Appendix C

Hydrology & Hydraulics

US Army Corps of Engineers®

St. Louis District

Piasa & Eagle's Nest Islands HREP HSR and AdH Model Study

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1 Introduction

1.1 Study reach

Between September 2015 and June 2016 the United States Army Corps of Engineers, St. Louis District (USACE) conducted a Hydraulic Sediment Response (HSR) model study and an Adaptive Hydraulics (ADH) model study of the Upper Mississippi River at the Piasa Island Complex, River Miles 216.0 – 205.0. These studies were intended to develop and evaluate alternatives to restore ecosystem structure and function by constructing project features to improve side channel, island, and wetland habitats. The results of the modeling were utilized to determine the efficacy of various alternative measures. These measures were then utilized in a planning model to determine the suite of measures to be included in the Tentatively Selected Plan (TSP) for this project.

The Piasa Island Complex study area is located within Pool 26, a 40-mile reach of the Upper Mississippi River System (UMRS), beginning below Lock and Dam 25 (RM 241.4) near Cap au Gris, Missouri, and ending at Melvin Price Locks and Dam (RM 200.8) at Alton, Illinois. Excluding entrance and exit conditions in the model, the study area encompasses Piasa Island and Eagle's Nest Island including Piasa Chute (the side channel located between Piasa Island and the Illinois bankline), and the unnamed chute between Piasa Island and Eagle's Nest Island. At the time of the study, the 11-mile reach had a total of 33 dikes. For a general project location please see Figure 1-1.

