Mississippi River Navigation Book Gets an Updated Low Water Reference Plane

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Introduction

Inland river waterways form a vital transportation network for commerce throughout the United States and must be maintained for the navigation of ships and the goods that they carry. Natural flowing water ways such as the Mississippi River are subject to constant change in channel morphology and the river channel must be maintained at minimum depth to ensure ship traffic does not run aground. Channel depths are maintained as measured from the Low Water Reference Plane (LWRP).

The Mississippi River LWRP is a hydraulic datum reference plane represented by a zero foot low water elevation established from long-term observations of the river's stages, discharge rates, and flow duration periods. Since river channels and capacities are so dynamic, it is necessary to calculate a new LWRP every five to ten years. In the past, the LWRP was interpreted along the channel based on time-consuming manual processing of sparse channel cross-section data. Utilizing LIDAR and Multi-Beam SONAR data, the U.S. Army Corps of Engineers has developed a new process to quickly generate a more accurate and more detailed Low Water Reference Plane.

Low Water Reference Plane

Water travels downstream due to differences in elevation of the channel bed and the water surface elevation gradient continually slopes downward. Comparing water surface elevations in NAVD88 survey vertical datum demonstrates the Mississippi River gradient. For example, the water surface elevation near Cairo, IL at river mile 953.8 is over 270 feet NAVD88 meanwhile the water surface elevation near Venice, LA at river mile 10.6 is typically less than 10 feet. Therefore, a survey vertical datum such as NAVD88 does not provide a way of comparing depths throughout the channel and instead requires a hydraulic vertical datum for this purpose.

The Low Water Reference Plane is a hydraulic-based, statistical vertical datum for channel depths. For the USACE New Orleans District, the Mississippi River 2007 LWRP from mile 313.7 to 265.4 is based on a 97% discharge duration of 146,000 cfs at Tarbert Landing (1954-2005) and a corresponding 10 year (1996-2005) mean stage of 14.8 ft. NAVD88 at Knox Landing, 13.5 ft. NAVD88 at Red River Landing, and 6.6 ft. NAVD88 at Bayou Sara. The 2007 LWRP below river mile 265.4, from Baton Rouge to Venice is based on a 97% stage exceedence of daily lows for the period of record (all historic readings) at each site (see figure 1).

For the many gages along the Mississippi River channel, the hydraulic analysis is performed based on the gage's river mile location along the channel. An adjustment factor is calculated to convert survey data referenced to NAVD88 to the LWRP datum (see table 1). For areas between two gage locations, linear interpolation is used to assign the LWRP adjustment factor to river miles at 0.1 mile increments. The end result of the hydraulic LWRP calculations is a table of adjustment factors for elevation/depth by 0.1 river mile increments that are used to develop a LWRP adjustment grid.

