hour 12-hour/day service disruption event assumed 12-hour/day service disruption Monday-Friday over 4.2 weekdays (4.2 calendar days). This service disruption was defined for rehabilitation of the north-eat and south-east guidewall face timbers work item event.

3.4.2.3 The Family of IHNC Lock Tonnage-Transit Curves

Error! Reference source not found.Error! Reference source not found. shows the service disruption tonnage-transit curves mapped against the full-operations tonnage-transit curve. The capacity value at 200 hours of average transit time for each curve is displayed in **Table** Error! Reference source not found.. Care is taken to insure that curves do not cross, as this is usually indicative of an error, as a project with less availability should have less capacity. This is generally the case when curves represent similar events. In Error! Reference source not found.*Error! Reference source not found.* however**,** the curve representing the 175-Hour 24 Hour/Day Hurricane event can be seen crossing several other curves. This curve represents a complete closure, while the other curves represent partial closures which allow for traffic to transit during specific times throughout the duration of the event. Without this mechanism for alleviating queuing during the event, the base average transit time for the 175-Hour Hurricane event is relatively higher than events with a similar base duration, thus the curve begins higher on the y-axis.

FIGURE ***A2-24FIGURE A2-24*** displays the relevant range of tonnage for the existing without-project condition in order to display the characteristics of the curves in relation to historic tonnages. Note that the curve for the 1140-Hour Work Item Event is not displayed, as the curve is not used in the equilibrium analysis. This event has special characteristics which differ from the lock's tonnage-transit curve.

FIGURE A2-24: IHNC Lock Existing / Without-Project Family of Curves - Relevant Range



4. IHNC LOCK WITH-PROJECT CONDITION CAPACITY ANALYSIS

The four alternatives considered in the IHNC Lock GRR entail building a larger concrete U-frame lock north of Claiborne Avenue varying by chamber size:

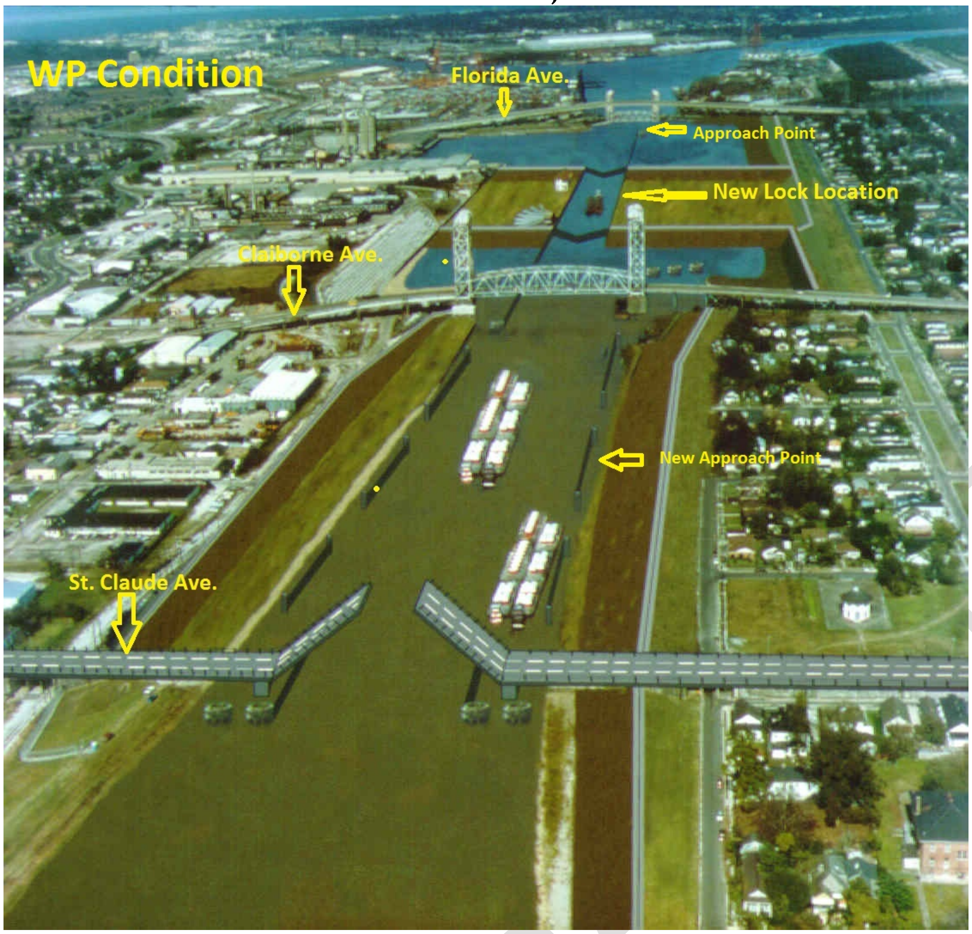
- Alternative #1 - 110' x 900' x 22'
- Alternative #2 - 110' x 1200' x 22'
- Alternative #3 - 75' x 900' x 22'
- Alternative #4 - 75' x 1200' x 22'

A detailed discussion of the with-project condition IHNC Lock capacity analysis follows.

4.1 Background

The new IHNC Lock (***FIGURE A2-25***) is to be located on between river miles 7 and 8 on the Gulf Intracoastal Waterway just north of the existing project between the Claiborne Avenue and Florida Avenue Bridges. The new project's south-side approach point will be located between the new St. Claude Ave. Bridge and the Claiborne Ave. Bridge and the approach area will end at the south-side sill of the new chamber. St. Claude is the only bridge that will be replaced in the WPC. The new bridge will be a low-rise bridge. St. Claude is being replaced for realignment purposes only. It's location along the Canal will not change. The new north-side approach point will be north of the Florida Ave. Bridge.

FIGURE A2-25: IHNC Lock – With-Project Condition Location



As with the existing / without-project condition scenario the processing of traffic through this reach of the canal and through IHNC Lock is expected to remain the same. For multi-cut tows, except during high water events on the Mississippi River, tows will break and make outside the canal area and employ "trip vessels" to shuttle their cuts through the canal and the new IHNC Lock. As under the without-project condition, for the most part, flotilla are expected to arrive at the new IHNC Lock as single cut powered flotilla. The new projects will have no tow-haulage equipment, and when tows break and make on the walls, a helper-boat will be required.

When vessels arrive in the LPMS arrival area they call into the lock to get assigned their arrival time and their queue position. The lockmaster will notify the vessel 2-hours prior to the expected lock transit so that the flotilla can acquire any needed trip vessels.

- Going north (up-bound) the 1st powered cut will queue on the wall, the 2nd powered cut will queue at the dolphins (mooring cells), and the 3rd and greater powered cuts will queue in the Mississippi River. The flotilla will then re-make north of the Florida Avenue Bridge.
- Going south (down-bound) the 1st powered cut will queue on the wall, the 2nd powered cut will queue along the bank of the canal, usually on the northern side, while the 3rd and greater cuts will queue further back in the canal and GIWW-East as necessary.

The lockmaster will re-order the queue and multi-vessel cut as needed to maximize throughput. Advantages of the larger lock chambers include the ability to process larger tows without the need to cut and allow multiple smaller tows to utilize the lock chamber in a single operation.

While the three bridges in the reach will still cause inefficiencies, there will no longer be a lift bridge (St. Claude Avenue Bridge) over the lower approach area.

4.2 With-Project Condition Input Data

The with-project condition data was built off the without-project condition data.

4.2.1 Processing Times

The WPC tonnage-transit curves were simulated in WAM based on adjustments made to the location parameter of the different WOPC component processing time distributions. It was assumed for this analysis that only chambering times will change from the WOPC to the WPC. The location parameter is shifted up by the amount by which the mean time increases for a specific processing component. This increase in the mean is in turn based on assumptions made about how changes to the size of IHNC lock will impact processing times. Therefore the shape and distribution type will not change for a specific component processing time distribution, but its location may shift if the average time for the distribution is expected to change from the WOPC to the WPC. The probability density curve will still have the same height, skewness, and kurtosis, with the only change being the curve is shifted to the right along the horizontal axis to indicate a uniform increase in the processing time for every observation within that distribution.

There was no indication that approach times would change from the WOPC to the WPC. The argument that the WOPC average upbound approach times will be the same as the downbound WPC times relies on the assumption that the WOPC south-side approach area has a length similar to that of the WPC north-side approach area, which is not the case. This argument also assumes that the bridge delay impact is the same from the St. Claude in the WOPC to that of the Florida Avenue Bridge in the WPC (since both bridges require raising for 100% of navigation). This is a questionable assumption since the Florida Avenue Bridge in the WPC is just beyond the north-side approach area, and therefore some vessels may be able to avoid waiting by requesting the bridge be raised before arriving to it. As previously mentioned, this coordination is also possible for many upbound long approaches at St. Claude in the WOPC, yet many approaches likely still having wait time for St. Claude since the start of their approach is close to the bridge and so on average they may not be able to call ahead as early as downbound vessels at Florida in the WPC (i.e., unlike with Florida, they cannot avoid the full bridge wait when approaching St. Claude). The start-of-lockage time begins once the chamber is ready to lock the cut. This is the start of the approach time, and since the beginning of the approach area is close to St. Claude many vessels have to wait briefly in the middle of their approach before the bridge is raised. Tows cannot request St. Claude's be raised before the lock chamber is ready for the tow.

It is easier to assume that the upbound WPC approach time will equal the WOPC approach time plus the increase in expected delay caused by Claiborne's lower clearance in the WPC relative to the WOPC. Nevertheless, this would result in WPC upbound approach times being less than 30 seconds longer than WOPC downbound approach times, which was considered a marginal difference to overall processing times. Therefore even if it was assumed that upbound WOPC approach times are equal to downbound WPC approach times and that upbound WPC approach times are less than 30 seconds longer than downbound WOPC times, the net impact will a 30 second increase to only vessels traveling downbound in the WPC, which was considered a small enough change that it can be disregarded. Disregarding this minor change is justifiable since this assumption does not account for the fact that even if the WOPC St. Claude's bridge impact to approach times is the same as the WPC Florida Avenue impact, the average WPC downbound approach time could in fact be different than the average WOPC upbound approach time because of other factors such as a change to the ratio of the south-side approach area's length to that of the north-side approach area from the WOPC to the WPC.

Entry times are also assumed to remain the same. Although a longer lock chamber entails a longer distance being traveled to enter the lock, it was assumed that the towboat can compensate for this by being able to enter the chamber at a slightly faster speed due to the longer available distance for breaking before the cut reaches the end of the chamber. Similarly to approach times, exit times were also assumed to stay the same.

Chambering times adjustments from the WOPC to the WPC were based on the results of hydraulic simulations, performed by hydraulic engineers from the Mississippi Valley Division, of WPC fill/spill times under the various new chamber sizes that are being considered. It was also assumed that gate operations (i.e., both opening and closing) for each gate will take 1.5 minutes on average, which was based on discussions with the IHNC lockmaster. The chambering time for a single-cut flotilla is equal to the fill or spill time of the chamber coupled with the gate operation time for each of the two gates. In the case of multi-cut lockages, the flotilla-based chambering time is the difference between the end-of-entry time for the first cut and the start-of-exit for its last cut (less any stoppage time). This encompasses: chambering time for the first cut, along with the exit time of the first cut; the chamber turnback time and processing time for each intermediate cut; and the chamber-turnback time, approach time, entry time, and chambering time for the last cut.

Distributions for single-cut and double-cut component processing times were fitted separately to develop distribution types for the single-cut and double cut component processing time distributions; whereas for flotillas of greater than two cuts the chambering time is calculated in WAM by combining times from the single-cut and double-cut distribution.

The MVN hydraulic engineers first simulated for each project alternative the average fill/spill time (*TABLE A2-17*) at five different ranges for lift height (i.e., how much the water must be raised or lowered to lock a vessel to a higher elevated pool or lower elevated pool). The relative frequency distribution or percentage frequency distribution of lift heights within each project alternative (i.e., the percentage share of total simulated fill/spill observations that occurred within each of the five lift ranges) were also simulated by the engineers (*TABLE A2-18*).

TABLE A2-17: Simulated Fill-Spill Times for Projects by Lift

Fill-spill Times								
Project Condition	Lock Size (ft)		Lift (ft)					Ratio of length to WOPC Chamber Length
	Length	Width	2'	4'	6'	8'	10'	
WOPC (640' x 75' x 31.5')	640	75	3.12	4.08	4.88	5.57	6.18	1.00
WPC 1 (900' x 75' x 22')	900	75	3.33	4.03	4.60	5.10	5.55	1.41
WPC 2 (900' x 110' x 22')	900	110	4.08	5.13	6.02	6.80	7.48	1.41
WPC 3 (1200' x 75' x 22')	1200	75	4.10	4.90	5.50	5.98	6.42	1.88
WPC 4 (1200' x 110' x 22')	1200	110	4.97	6.03	6.88	7.62	8.30	1.88

TABLE A2-18: Simulated Lift Frequency Distribution

Probabilty Distribution for *IHNC Lifts* (distribution assumed to be same at new location as at current location)		
Lift (ft)	**Percentage of Occurrence**	**Probability of Occurrence (i.e. weight)**
0' - 2'	31%	0.31
2' - 4'	20%	0.20
4' - 6'	15%	0.15
6' - 8'	16%	0.16
8' - 10'	18%	0.18
Cumulative Probability	100%	1.00

A weighted-average fill/spill time per project alternative is then calculated by weighting the average fill/spill time at each lift range by the relative frequency or percentage frequency of total fill/spill observations accounted for by that simulated lift range, and then summing together the weighted fill-spill times across lift ranges within each alternative. Once this is calculated, the weighted-average fill/spill time for each WPC is divided by the WOPC weighted-average fill/spill time to derive a ratio for the WPC-to-WOPC fill/spill time, as seen in ***TABLE A2-19***.