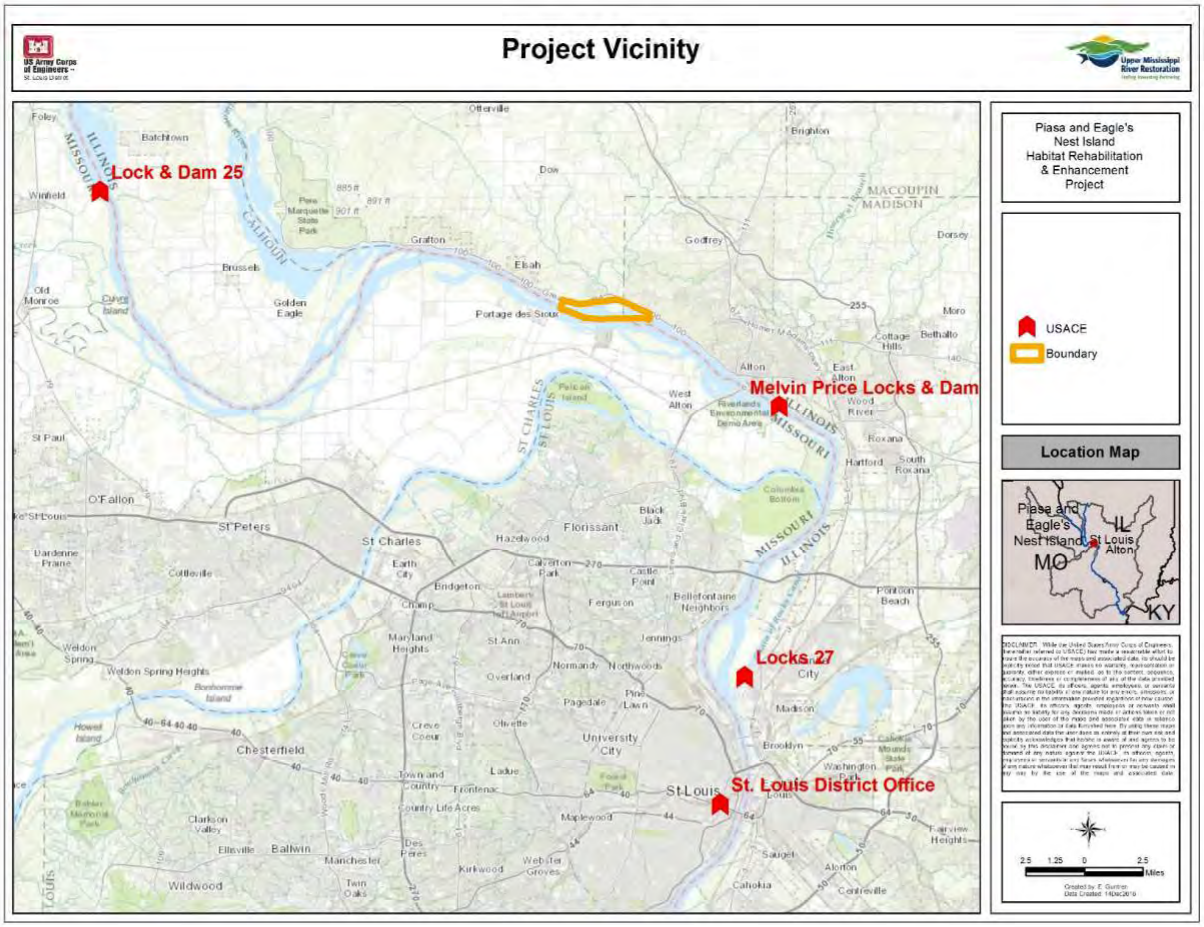


Figure 1-1. Piasa and Eagle's Nest Islands Project Location

1.2 Historical Information

The Project consists of two islands (Piasa and Eagle's Nest Islands) and associated side channel and backwater habitats. The area is bounded on the north by the State Highway 100 and bluffs that run along the Mississippi River. The southern portion of the site is bounded by the alluvial floodplain located in Missouri. Most of this floodplain is cut-off from the river by levees. Prior to settlement, the area to the south of the Project was a mosaic of terrestrial and aquatic habitats. The area to the north of the Project was a mix of forest and upland prairie. The Project site itself was a dynamic area of continuous changing formations of islands, wetlands, sand bars, side channels, and backwaters with varying depths.

Since the mid-19th century, the Army Corps of Engineers has been charged by Congress to improve the Mississippi River for navigation through dredging, snagging and clearing, and channel constriction. The latter procedure began with authorization of the 4-foot channel in 1866, 4 ½-foot channel in 1878, and continued with 6-foot channel in 1907. Between 1930 and 1940, the Corps constructed the Upper Mississippi River and Illinois Waterway 9-Foot Channel Project. Today, the 9-Foot Channel Project includes 37 locks and 1,200 miles of nine-foot deep navigable waterway in Illinois, Iowa, Minnesota, Missouri, and Wisconsin. Levee construction began on the UMRS in the 1880s. By 1890, much of the surrounding area to the Project, including a portion of Piasa Island itself, had been cleared for agriculture purposes. Approximately 30 acres of Piasa Island were under cultivation, while the remainder was forested (Figure 2-1). At that time, Eagle's Nest Island was mainly mud and sand flats, but by 1932 it was forested. There is no indication that Eagle's Nest Island was ever cultivated. While conversion of native habitat to agriculture affected the surrounding area, the impacts of constructing a stable and reliable navigation channel had greater impacts to the Project.

In order to address complaints related to shallow water from steamboaters, a submergible dam was built in 1875-1877 between Piasa Island and the Missouri shore for the purpose of moving more water through the channel north of Piasa Island and deepening that channel for navigation. However, after dam construction, a continuous rock ledge extending from the head of Piasa Island to the Illinois shore was discovered, which prevented the desired outcome to be achieved. The dam was abandoned and the decision was made to close the channel north of Piasa Island, and adopt the southern channel as the navigation channel. The dam was removed and additional dikes, including a dike from the Illinois shore to the head of Eagle's Nest Island, were constructed to direct flow into the southern channel (USACE, 1881). Over time, these historic dikes and closing structures led to increased sedimentation at the upstream end of Piasa Chute (i.e., the northern channel), and decreased depth diversity within the chute. Today, the navigation channel still runs south of both Piasa and Eagle's Nest Islands.

As part of the construction of Lock and Dam 26 and the creation of Pool 26, Piasa and the other islands in the Project were acquired by the government (Figure 2-2). Construction of Lock and Dam 26 was completed in 1939. The dam raised the water level in the vicinity of the Project inundating much of the wetlands and smaller islands surrounding Piasa and Eagle's Nest Islands. Figure 2-3 provides a series of aerial photographs of the Project from 1932 (pre-lock and dam), 1941 (post- lock and dam), 1979, and 2007. The gage data (Grafton gage located at RM 218.0) in 1932 was much lower as compared to the post-lock and dam photos which have more similar gage readings (Figure 2-3). These raised gage data post-lock and dam are expected due to the inundation. The raising of the water level frequently or permanently inundated parts of Piasa Island, which directly led to island loss and creation of more open water habitat. In addition, several of the smaller islands were permanently inundated.