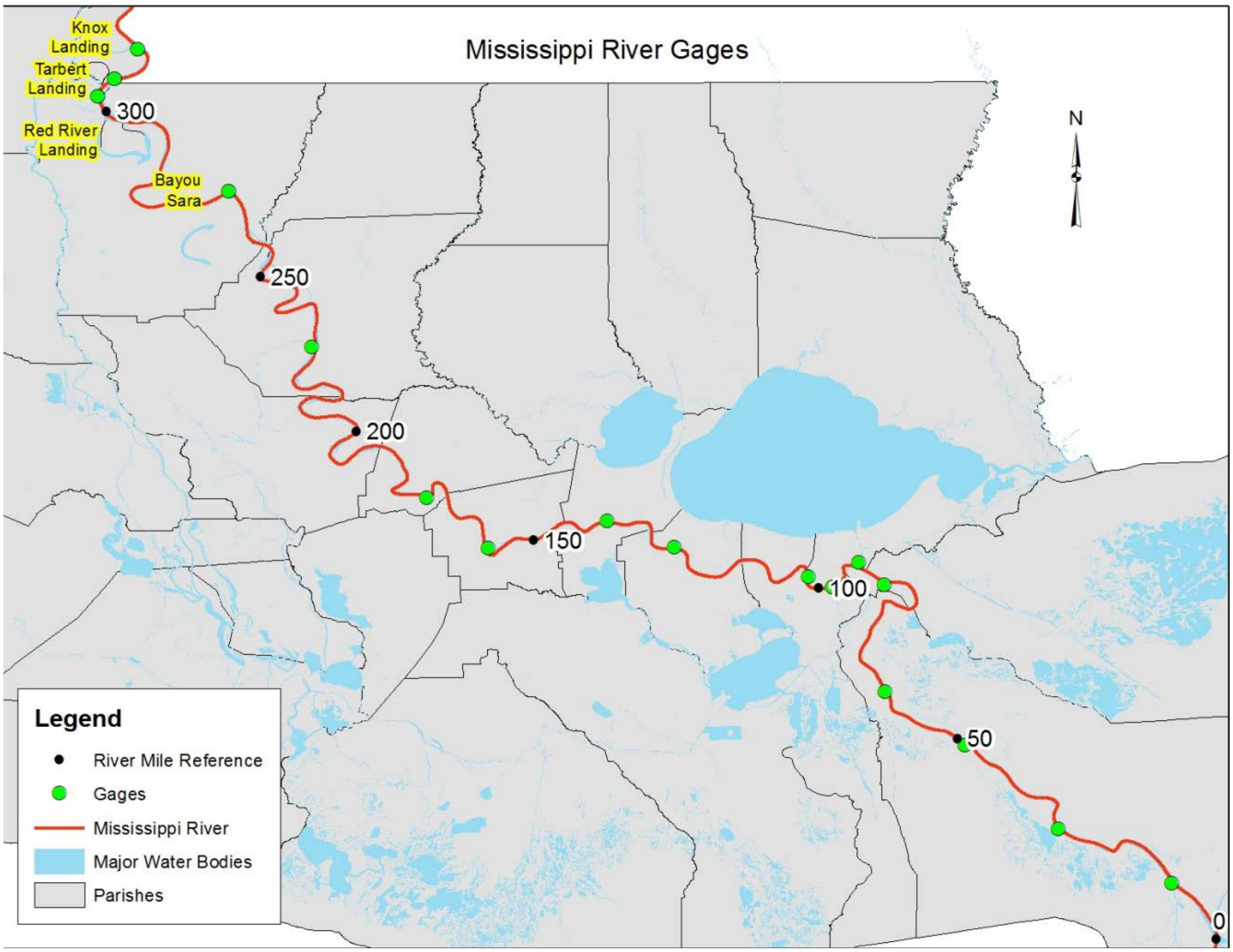

Figure 1: Gage locations along the Mississippi River (New Orleans District)

Gage Name	River Mile (Above Head of Passes)	Adjustment Factor NAVD88 to LWRP (ft)
Knox Landing, LA	313.7	14.8
Bayou Sara, LA	265.4	6.6
Baton Rouge, LA	228.4	2.5
New Orleans, LA	102.8	0.6
Venice, LA	10.6	0.1

Table 1: LWRP Adjustment Factors at gage locations along the Mississippi River (not a comprehensive listing)

Lower Mississippi River Navigation Book

The Lower Mississippi River Navigation Book is an atlas of navigational charts published by the U.S. Army Corps of Engineers. There are several features included in the published navigation charts that aide river pilots' ability to safely navigate the river and many are based on the Low Water Reference Plane: the surface water course area (0ft LWRP), shallow draft channel (9ft LWRP), and the deep draft channel (45ft LWRP).

Previous Geo-Processing Workflow

Historically, linear survey cross-sections were collected along the river at two-mile intervals. The LWRP adjustment factor was applied and the zero-ft location was calculated for each cross-section along the left descending bank and/or right descending bank. These zero-ft locations were the basis for generating a zero-ft contour. Contour lines had to be generated manually using the 0-ft intersection points and other datasets such as imagery. The process of drafting the 0-ft contour required interpretation by the analyst as the river channel (and the 0-ft contour) was not a straight line. The analyst was required to approximate the 0-ft LWRP contour in areas where linear surveyed cross-sections did not exist, including bends of varying degrees along the river channel.

Generating the NAVD88 Survey Raster Grid

The USACE has many responsibilities and areas of focus. The Mississippi river channel is routinely monitored for changes in the river bottom that impact the course of the channel's navigable route and require the channel be dredged. Additionally, the channel is monitored for scour locations that impact the stability of the channel banks and threaten levees, floodwalls, or other water control structures, such as the Morganza Spillway Control Structure. This business focus has necessitated regular surveying of the channel using multi-beam side-scan SONAR technology. The use of multi-beam side-scan SONAR technology has typically replaced the need for collecting linear survey cross-sections of the river channel. Following the high-water event of 2011, the entire Mississippi River Channel required a large scale multi-beam SONAR data collection effort during a period of low water to identify areas of concern for channel stability.