TABLE A2-19: Weighted Fill-Spill Times for Projects by Lift

IHNC Lock - Fill or Spill Time (minutes) by Lifts and Lock Size								
Lock Size (feet)	**Project Condition**	**Lifts (feet)**					**Weighted-Avg. Fill/Spill Time (minutes)**	**WPC-to-WOPC Fill/Spill Time Ratio**
		2'	**4'**	**6'**	**8'**	**10'**		
675'x75'x31.5' (existing lock)	WOPC (640' x 75' x 31.5')	0.98	0.83	0.71	0.88	1.11	4.51	
970'x75'x22'	WPC 1 (900' x 75' x 22')	1.05	0.82	0.67	0.80	1.00	4.33	**0.96**
970'x110'x22'	WPC 2 (900' x 110' x 22')	1.28	1.04	0.88	1.07	1.34	5.61	**1.25**
1287.67'x75'x22'	WPC 3 (1200' x 75' x 22')	1.29	0.99	0.80	0.94	1.15	5.18	**1.15**
1287.67'x110'x22'	WPC 4 (1200' x 110' x 22')	1.56	1.22	1.00	1.20	1.49	6.48	**1.44**

These fill-spill ratios then allow for calculation of the WPC chambering times according to the logic shown in ***FIGURE A2-26***.

FIGURE A2-26: Calculation of Upbound With-Project Condition 1 (900' x 75' x 22') Chambering Time

WPC 1 Chambering Time = ([WOPC Chambering Time – (2 * Gate Operation Time per Gate)] * (Ratio of WPC 1 Fill/Spill to WOPC Fill/Spill) + (2 * Gate Operation Time per Gate)

The difference between the estimated average chambering time for each alternative and the WOPC average chambering time is the amount by which the location parameter for the fitted distribution of the WOPC upbound chambering times must be shifted to the right (assuming the WPC chambering time exceeds that of the WOPC) to calculate the location parameter for the WPC fitted distribution that needs to be simulated. Shifting the location parameter for the WPC is the only parameter that changes from the WOPC to the WPC for each component processing time distribution. This is because the WPC probability density curve for each component processing time distribution has the same shape as that of its WOPC counterpart, and has simply been shifted to the right to reflect a uniform increase in all of the distributions times from the WOPC to the WPC.

Therefore the parameters that are input in to WAM for each approach time, entry time, or exit time distribution will not change from the WOPC to the WPC. The only changes will be increases to the location parameters for chambering time distributions from the WOPC to the WPC.

4.2.2 Non-Curfew Random Minor Downtimes

The non-curfew random minor downtimes were assumed the same as under the without-project condition for all with-project condition alternatives (***TABLE A2-9***).

4.2.3 Fleet

The fleet was not expected to change under any of the with-project condition alternatives. The without-project condition vessel (section 3.2.3.1), towboat (section 3.2.3.2), and barge types (section 3.2.3.3) were assumed.

4.3 WAM With-Project Condition Calibration and Validation

Given that the fleet is not assumed to change under the with-project condition, no additional WAM calibration and validation was required.

4.4 With-Project Condition Capacity Analysis

4.4.1 Identification of Optimal Lockage Policy

After input preparation, shipment list calibration, and processing and delay time validation, the next step is to determine the most efficient lockage policy. This is done to satisfy Corps regulation ER-1105-2-100 section II, E-9.c.a which states in part "*Assume that all reasonably expected non-structural practices …. Including … lockage policies are implemented at the appropriate time.*" Two lockage policies are typically evaluated:

First-In First-Out (FIFO); and

6-up / 6-down service policy.

Often to determine the best or "*optimal*" lockage policy, simulation runs are made at high project utilization levels for each lockage policy. The 'optimal' lockage policy is the policy that results in the highest tonnage level with the lowest transit time at maximum lock utilization. With a 6-up / 6-down service policy in WAM, FIFO is practiced until the n-up / n-down policy becomes optimal. The n-up / n-down policy is typically optimal at high utilization levels as it minimizes chamber turn-back operations.

For the analysis of the IHNC Lock with-project condition alternatives, a 6-up / 6-down lockage policy was assumed.

4.4.2 Service Disruption Tonnage-Transit Curves

For the economic analysis of each with-project condition nine service disruption curves were also needed and developed. The service disruption events are summarized below.

4.4.2.1 1,440-Hour 24-Hour/Day Work Item Event

The tonnage-transit curve simulations for the 1,440-hour 24-hour/day service disruption event assumes a consecutive 60-day closure of the lock. This service disruption event was defined for dewatering & monitoring, major repair, and gate work item event. As with the existing condition event, this curve is included for reference and is not used in this study.

4.4.2.2 825-Hour 12-Hour/Day Event

The tonnage-transit curve simulations for the 825-hour 12-hour/day service disruption event assumed 12-hour/day service disruption Monday-Friday over 69 weekdays (95 calendar days). This service disruption event was defined for both the Rehabilitation of Chamber Guidewall (W & E) and Rehabilitation of Guidewall & Dolphin (NW & SW) work item events.

4.4.2.3 720-Hour 12-Hour/Day Event

The tonnage-transit curve simulations for the 720-hour 12-hour/day service disruption event assumed 12-hour/day service disruption Monday-Friday over 60 weekdays (82 calendar days). This service disruption event was defined for the Rehabilitation of Guidewall & Dolphin (NE & SE) work item event.

4.4.2.4 175-Hour 24-Hour/Day Event

The tonnage-transit curve simulations for the 175-hour 24-hour/day service disruption event assumed 24-hour/day service disruption for 7.29 days straight. This service disruption was defined for unscheduled hurricane events.

4.4.2.5 175-Hour 12-Hour/Day Event

The tonnage-transit curve simulations for the 175-hour 12-hour/day service disruption event assumed 12-hour/day service disruption Monday-Friday over 14.6 weekdays (18.6 calendar days). This service disruption was defined for the _Rewiring and Machinery Rehabilitation work item event.

4.4.2.6 150-Hour 12-Hour/Day Event

The tonnage-transit curve simulations for the 150-hour 12-hour/day service disruption event assumed 12-hour/day service disruption Monday-Friday over 12.5 weekdays (16.5 calendar days). This service disruption was defined for the Maintenance by Hired Labor Units work item event.

4.4.2.7 100-Hour 12-Hour/Day Event

The tonnage-transit curve simulations for the 100-hour 12-hour/day service disruption event assumed 12-hour/day service disruption Monday-Friday over 8.3 weekdays (10.3 calendar days). This service disruption was defined for the Rehabilitation of Chamber Guidewall Armoring (W & E) work item event.

4.4.2.8 75-Hour 12-Hour/Day Event

The tonnage-transit curve simulations for the 75-hour 12-hour/day service disruption event assumed 12-hour/day service disruption Monday-Friday over 6.3 weekdays (8.3 calendar days). This service disruption was defined for the Rehabilitation of Guidewall Face Timber (NW & SW) work item event.

4.4.2.9 50-Hour 12-Hour/Day Event

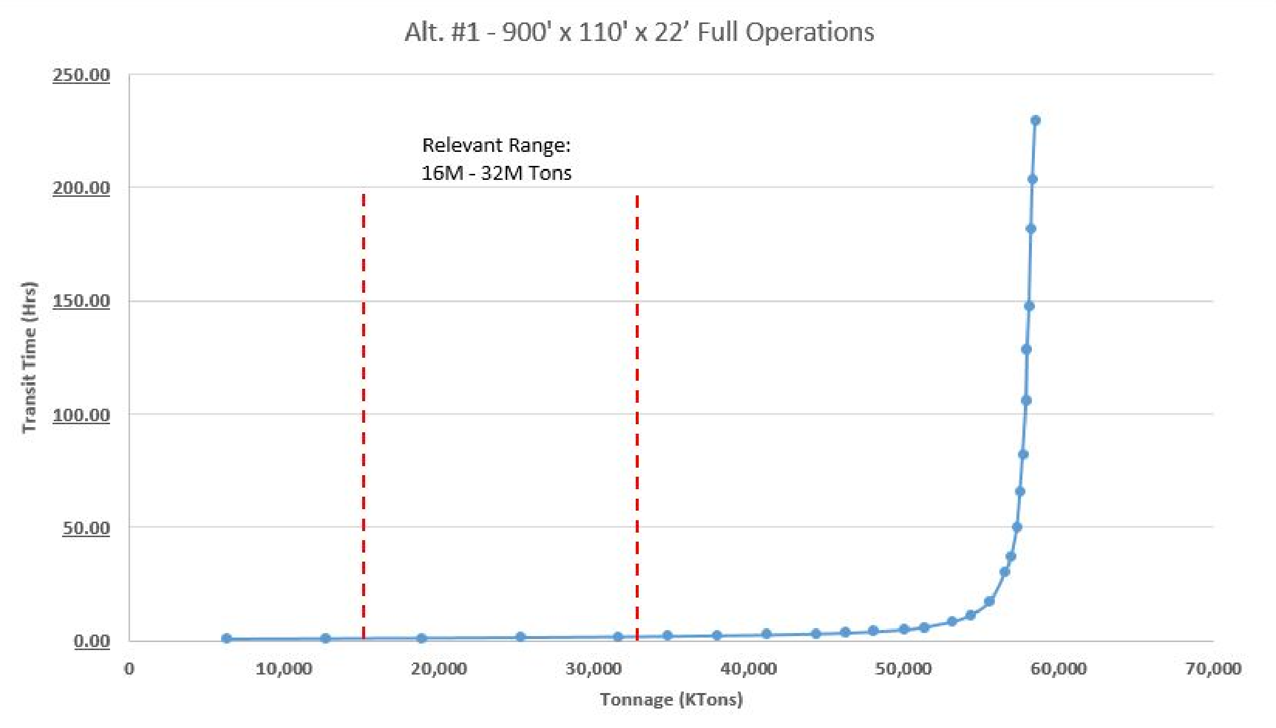
The tonnage-transit curve simulations for the 50-hour 12-hour/day service disruption event assumed 12-hour/day service disruption Monday-Friday over 4.2 weekdays (4.2 calendar days). This service disruption was defined for the Rehabilitation of Guidewall Face Timber (NE & SE) work item event.

4.4.3 Alternative #1 - 110' x 900' x 22' Capacity Results

4.4.3.1 Full-Operations Tonnage-Transit Curve

Full-operation tonnage-transit curves were developed for IHNC Lock Alternative #1. The capacity for the new single main chamber operating for the entire year with only random minor downtimes is shown in

FIGURE A2-27: IHNC Lock Alternative #1 Tonnage-Transit Curve – Full Operations



4.4.3.2 Service Disruption Tonnage-Transit Curves

TABLE A2-20 shows the tonnage-transit curve information for Alternative #1. The full-operations capacity is displayed along with each of the nine service disruption curves as well as the average processing and transit times. The family of curves for Alternative #1 is displayed in ***FIGURE A2-28*** and the relevant range is displayed in ***FIGURE A2-29***. Note that the 1440-Hour event is not displayed in ***FIGURE A2-29*** and was not used in the equilibrium modeling as it is not reflective of the diversion routing that is planned to accommodate this closure.