Lock and Dam 26 was later replaced by the construction of Mel Price Locks and Dam (RM 200.5), located approximately 2 miles downstream of the original Lock and Dam 26. Mel Price became operational by 1990, and the original Lock and Dam 26 was removed. Lock and Dam 26 was later replaced by the construction of Mel Price Locks and Dam (RM 200.5), located approximately 2 miles downstream of the original Lock and Dam 26. Mel Price became operational by 1990, and the original Lock and Dam 26 was removed.

1.3 Project Purpose and Need

The Corps of Engineers proposes to rehabilitate and enhance Piasa and Eagle's Nest Islands through restoring ecosystem structure and function by constructing project features to improve side channel, island, and wetland habitats. This study is being conducted by the U.S. Army Corps of Engineers (USACE) with the Illinois Department of Natural Resources (IDNR) serving as the non-federal project sponsor.

In order to understand the fluvial processes leading to the shallowing of Piasa Chute, the U.S. Army Corps of Engineers, St. Louis District, conducted an investigation to evaluate the existing conditions and the hydrographic survey records between River Miles (RM) 216.0 and 208.0 (Brown 2007). The bathymetric analysis included surveys from 2004, 1998, 1987, 1983, 1977, 1971, and 1956. Overall, the main river channel upstream of Piasa Chute remained unchanged, which can be explained by its location within the navigation pool and having adequate width and depth. However, one change worthy of note is the scour hole (appx. 40 feet deep, 1 mile long, 1,000 ft wide) located 2 miles upstream of the entrance to Piasa Chute (RM 213.0-214.0) which switched back and forth from the right descending bank to the left descending bank between 1956 and 2004. Brown (2007) concluded that based on the scour hole's characteristics it can be considered to have direct consequences to the bathymetry of Piasa Chute. A line of scour near the north side of Eagle's Nest Island is present in the surveys. This scour line suggests a substantial amount of energy entering Piasa Chute complex exits between Piasa Island and Eagle's Nest Island, leaving less energy to pass through the remainder of Piasa Chute (Brown 2007). In addition, the 2015 hydrographic survey discovered a large sediment wave at RM 211 upstream of Eagle's Nest Island along the Illinois bankline that previous surveys missed or only captured a portion of. Sediment grab samples in the area of the sediment wave determined there was a mix of coarse sand, hardened clay, and woody debris. This feature was observed through aerial photography (Figure 1-2) and through field observations in 2015 during lower water conditions.

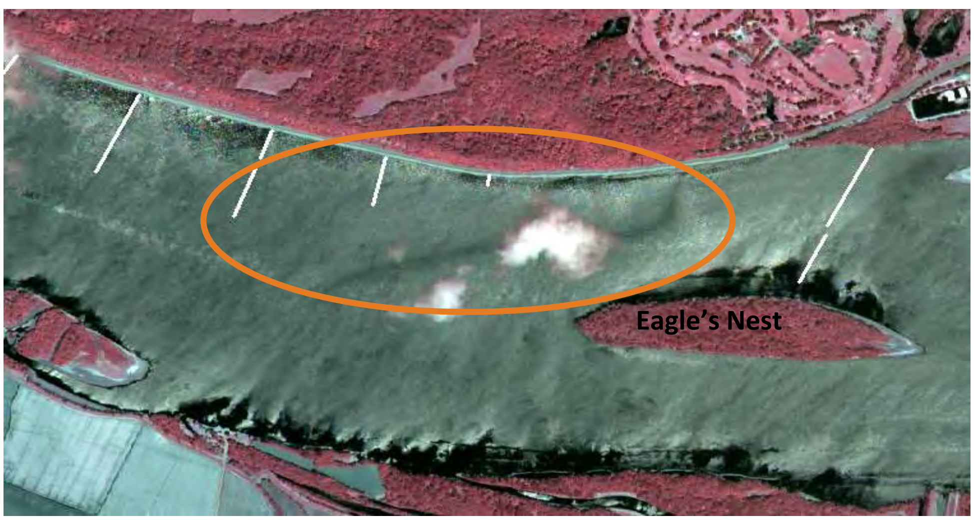


Figure 1-2. Satellite Image Showing Surface Effects of Sediment Wave

This feature appears to influence the entrance conditions into Piasa Chute by causing the flow to come into Piasa Chute at almost 90 degrees. This "shelf" drops off approximately 10 feet on the downstream edge. Acoustic Doppler Current Profiler (ADCP) data were collected in May 2015 (Plate 12) to document the flow (feet per second) within the Project. It appears that flow entering the Piasa Chute complex hugs the northern side of Eagle's Nest Island with slightly faster flows being closer to Eagle's Nest Island.