Meanwhile, the business of flood risk reduction requires routine monitoring of the levee system in order to maintain the required elevation. This requires the collection of LIDAR surveys as a supplemental data source to conventional profile and cross-section surveys.

Together, these business functions and data collection efforts provide the survey data to cover the Mississippi River channel and support the generation of a raster grid. A new mosaic survey surface grid is generated by merging the latest multi-beam SONAR data and the LIDAR data in order to provide a comprehensive coverage area in the NAVD88 survey vertical datum.

Generating an LWRP Adjustment Grid

Hydraulic analysis for the LWRP provides tabular data that includes an adjustment factor for each river mile (at 0.1 mile increments) that is used to convert survey data from the NAVD88 survey vertical datum to the LWRP datum. In order to develop an Adjustment Grid, the HECRAS hydraulic model for the Lower Mississippi River (New Orleans District) is used to export channel cross-sections into shapefile format. The channel cross-sections have a river mile attribute which is used to join to the tabular LWRP adjustment table. The channel cross-sections are extended 4000 feet to ensure they reach beyond the top-line elevation of the levee system along the river channel (see figure 2).

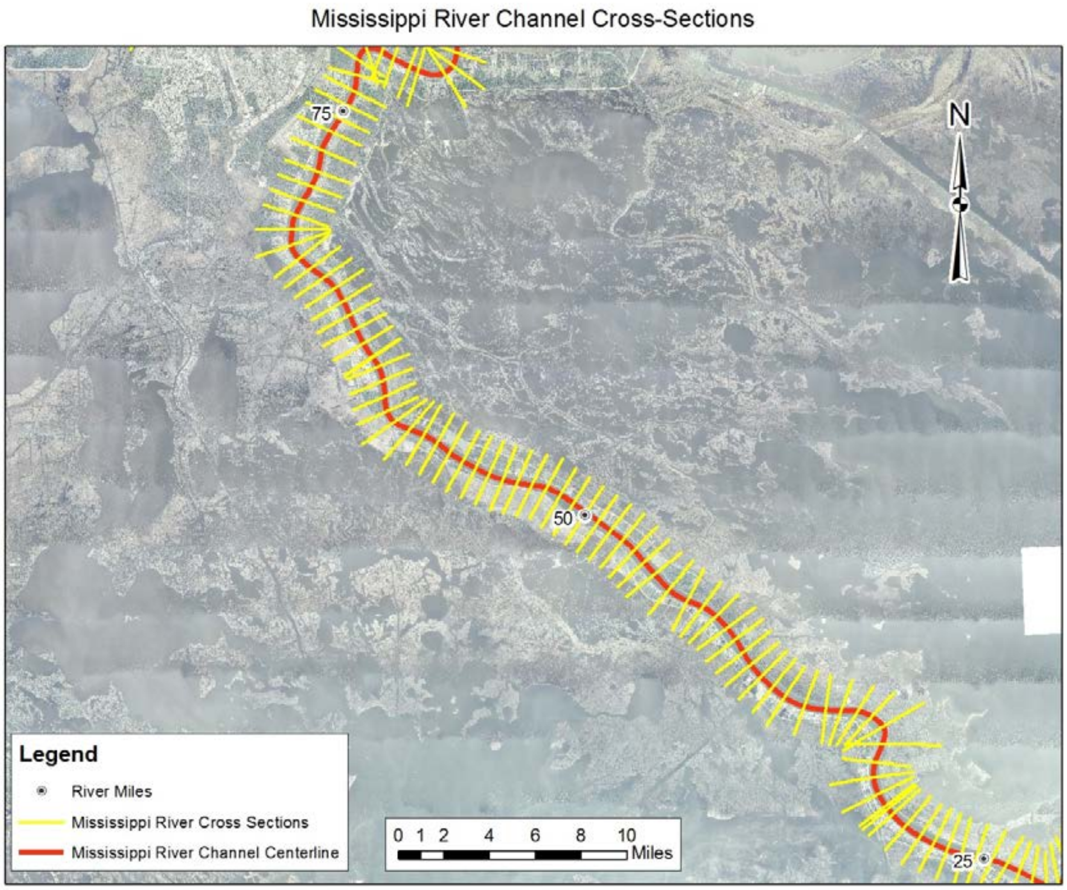

Figure 2: Mississippi River Mile Cross-sections and the centerline of the Mississippi River Channel between Mississippi River Mile A.H.P (Above Head of Passes) 25 and 75.