TABLE A2-20: IHNC Lock Alternative #1 – 110' x 900' x 22' Capacity and Transit Times

Simulated Event Name	Tonnage at Capacity	Average Transit Time (Hours)	Average Processing Time (Hours)
Full Operation	58,247,737	200.00	0.81

50-Hour 12-Hour/Day Work Item Event	57,975,189	200.00	0.81
75-Hour 12 Hour/Day Work Item Event	57,816,426	200.00	0.81
100-Hour 12 Hour/Day Work Item Event	57,642,953	200.00	0.81
150-Hour 12 Hour/Day Work Item Event	57,287,685	200.00	0.81
175-Hour 12 Hour/Day Work Item Event	58,113,847	200.00	0.81
175-Hour 24-Hour/Day Hurricane Event	56,693,750	200.00	0.81
720-Hour 12 Hour/Day Work Item Event	52,234,365	200.00	0.81
825-Hour 12 Hour/Day Work Item Event	51,359,127	200.00	0.81
1440-Hour 24-Hour/Day Work Item Event	39,355,443	200.00	0.81

FIGURE A2-28: Inner Harbor Lock Alternative #1 Tonnage-Transit Curve Family

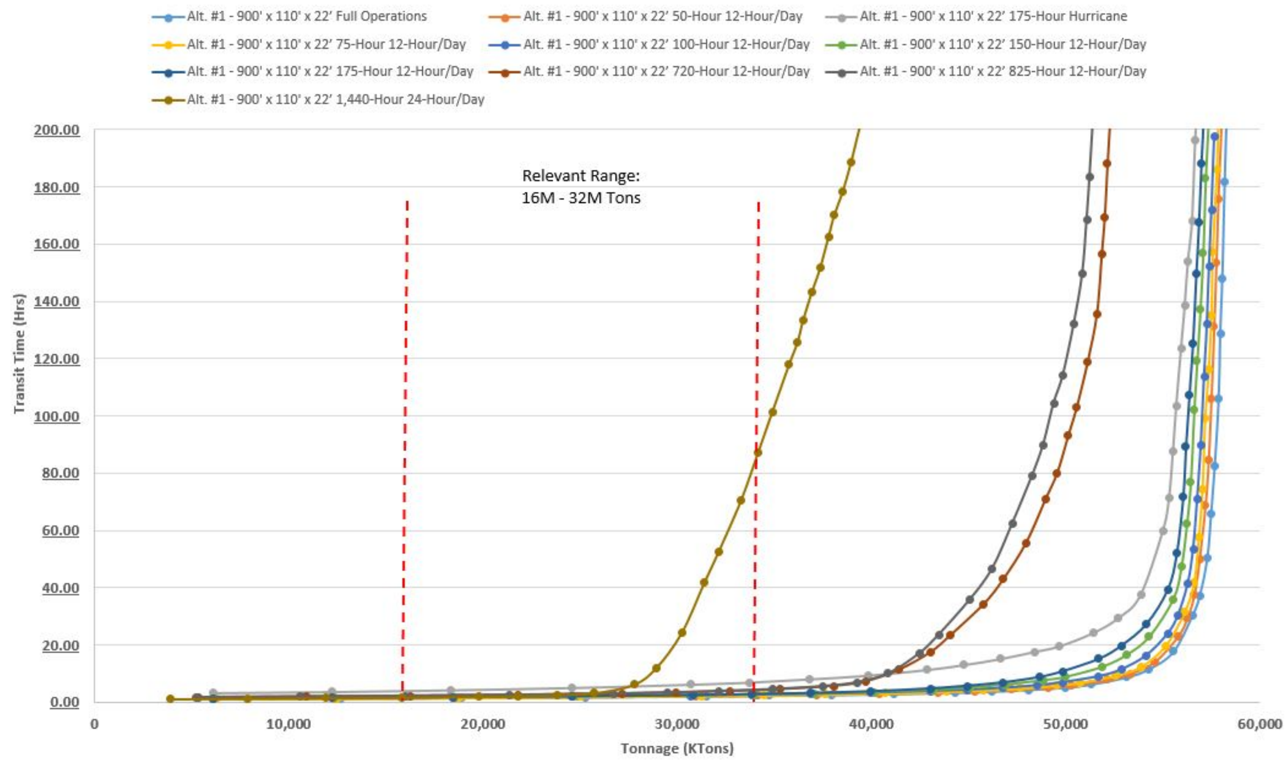
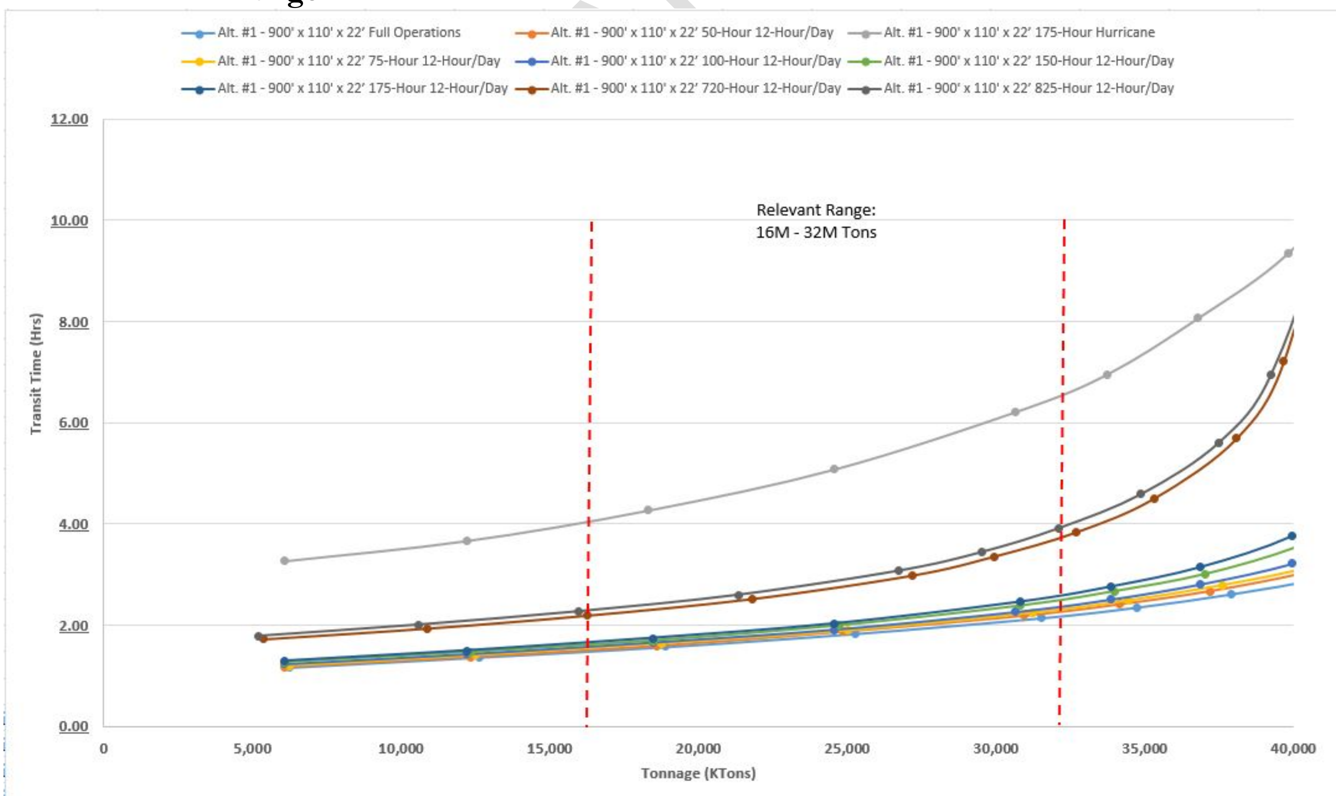


FIGURE A2-29: Inner Harbor Lock Alternative #1 Tonnage-Transit Curve Family - Relevant Range



4.4.4 Alternative #2 - 110' x 1200' x 22’ Capacity Results

4.4.4.1 Full-Operations Tonnage-Transit Curve

Full-operation tonnage-transit curves were developed for IHNC Lock Alternative #2. The capacity for the new single main chamber operating for the entire year with only random minor downtimes is shown in ***FIGURE A2-30***

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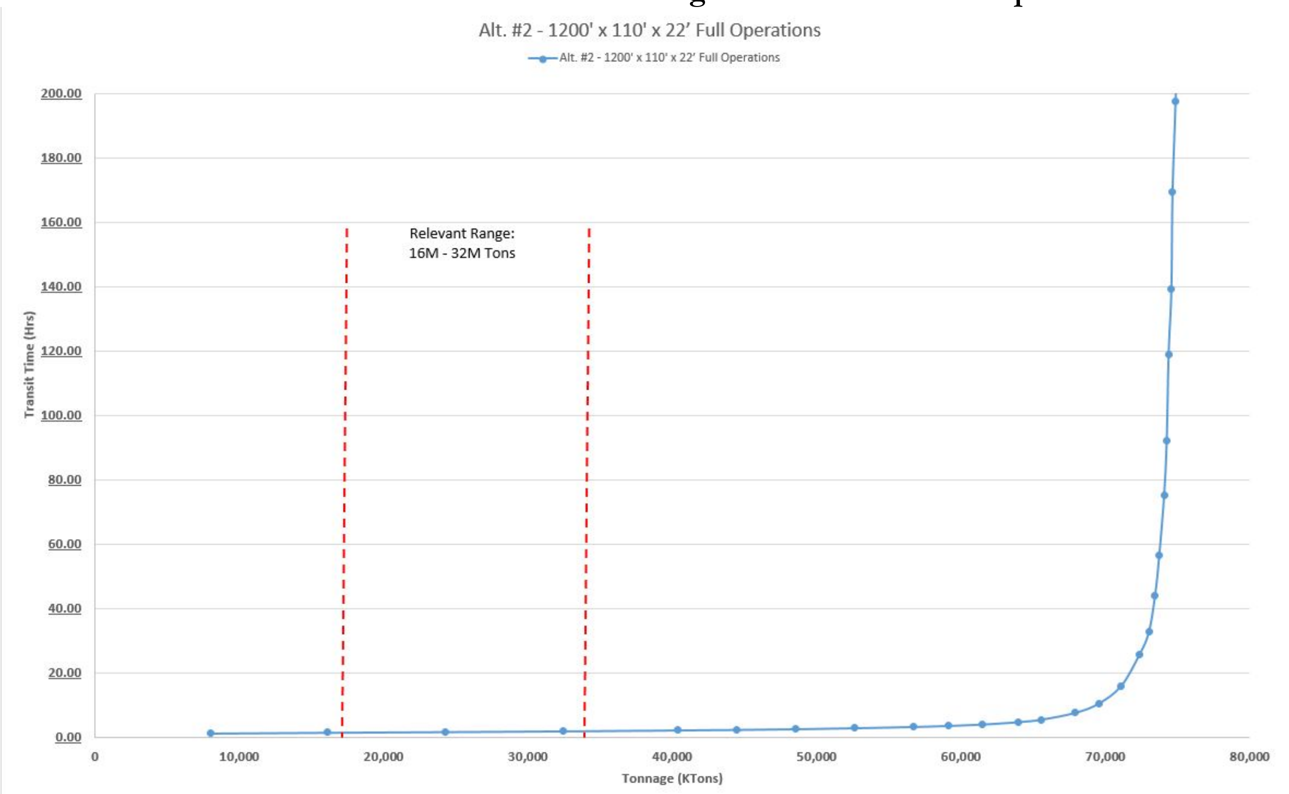
FIGURE A2-30: IHNC Lock Alternative #2 Tonnage-Transit Curve Full Operation



4.4.4.1 Service Disruption Tonnage-Transit Curves

TABLE A2-21 shows the tonnage-transit curve information for Alternative #2. The full-operations capacity is displayed along with each of the nine service disruption curves as well as the average processing and transit times. The family of curves for Alternative #2 is displayed in

FIGURE A2-31 and the relevant range is displayed in ***FIGURE A2-32.*** Note that the 1440-Hour event is not displayed in ***FIGURE A2-32*** and was not used in the equilibrium modeling as it is not reflective of the diversion routing that is planned to accommodate this closure.

TABLE A2-21: IHNC Lock Alternative #2 – 110’ x 1200’ x 22’ Capacity and Transit Times

Simulated Event Name	Tonnage at Capacity	Average Transit Time (Hours)	Average Processing Time (Hours)
Full Operation	74,847,657	200.00	0.89
50-Hour 12-Hour/Day Work Item Event	74,469,028	200.00	0.89
75-Hour 12 Hour/Day Work Item Event	74,237,277	200.00	0.89

100-Hour 12 Hour/Day Work Item Event	74,065,834	200.00	0.89
150-Hour 12 Hour/Day Work Item Event	73,602,783	200.00	0.89
175-Hour 12 Hour/Day Work Item Event	73,272,143	200.00	0.89
175-Hour 24-Hour/Day Hurricane Event	72,834,957	200.00	0.89
720-Hour 12 Hour/Day Work Item Event	67,043,273	200.00	0.89
825-Hour 12 Hour/Day Work Item Event	65,957,352	200.00	0.89
1440-Hour 24-Hour/Day Work Item Event	50,518,275	200.00	0.89

FIGURE A2-31: IHNC Lock Alternative #2 Tonnage-Transit Curve Family

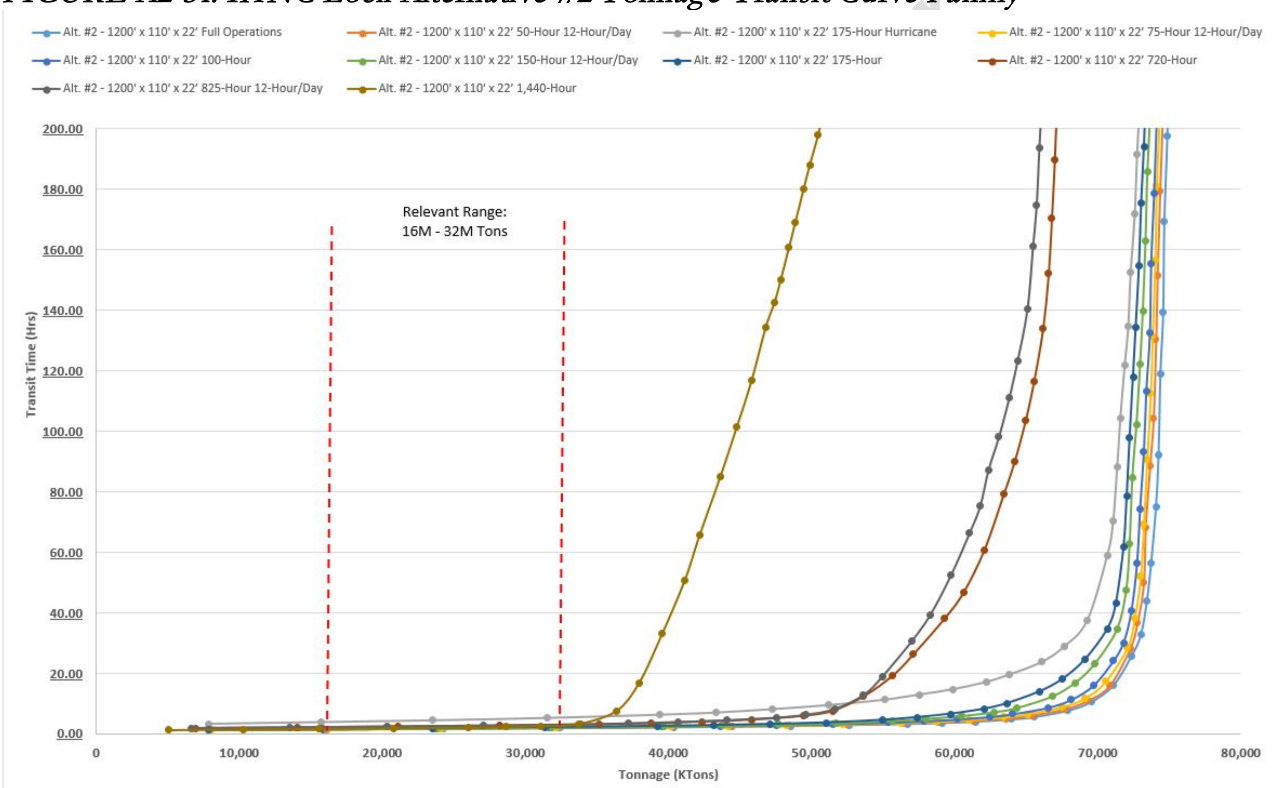
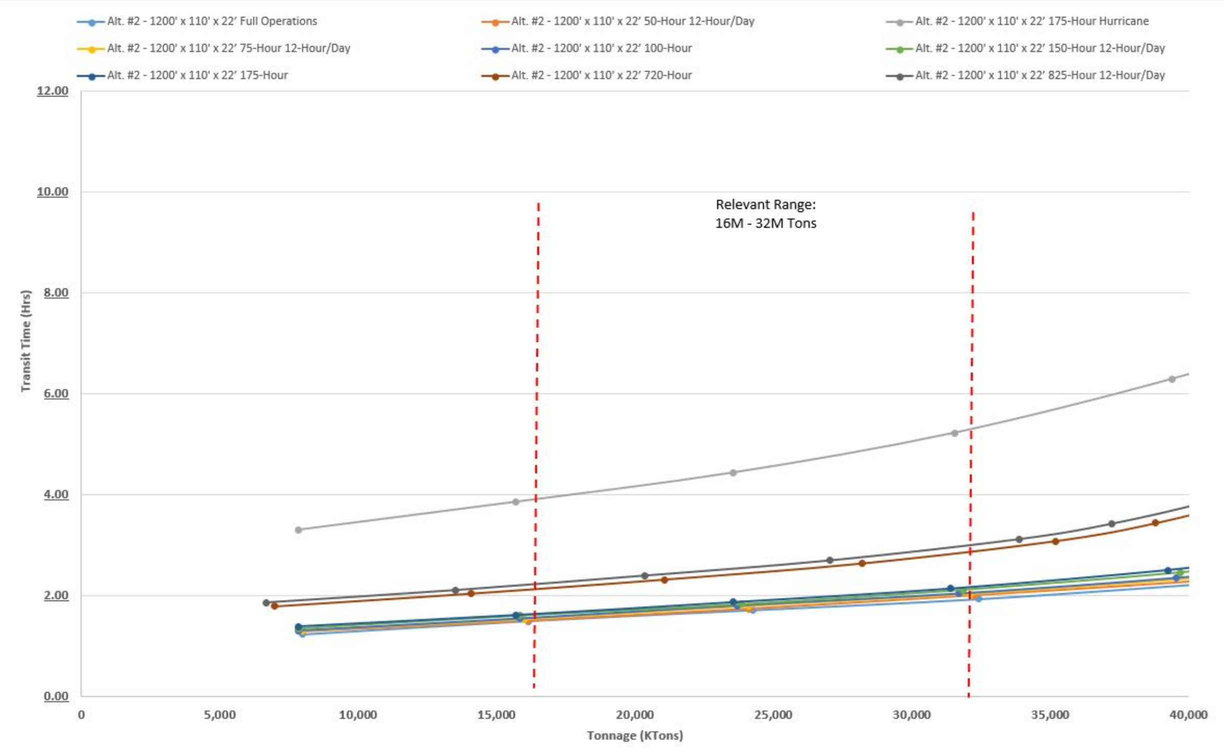


FIGURE A2-32: Inner Harbor Lock Alternative #2 Tonnage-Transit Curve Family - Relevant Range



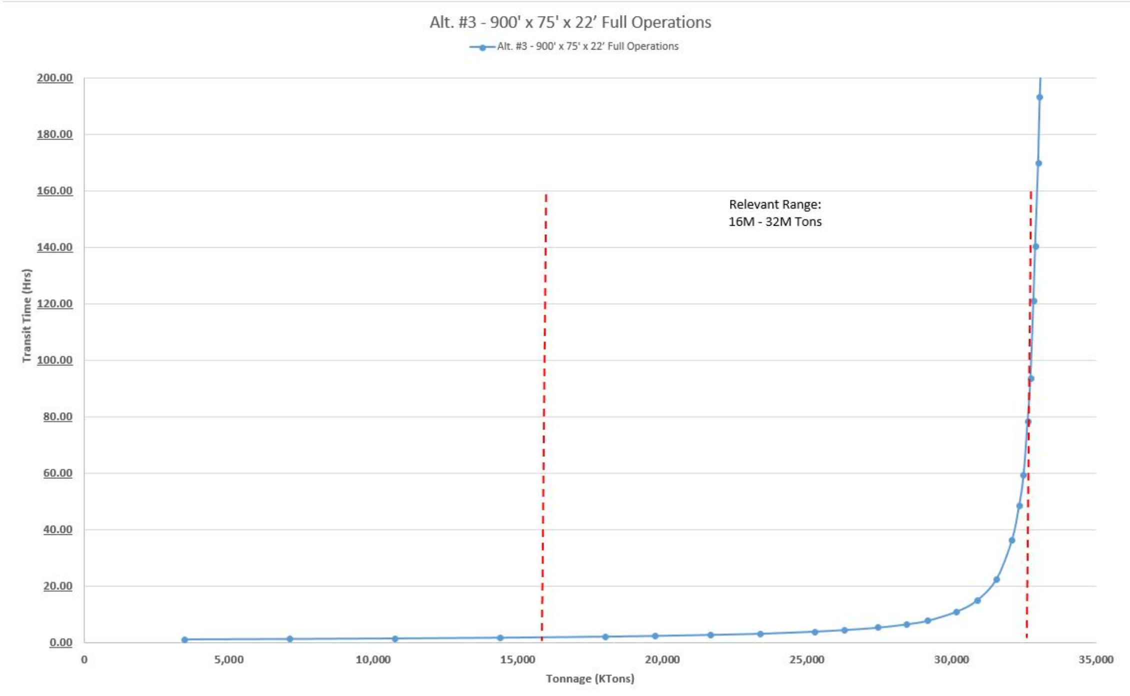
4.4.5 Alternative #3 - 75' x 900' x 22' Capacity Results

4.4.5.1 Full-Operations Tonnage-Transit Curve

Full-operation tonnage-transit curves were developed for IHNC Lock Alternative #3. The capacity for the new single main chamber operating for the entire year with only random minor downtimes is shown in

FIGURE A2-33.

FIGURE A2-33: IHNC Lock Alternative #3 Tonnage-Transit Curve Full Operations



4.4.5.2 Service Disruption Tonnage-Transit Curves

TABLE A2-22 shows the tonnage-transit curve information for Alternative #3. The full-operations capacity is displayed along with each of the nine service disruption curves as well as the average processing and transit times. The family of curves for Alternative #3 is displayed in ***FIGURE A2-34*** and the relevant range is displayed in ***FIGURE A2-35.*** Note that the 1440-Hour event is not displayed in ***FIGURE A2-35*** and was not used in the equilibrium modeling as it is not reflective of the diversion routing that is planned to accommodate this closure.

TABLE A2-22: IHNC Lock Alternative #3 – 75’ x 900’ x 22’ Capacity and Transit Times

Simulated Event Name	Tonnage at Capacity	Average Transit Time (Hours)	Average Processing Time (Hours)
Full Operation	33,075,529	200.00	0.78
50-Hour 12-Hour/Day Work Item Event	32,891,264	200.00	0.78
75-Hour 12 Hour/Day Work Item Event	32,781,866	200.00	0.78
100-Hour 12 Hour/Day Work Item Event	32,696,174	200.00	0.78
150-Hour 12 Hour/Day Work Item Event	32,514,519	200.00	0.78
175-Hour 12 Hour/Day Work Item Event	32,346,206	200.00	0.78
175-Hour 24-Hour/Day Hurricane Event	32,183,651	200.00	0.78
720-Hour 12 Hour/Day Work Item Event	29,673,771	200.00	0.78
825-Hour 12 Hour/Day Work Item Event	29,154,183	200.00	0.78