At this point, the vertices of the channel cross-sections are converted to a point shapefile using the Data Management Tools > Features > Feature Vertices to Points tool from ArcToolbox. In order to generate the adjustment grid, the Spatial Analyst Extension (Spatial Analyst Tools > Interpolation > IDW) is utilized to interpolate the point feature class using the IDW interpolation methodology (see figure 3). The Inverse Distance Weighted grid interpolation options include a cell size of 500, a power of 2, and a variable search radius determined by a minimum of 3 points and an unlimited maximum distance in order to fill the grid extent. The Input barrier polyline features option is not used since the elevation of the levee system serves as a natural barrier in the data results where the levee system exists and areas not bound by the levee system will still receive an adjustment value. The resulting adjustment grid to convert from NAVD88 to LWRP is shown in Figure 4.

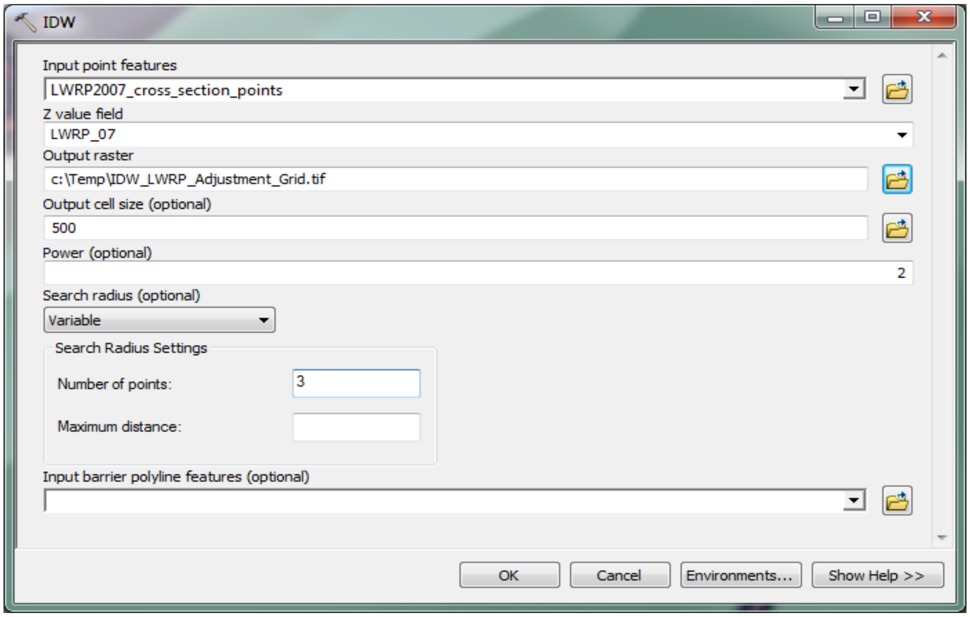

Figure 3: Inverse Distance Weighted interpolation options for generating the LWRP Adjustment Grid.