1440-Hour 24-Hour/Day Work Item Event	22,366,054	200.00	0.78

FIGURE A2-34:
IHNC Lock Alternative #3 Tonnage-Transit Curve Family

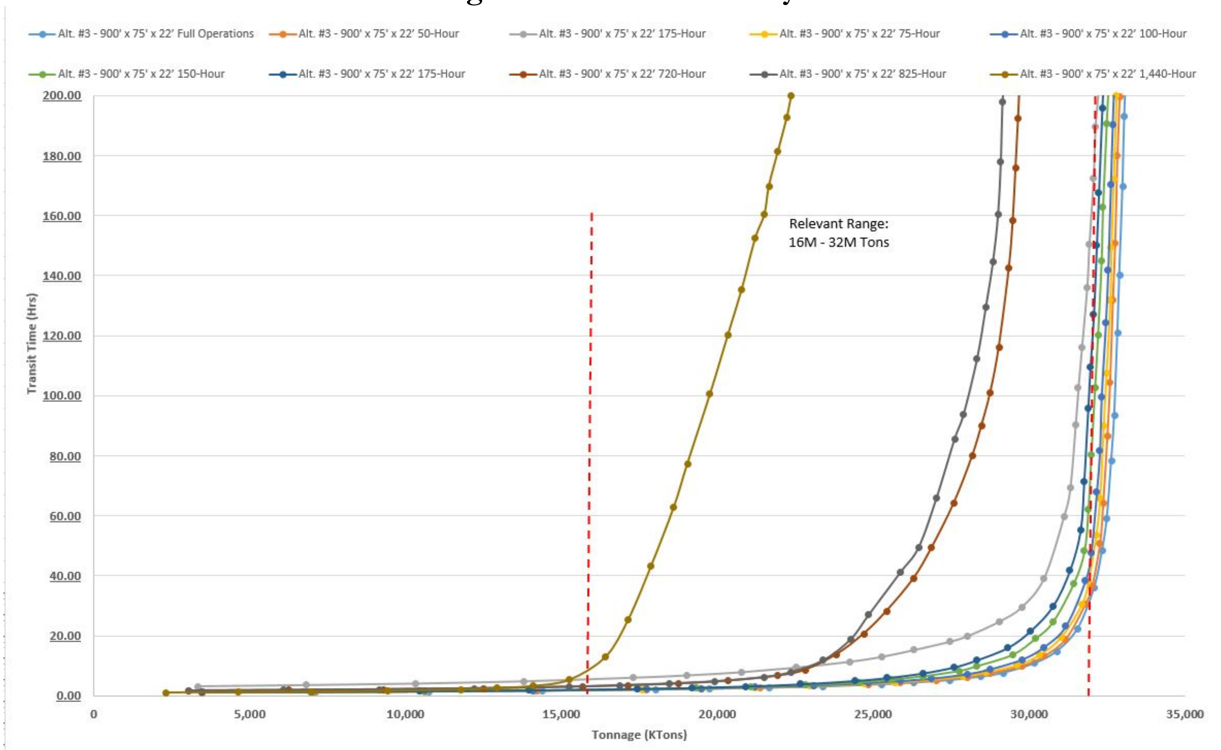
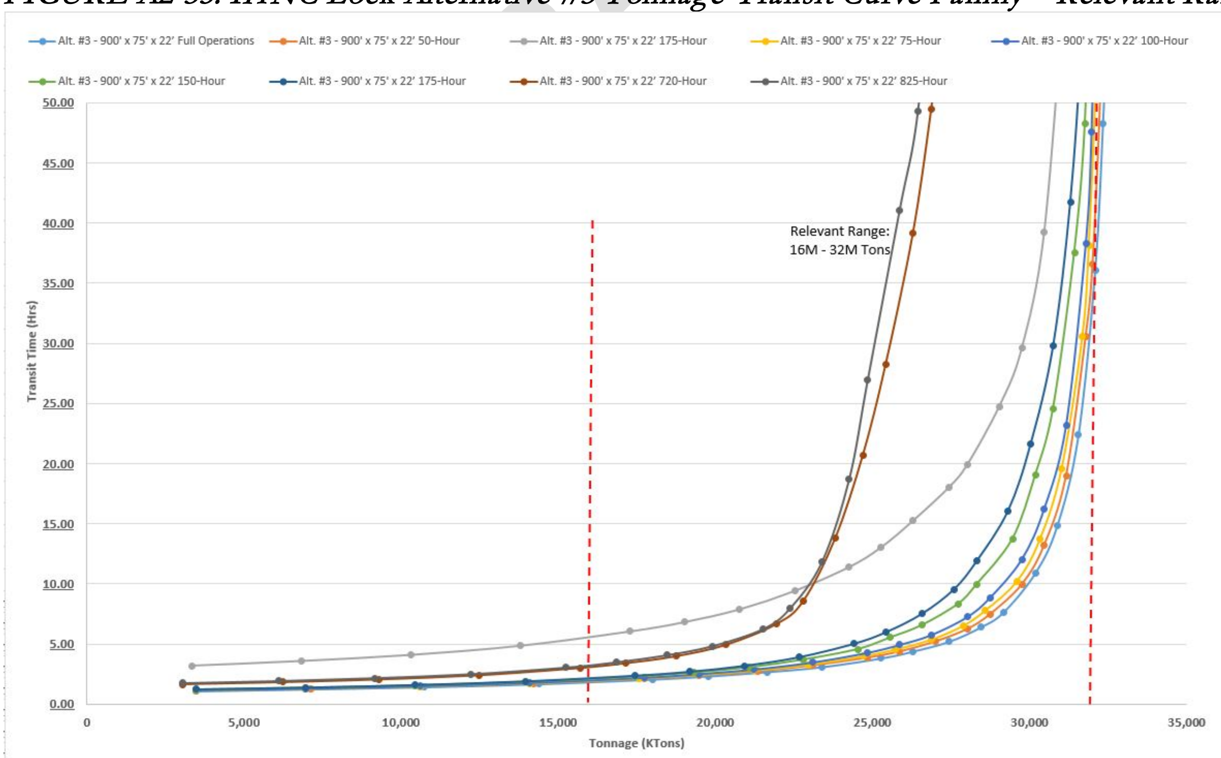


FIGURE A2-35: IHNC Lock Alternative #3 Tonnage-Transit Curve Family – Relevant Range

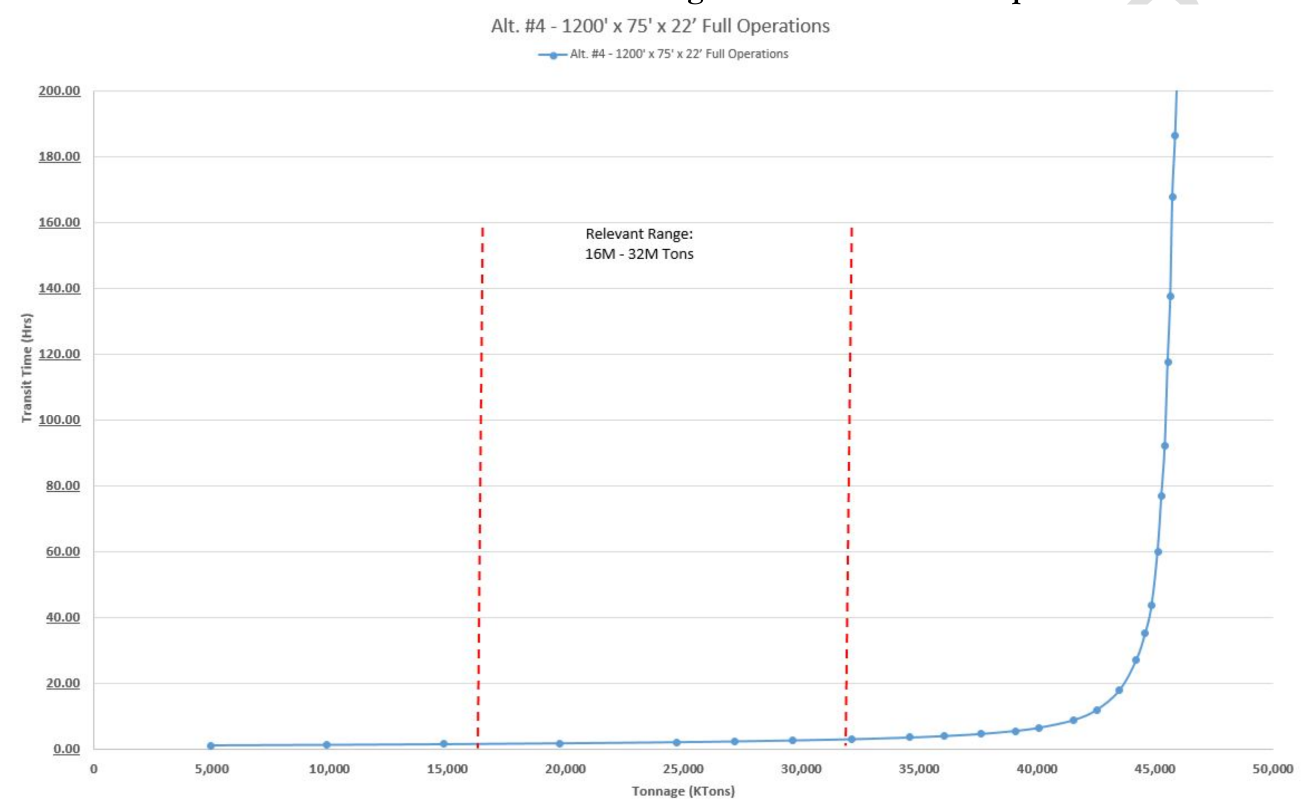


4.4.6 Alternative #4 - 75' x 1200' x 22’ Capacity Results

4.4.6.1 Full-Operations Tonnage-Transit Curve

Full-operation tonnage-transit curves were developed for IHNC Lock Alternative #1. The capacity for the new single main chamber operating for the entire year with only random minor downtimes is shown in ***FIGURE A2-36.***

FIGURE A2-36: IHNC Lock Alternative #4 Tonnage-Transit Curve Full Operations



4.4.6.2 Service Disruption Tonnage-Transit Curves

TABLE A2-23 shows the tonnage-transit curve information for Alternative #4. The full-operations capacity is displayed along with each of the nine service disruption curves as well as the average processing and transit times. The family of curves for Alternative #4 is displayed in ***FIGURE A2-37*** and the relevant range is displayed in

FIGURE A2-38. Note that the 1440-Hour event is not displayed in

FIGURE A2-38 and was not used in the equilibrium modeling as it is not reflective of the diversion routing that is planned to accommodate this closure.

TABLE A2-23: IHNC Lock Alternative #4 – 75' x 1200' x 22' Capacity and Transit Times

Simulated Event Name	Tonnage at Capacity	Average Transit Time (Hours)	Average Processing Time (Hours)
Full Operation	45,904,760	200.00	0.78
50-Hour 12-Hour/Day Work Item Event	45,645,972	200.00	0.78
75-Hour 12 Hour/Day Work Item Event	45,515,400	200.00	0.78
100-Hour 12 Hour/Day Work Item Event	45,372,539	200.00	0.78
150-Hour 12 Hour/Day Work Item Event	45,118,923	200.00	0.78
175-Hour 12 Hour/Day Work Item Event	44,905,456	200.00	0.78
175-Hour 24-Hour/Day Hurricane Event	44,658,710	200.00	0.78
720-Hour 12 Hour/Day Work Item Event	41,176,910	200.00	0.78
825-Hour 12 Hour/Day Work Item Event	40,473,116	200.00	0.78
1440-Hour 24-Hour/Day Work Item Event	31,074,508	200.00	0.78

FIGURE A2-37: IHNC Lock Alternative #4 Tonnage-Transit Curve Family

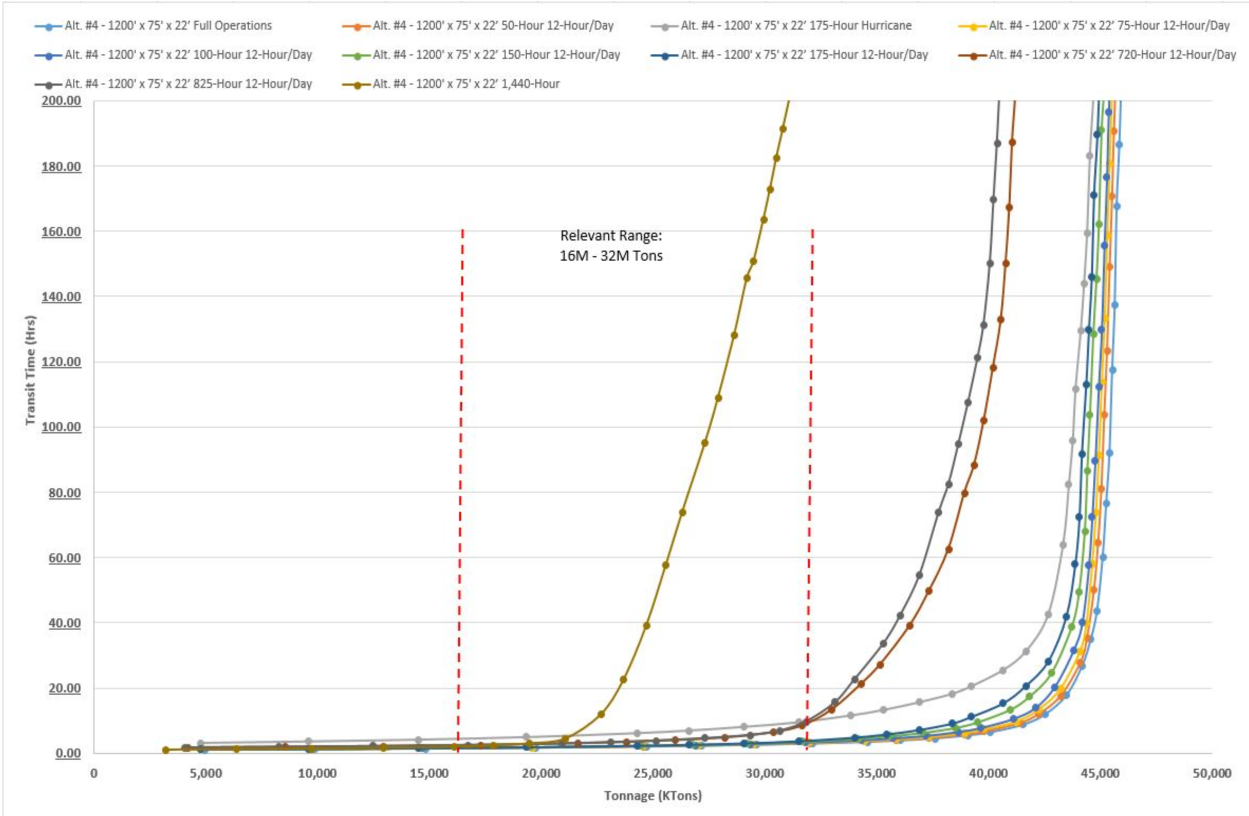
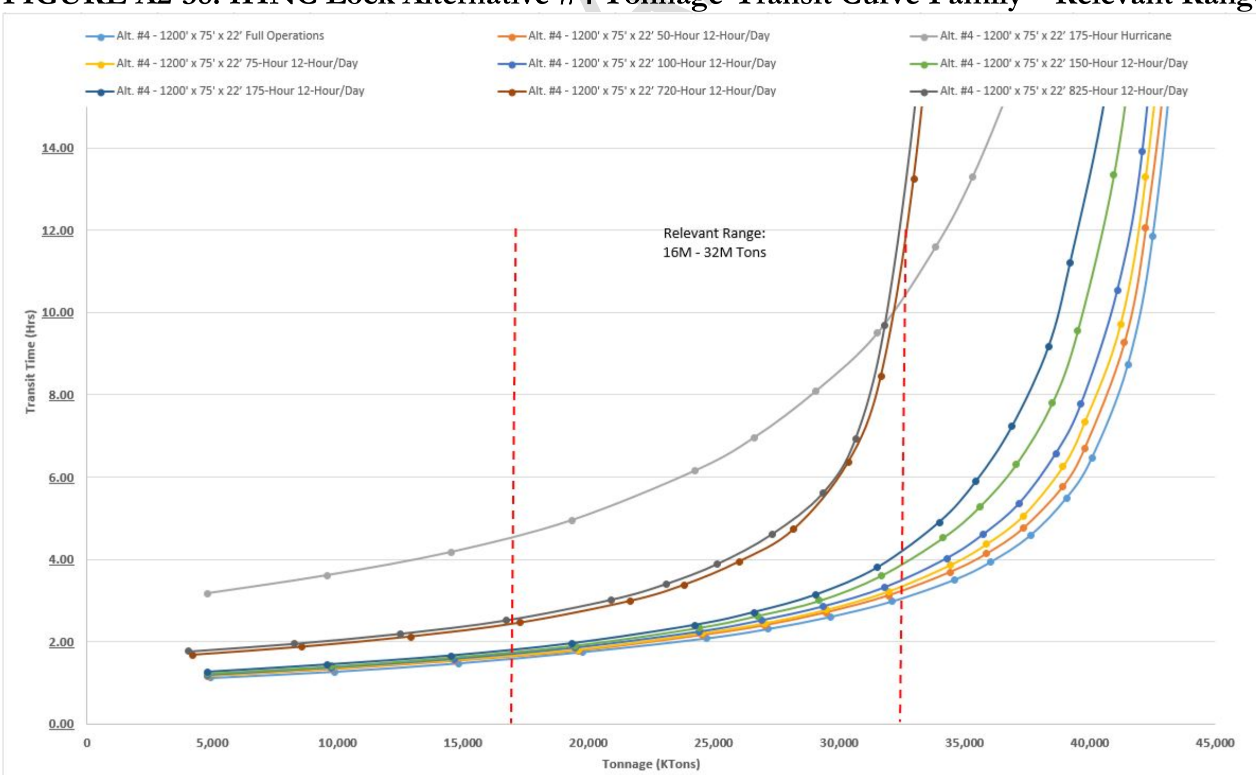


FIGURE A2-38: IHNC Lock Alternative #4 Tonnage-Transit Curve Family – Relevant Range



5. SUMMARY OF OTHER PROJECT CAPACITIES

As discussed, the IHNC Lock system analysis included nine lock projects in the region, however, this capacity analysis was focused on the IHNC Lock and it's proposed with-project conditions. The capacities and tonnage-transit time relationships for the other eight projects were obtained from the capacity analysis work performed in the 2014 Calcasieu Final Integrated Feasibility Study and EIS Report and are summarized below.

The Corps of Engineers, Lock Performance Monitoring System (LPMS) served as the data source for defining detailed processing time distributions. Although 2007 was chosen as the base year in the Calcasieu Lock analysis, data from 2000 through 2009 were reviewed and mostly all of the lock component time distributions were created using years 2000-2009.

After input preparation, shipment list calibration, and processing and delay time validation, the next step is to determine the most efficient lockage policy. This is done to satisfy Corps regulation ER-1105-2-100 section II, E-9.c.a which states in part "Assume that all reasonably expected non-structural practices including lockage policies are implemented at the appropriate time." Two lockage policies were evaluated at these eight lock projects: a First-In, First-Out (FIFO) and a 6-up / 6-down service policy.

To determine the best or "optimal" lockage policy, 10 WAM runs were made at a high utilization level at each project for each lockage policy. The 'optimal' lockage policy is the policy that results in the highest tonnage level with the lowest processing time at maximum lock utilization. Typically n-up / n-down policies are the best, however, some were FIFO. A summary of the capacities, average processing time, and optimal lockage policy are show in ***TABLE A2-24***.

TABLE A2-24: Summary of Lock Project Capacities

Waterway / Lock Project	**Capacity (Millions of Tons)**	**Avg. Processing Time (min/tow)**	**Lockage Policy**
GIWW West			
Algiers Lock	35.2	45.21	FIFO
Bayou Boeuf Lock	58.5	21.74	6-up / 6-down
Calcasieu Lock	78.9	59.4	FIFO
Harvey Lock	13.6	38.65	FIFO
Leland Bowman Lock	86.3	18.83	6-up / 6-down
GIWW Alternate Route			
Bayou Sorrel Lock	32.5	59.98	6-up / 6-down
Port Allen Lock	38.3	76.70	FIFO
Atchafalaya – Mississippi River Link			
Old River Lock	46.8	43.26	FIFO

Source*:* 2014 Calcasieu Lock Feasibility Capacity Attachment.

5.1 GIWW West Projects

The GIWW West lock projects included: Algiers, Bayou Boeuf, Calcasieu, Harvey, and Leland Bowman Locks. All five of these projects were analyzed in the 2014 Calcasieu Lock Study using the WAM.

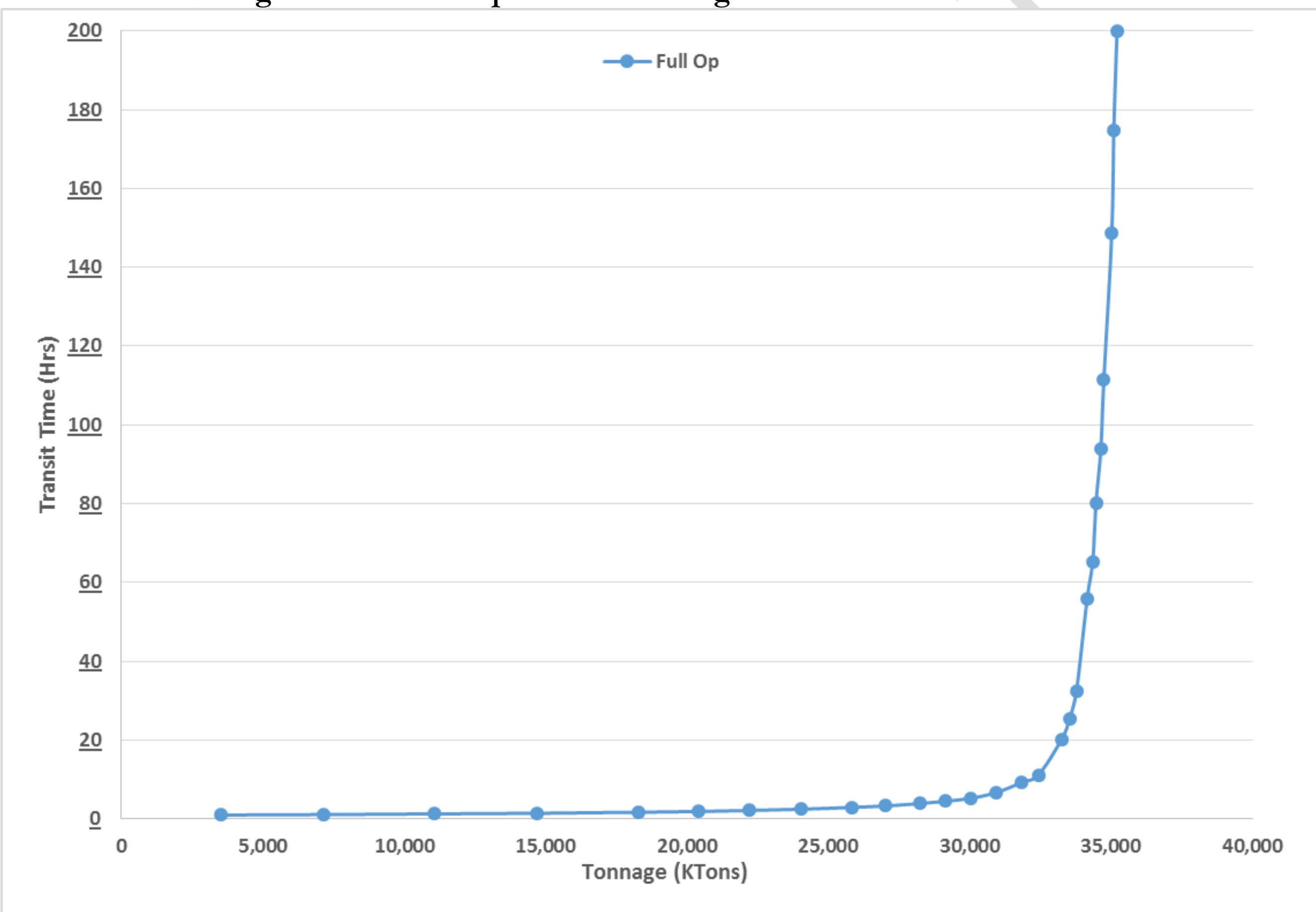
5.1.1 Algiers Lock

Algiers Lock is located on river mile 0 on the Gulf Intracoastal Waterway and consists of 760’ x 75’ single main chamber with a lift of 18 feet at normal pool.

5.1.1.1 Full-Operations Project Capacity

FIGURE A2-39 shows the tonnage-transit curve, and the relevant traffic range, for Algiers Lock under a full-operation scenario with only random downtimes. Algiers Lock was estimated to have a capacity of 35.2 million tons annually.

FIGURE A2-39: Algiers Lock Full Operations Tonnage-Transit Curve



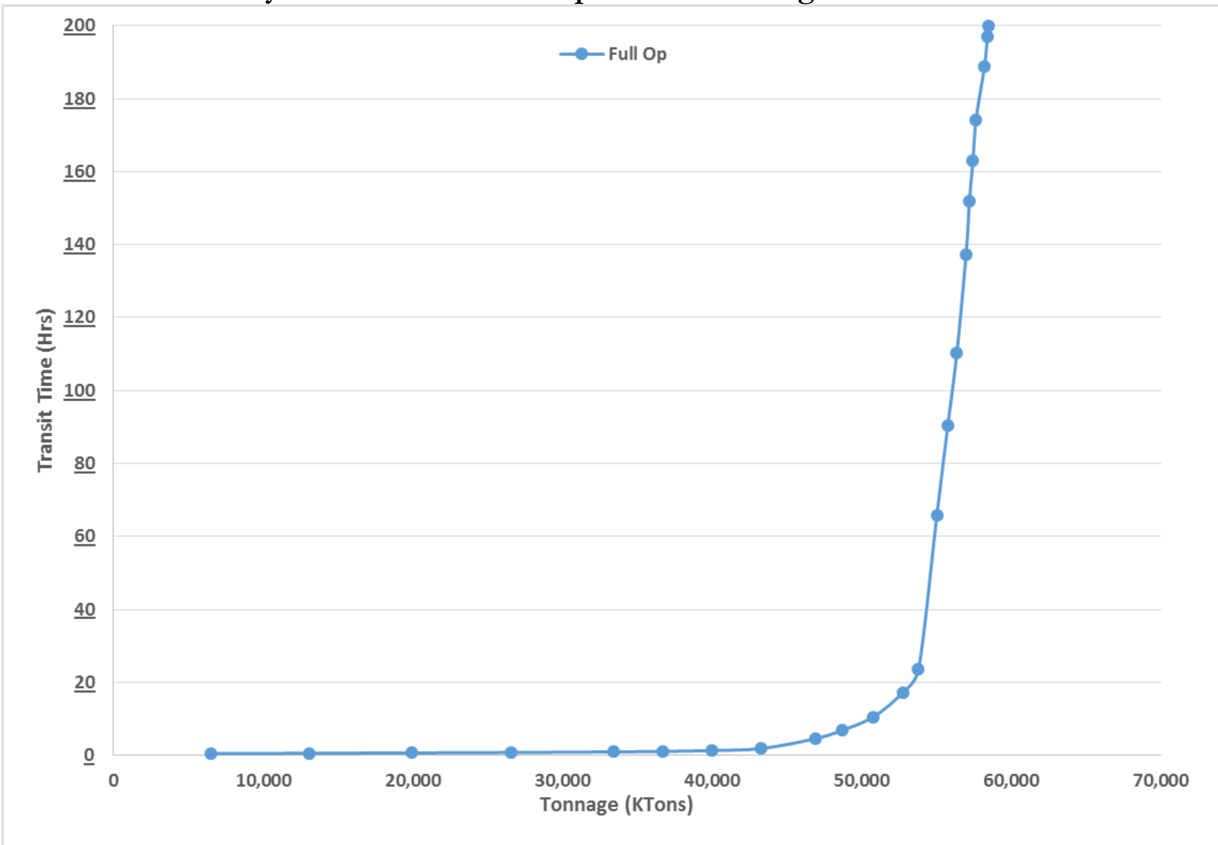
5.1.2 Bayou Boeuf Lock

Bayou Boeuf Lock is located on river mile 93.3 on the Gulf Intracoastal Waterway and consists of a single main chamber 1156’ x 75’ with a lift of 11 feet at normal pool.

5.1.2.1 Full-Operations Project Capacity

FIGURE A2-40 shows the tonnage-transit curve, and the relevant traffic range, for Bayou Boeuf Lock under a full-operation scenario with only random downtimes. Bayou Boeuf Lock was estimated to have a capacity of 58.5 million tons annually.