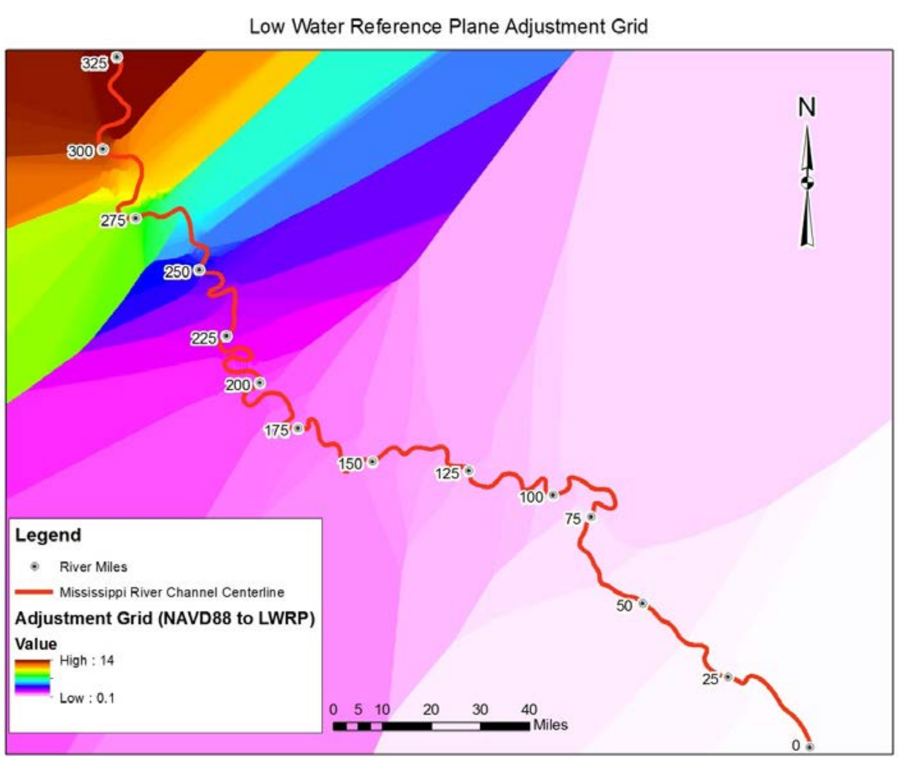

Figure 4: Illustration of the NAVD88 to LWRP Adjustment Grid.

Applying the Adjustment Grid

The pieces to the equation now exist in the form of the NAVD88 vertical datum-based survey grid and the NAVD88 to LWRP Adjustment Grid. Utilizing the Spatial Analyst extension, the adjustment grid is subtracted from the NAVD88 survey grid to produce the LWRP surface grid in heights (Spatial Analyst Tools > Math > Minus). Since the Lower Mississippi Navigation Book is interested in depths (not heights), the Spatial Analyst Extension's "negate" function is applied to turn the LWRP surface grid into depths having positive numbers. This generates the final LWRP surface grid on which the various required features will be extracted for use in the Lower Mississippi River Navigation Book. Recall these features include: the surface water course area (0ft LWRP), deep draft channel (45ft LWRP), and shallow draft channel (9ft LWRP).

Generating the Low Water Reference Plane

The 0ft depth polygon is the representation of the Low Water Reference Plane in the Lower Mississippi River Navigation Book. In order to extract a polygon feature, the contour function is applied. The contour operation is successful in many areas but produces undesirable results in other areas. Investigation of the multi-beam SONAR data reveals No Data gaps at locations of barge fleeting areas. Due to the undesirable results of the contour approach, we adopt an alternative methodology that extracts the LWRP surface grid where the value is greater than the zero-foot LWRP value. Using the Raster Calculator and the "con" function (Spatial Analyst > Map Algebra > Raster Calculator), all values zero and above are assigned the value of one and all values below zero are assigned the value of 0. A polygon shapefile is generated using the Raster to Polygon function under the Conversion Tools. All polygon features with a value of 1 are exported to a new polygon shapefile that only contains polygons of 0-foot LWRP depths or greater. The polygons are evaluated for containment within the channel and retained or discarded. The end result is a polygon representation of the 0ft LWRP also referred to as the surface water course area.

Additional Processing

Review of the LWRP polygon reveals the existence of gaps in the multi-beam SONAR data where barge fleeting areas occupy and interfere with the collection of data (see figure 5). These false holes are dropped from the shapefile and areas incorporated into the LWRP polygon. Similar gaps are identified at some docks/piers and other facilities that extend into the Mississippi River Channel and these gaps are also incorporated into the LWRP polygon.

Additional gaps are identified in the extreme down-river areas, approaching the area most impacted by tidal influence. These gaps are located along the banks of the channel where the water depth at the time of the survey is insufficient for the multi-beam SONAR survey equipment to capture the 0ft LWRP. These areas are compared with the linear cross-section surveys and the LWRP polygon boundary is revised to align more closely with the available data.