FIGURE A2-40: Bayou Boeuf Lock Full Operations Tonnage-Transit Curve



5.1.3 Calcasieu Lock

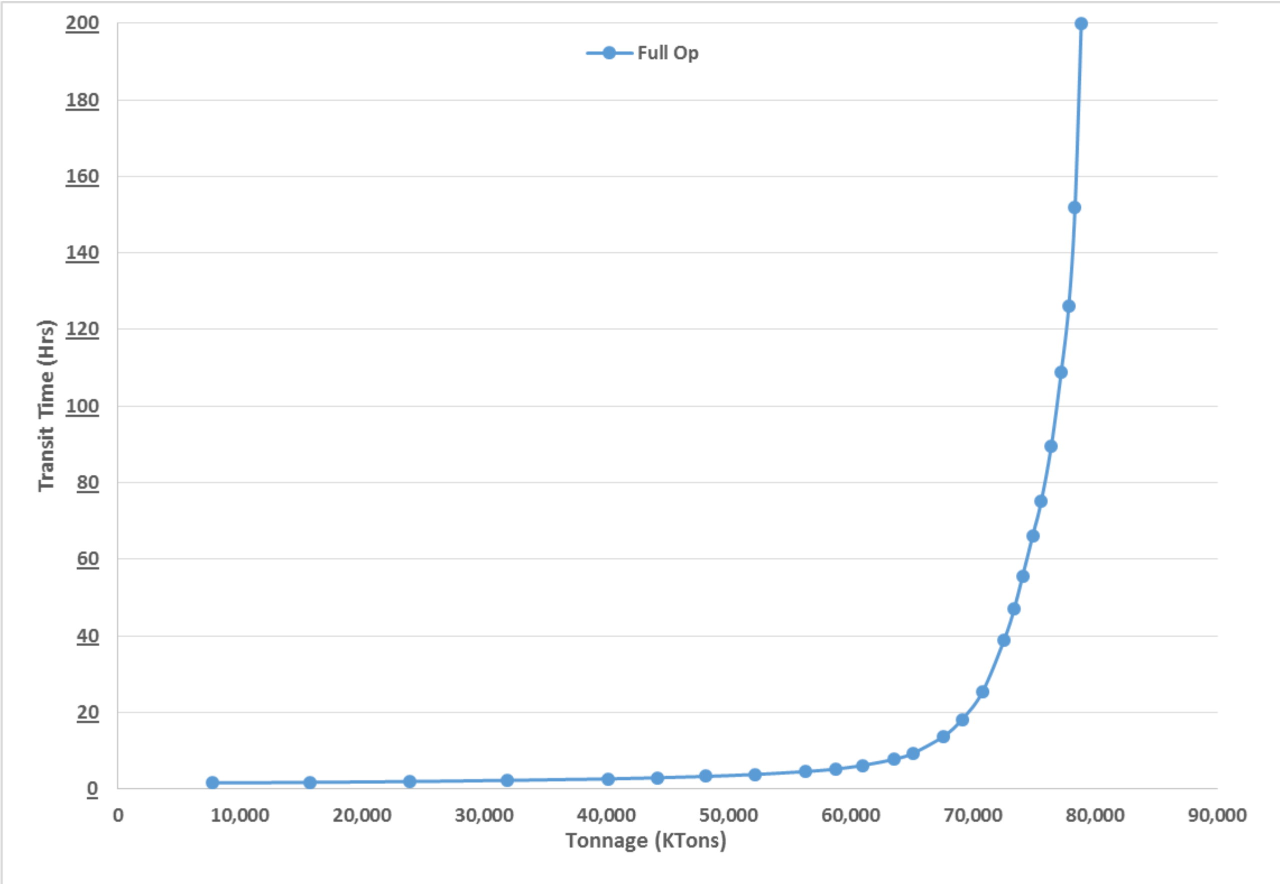
Calcasieu Lock is located approximately 238 waterway miles west of New Orleans LA on the Gulf Intracoastal Waterway. Calcasieu consists of one 1205' x 75' lock chamber which serves three purposes; as a navigation lock, to prevent saltwater intrusion, and as a flood way to drain the Mermanteau River Basin.

The multi-purpose nature of Calcasieu Lock made it a more complicated lock to model than typical single purpose locks in the Corps. Whereas typical single purpose locks primarily pass traffic with "standard" lockages where a chamber is filled or emptied with the gates closed on both ends, Calcasieu passes traffic with a combination of "standard" and "open pass" lockages. Open pass lockages occur when the gates at both ends of the chamber are "open" and the vessel is allowed to "pass" through the lock without the chamber being filled or emptied. Calcasieu was considered to be in "standard" locking mode whenever the east gage is less than 2.5 feet. The lock was considered to be in "open pass" mode whenever the east gage is greater than 2.5 feet and the west gage is lower than the east. An additional complication occurs during open pass lockages; depending on the differential between the east and west gages during open pass operations, some tows may not be able to pass through the lock due to the towboat horsepower being insufficient to push through the current velocity in the chamber.

5.1.3.1 Full-Operations Project Capacity

FIGURE A2-41FIGURE A2-39 shows the tonnage-transit curve for Calcasieu Lock under a full-operation scenario with only random downtime. Calcasieu Lock was estimated to have a capacity of 78.9 million tons annually.

FIGURE A2-41: Calcasieu Lock Full Operations Tonnage-Transit Curve



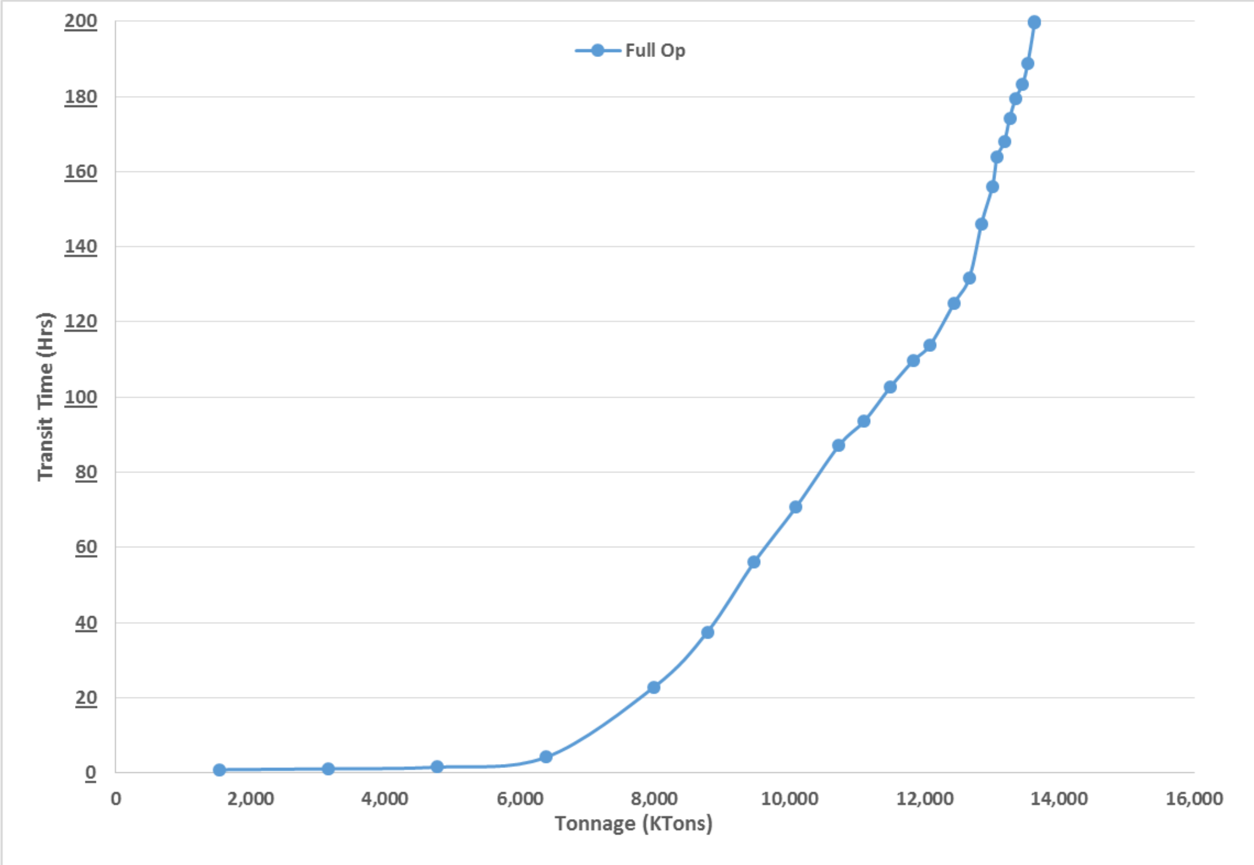
5.1.4 Harvey Lock

Harvey Lock is located on river mile 0 on the Gulf Intracoastal Waterway West and consists of 425' x 75' single main chamber with a lift of 20 feet at normal pool.

5.1.4.1 Full-Operations Project Capacity

FIGURE A2-42 shows the tonnage-transit curve, and the relevant traffic range, for Harvey LOCK under a full-operation scenario with only random downtimes. Harvey Lock was estimated to have a capacity of 13.6 million tons annually.

FIGURE A2-42: Harvey Lock Full Operations Tonnage-Transit Curve



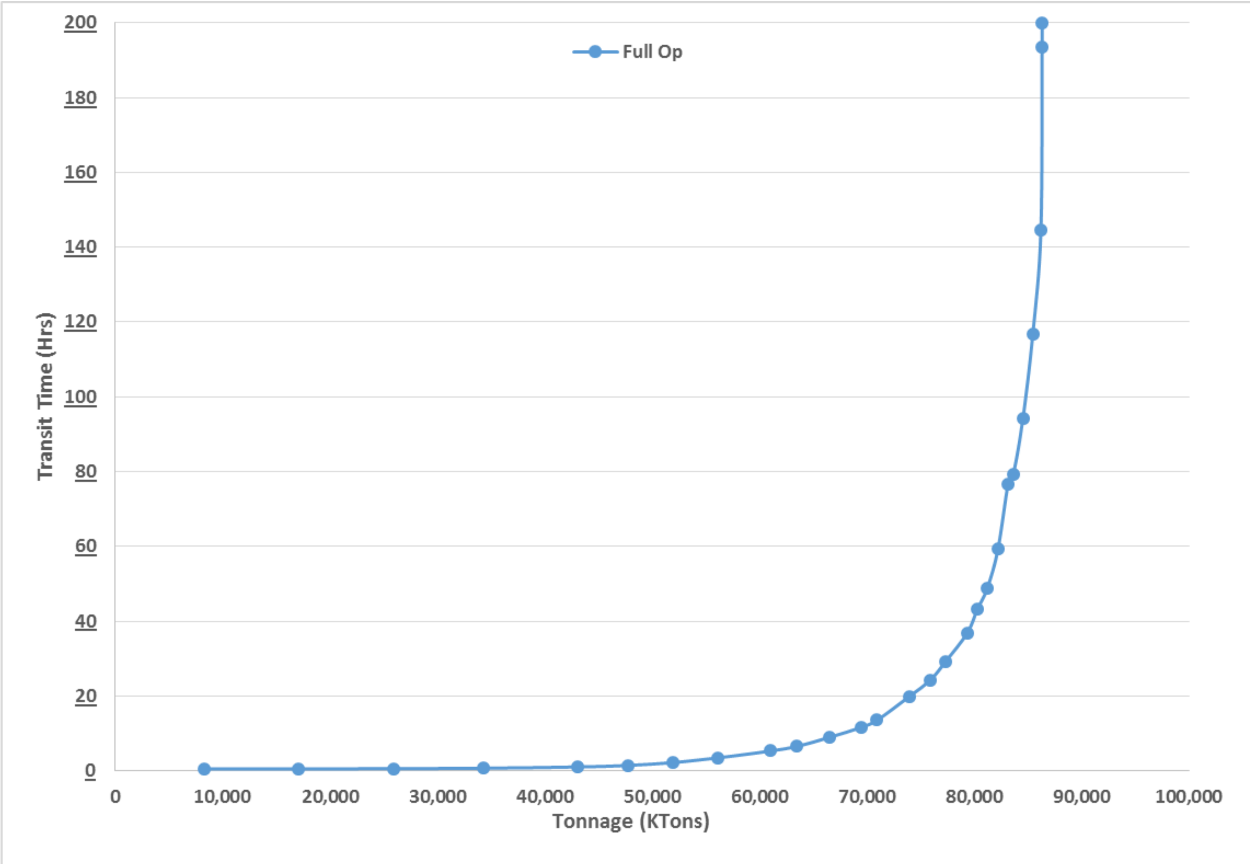
5.1.5 Leland Bowman Lock

Leland Bowman Lock is located on river mile 162.7 on the Gulf Intracoastal Waterway and consists of a single 1200' x 110' main chamber with a lift of 5 feet at normal pool.

5.1.5.1 Full-Operations Project Capacity

FIGURE A2-43 shows the tonnage-transit curve, and the relevant traffic range, for Leland Bowman Lock under a full-operation scenario with only random downtimes. Of the 9 locks modeled in the 2014 Calcasieu Lock study, Leland Bowman had the highest lock capacity at 86.3 million tons annually.

FIGURE A2-43: Leland Bowman Lock Full Operations Tonnage-Transit Curve



5.2 GIWW Morgan City – Port Allen Alternate Route

The GIWW Alternative Route lock projects included: Bayou Sorrel and Port Allen Locks. Both projects were analyzed in the 2014 Calcasieu Lock Study using the WAM. Their full-operation tonnage-transit curves are discussed in the sections below.

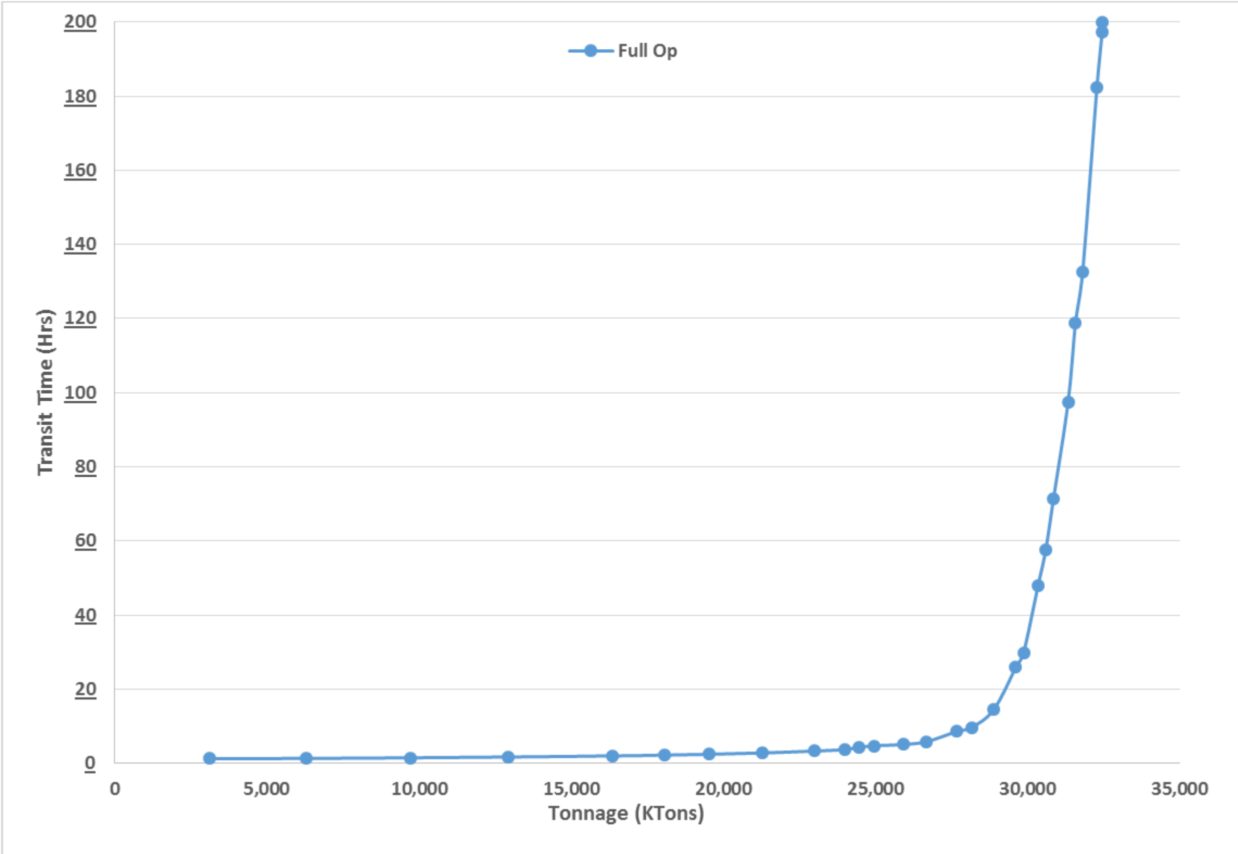
5.2.1 Bayou Sorrel Lock

Bayou Sorrel Lock is located on river mile 37.5 on the Gulf Intracoastal Waterway and consists of 800' x 56' single main chamber with a lift of 21 feet at normal pool.

5.2.1.1 Full-Operations Project Capacity

FIGURE A2-44 shows the tonnage-transit curve, and the relevant traffic range, for Bayou Sorrel Lock under a full-operation scenario with only random downtimes. Bayou Sorrel Lock was estimated to have a capacity of 32.5 million tons annually.

FIGURE A2-44: Bayou Sorrel Lock Full Operations Tonnage-Transit Curve



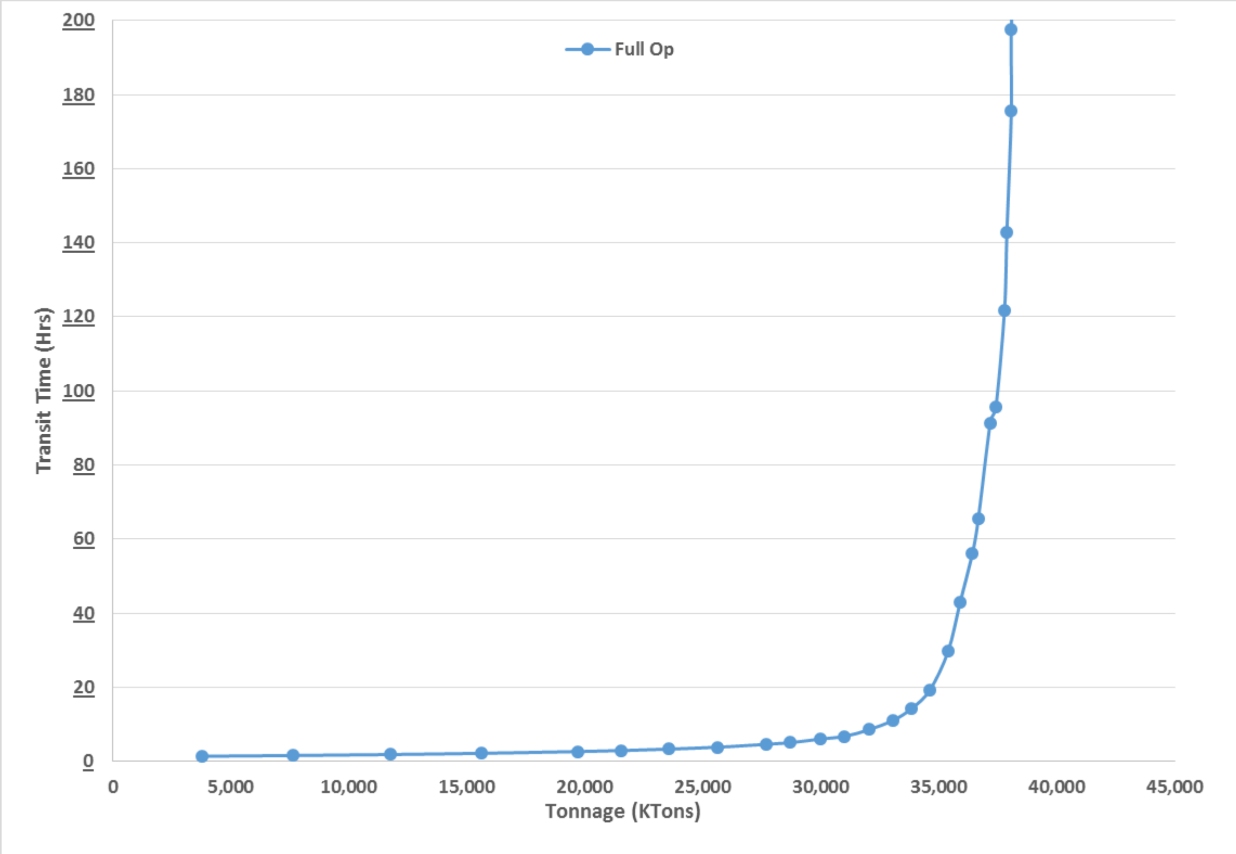
5.2.2 Port Allen Lock

Port Allen Lock is located on river mile 64.1 and consists of 1202' x 84' single main chamber with a lift of 45 feet at normal pool.

5.2.2.1 Full-Operations Project Capacity

FIGURE A2-45 shows the tonnage-transit curve, and the relevant traffic range, for Port Allen Lock under a full-operation scenario with only random downtimes. Port Allen Lock was estimated to have a capacity of 38.3 million tons annually.

FIGURE A2-45: Port Allen Lock Full Operations Tonnage-Transit Curve



5.3 Atchafalaya – Mississippi River Link

The Atchafalaya – Mississippi River Link only includes one lock project: Old River Lock. As with the other non-IHNC Lock projects, Old River Lock was analyzed in the 2014 Calcasieu Lock Study using the WAM. The Old River Lock full-operation tonnage-transit curve is discussed in the section below.

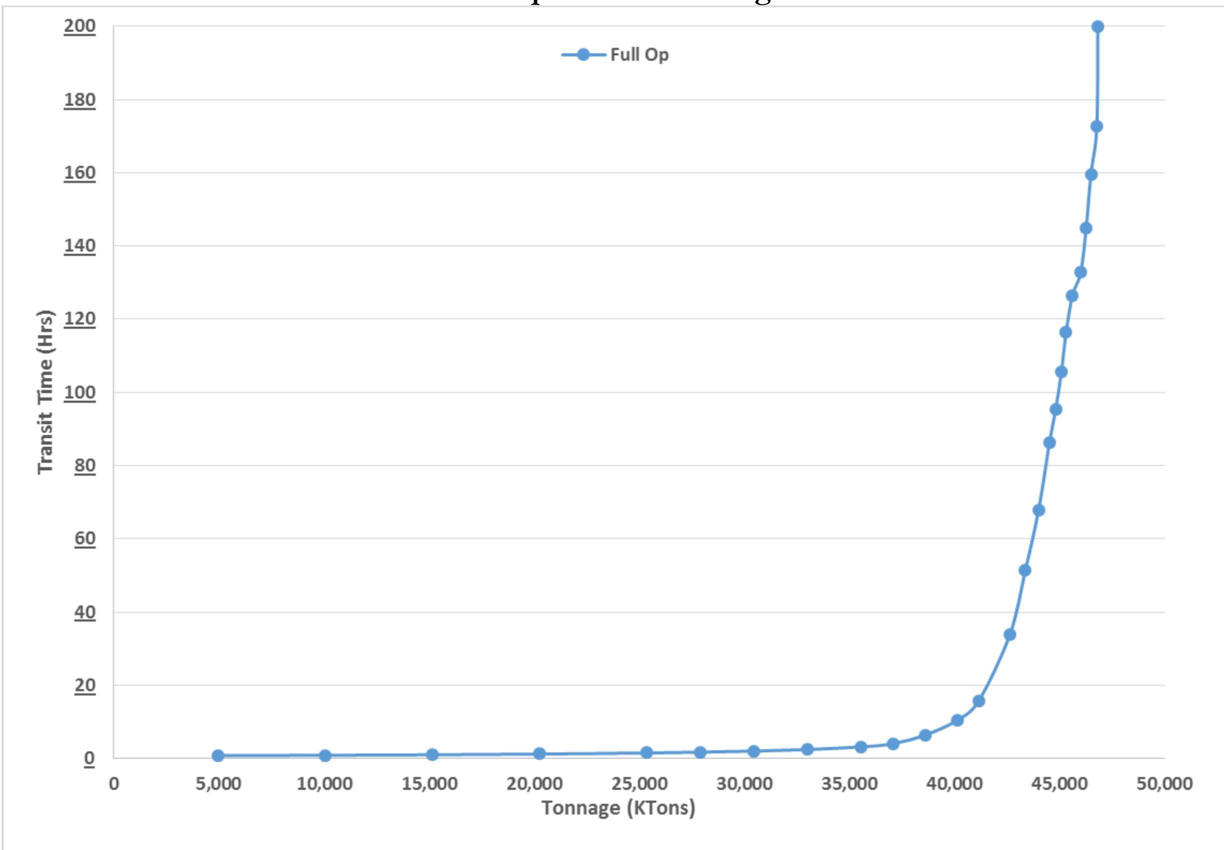
5.3.1 Old River Lock

Old River Lock is located on river mile 1 on the Old River and consists of 1200' x 75' single main chamber with a lift of 35 feet at normal pool.

5.3.1.1 Full-Operations Project Capacity

FIGURE A2-46 shows the tonnage-transit curve, and the relevant traffic range, for Old River Lock under a full-operation scenario with only random downtimes. Old River Lock was estimated to have a capacity of 46.8 million tons annually.

FIGURE A2-46: Old River Lock Full Operations Tonnage-Transit Curve



ATTACHMENT 3: GEC TRAFFIC DEMAND FORECASTS

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