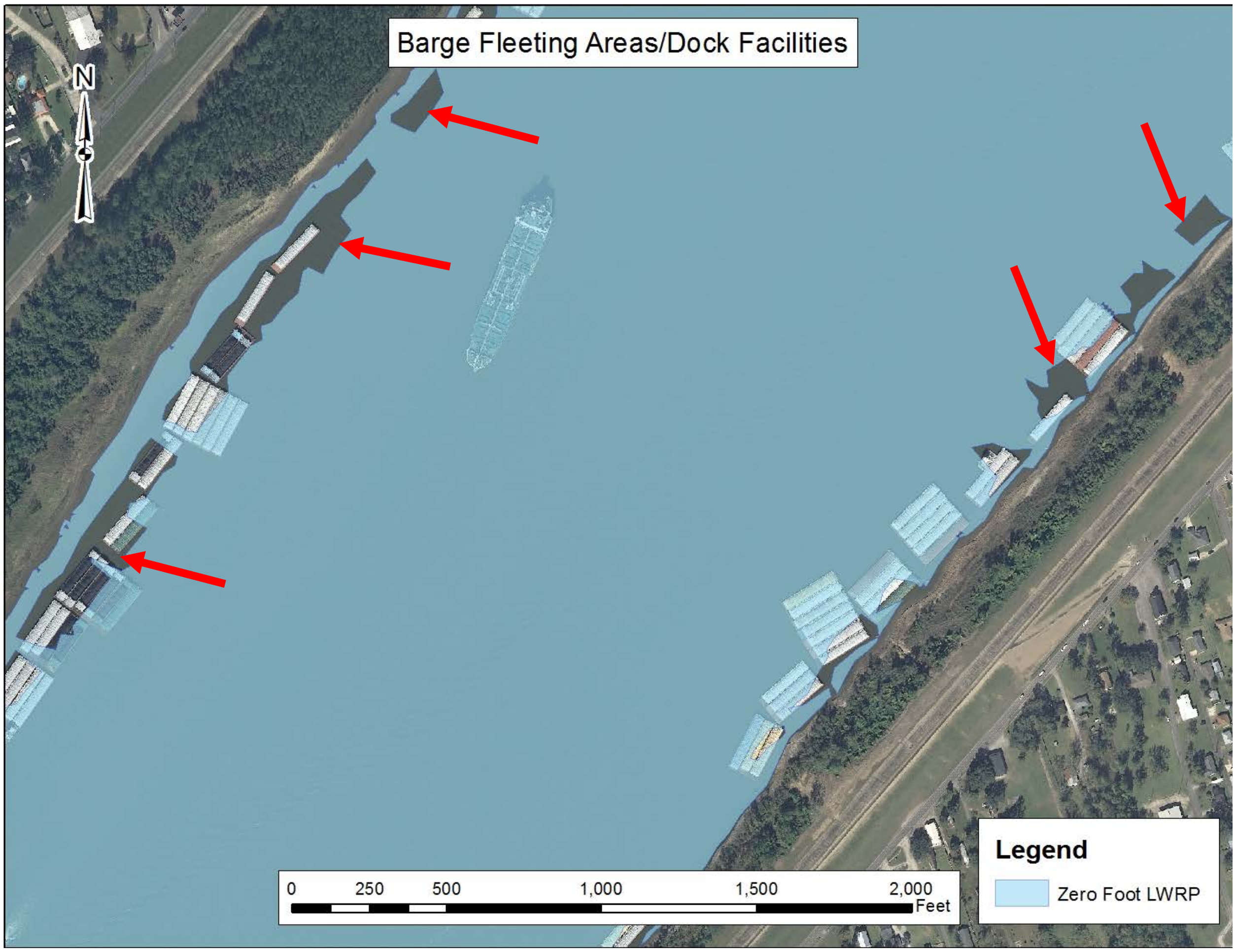

Figure 5: Gaps in the Zero-Foot LWRP in the vicinity of barge fleeting areas.

Results

The process of using LIDAR and multi-beam SONAR for development of the LWRP representation utilizes data sources that are collected by other offices within the U.S. Army Corps of Engineers as part of existing programs and reduces the processing time for LWRP development to a fraction of the previous workflow. Increasing the data-driven nature of the workflow and reducing the manual interpretation of the data increases the accuracy of the results and provides a more repeatable work flow for future epochs of the Low Water Reference Plane.

Recommendations for Future

As this new workflow utilizes data collection from other programs and not directly for the purpose of LWRP development, some refinements in the survey requirements will improve future generations of LWRP work. Generally, LIDAR surveys of the levee system are flown during the winter to improve data quality as the interference from vegetative growth is at its lowest. The focus of the levee LIDAR surveys is to cover the area between the toes of the levee. Extending the coverage area to capture up to the water edge would improve coverage in areas where the levee system is set back from the river channel.

The multi-beam side-scan SONAR data collection occurs during a period of low-water. During the low-water period, barges are very close to the channel bottom within the barge fleeting areas and do not provide enough clearance for the multi-beam side scan SONAR data to be fully collected. If adjustment to the time of data collection is changed to occur prior to low-water for areas where barge fleeting areas are located, the data gaps could be reduced or eliminated.

Implementing these recommendations will provide an overlap between the LIDAR and the SONAR data coverage, reduce gaps in the data, and increase the accuracy of future Low Water Reference Plane epochs.