Within Piasa Chute the flows are very slow. The ADCP data support the conclusion from Brown (2007) that the majority of flow entering the Piasa Chute complex exits between Eagle's Nest Island and Piasa Island, leaving less flow (energy) to pass through the remainder of the side channel. This low energy in Piasa Chute has caused deposition to occur, leading to a lack of environmental diversity over time.

2 HSR Modeling

2.1 Introduction

In September 2015 the United States Army Corps of Engineers, St. Louis District (USACE) conducted a Hydraulic Sediment Response (HSR) model study of the Upper Mississippi River at the Piasa Island Complex, River Miles 216.0 – 205.0, to develop and evaluate alternatives to restore ecosystem structure and function by constructing project features to improve side channel, island, and wetland habitats. HSR models are small-scale mobile-bed physical models used to evaluate geomorphic response to channel modifications. HSR models were introduced in 1994 by the USACE St. Louis District to predict bathymetric response for proposed channel modifications, including river training structures, for navigation and environmental effects, and have been used as a screening tool for evaluating sedimentation and scour for more than seventy engineering projects. Plate 1 is a location and vicinity map of the Piasa Island Complex.

Excluding entrance and exit conditions in the model, the study area en-compassed Piasa Island and Eagle's Nest Island including Piasa Chute (the side channel located between Piasa Island and the Illinois bankline), and the unnamed chute between Piasa Island and Eagle's Nest Island. At the time of the study, the 11-mile reach had a total of 33 dikes. Plate 2 details the planform and nomenclature of the reach. Figure 2-1 shows the layout of the HSR model.

Figure 2-1. Piasa & Eagle's Nest Island Complex HSR Model

2.2 Model Calibration and Replication

The HSR modeling methodology employed a calibration process designed to replicate the general conditions in the river at the time of the model study. Replication of the model was achieved during calibration and involved a three step process.

First, planform "fixed" boundary conditions of the study reach, i.e. banklines, islands, side channels, tributaries and other features were established according to the most recent available high resolution aerial photographs. Various other fixed boundaries were also introduced into the model including any channel improvement structures, underwater rock, clay and other non-mobile boundaries.

Second, "loose" boundary conditions of the model were replicated. Bed material was introduced into the channel throughout the model to an approximate level plane. The combination of the fixed and loose boundaries served as the starting condition of the model.

Third, model tests were run using steady state discharge. Adjustment of the discharge, sediment volume, model slope, fixed boundaries, and entrance conditions were refined during these tests as part of calibration. The bed progressed from a static, flat, arbitrary bed into a fully-formed, dynamic, three dimensional mobile bed response. Repeated tests were simulated for the assurance of model stability and repeatability. When the general trends of the model bathymetry were similar to observed recent river bathymetry, and the tests were repeatable, the model was considered calibrated and alternative testing began.

Observed recent prototype bathymetry trends were determined using single beam and multibeam hydrographic surveys of the Mississippi River from 2006 to 2015. Main channel surveys included years 2007, 2011, 2014, and 2015 (Plates 3 – 6) while side channel surveys included years 2006 and 2013 (Plates 7 and 8). A multibeam survey was conducted to verify the elevation and condition of existing river training structures located within the reach (Plate 9). Furthermore, ADCP surveys from April 2013, July 2013, and May 2015 can be found on Plates 10 – 12. The most recent surveys were used as they showed the most recent construction and the resultant river bed changes. After comparison of the hydrographic surveys, the following bathymetric trends remained relatively consistent from 2006 to 2015:

Table 2-1. Prototype Bathymetric Trends

River Miles	Description
216.0 - 214.0	The thalweg was located along the Left Descending Bank (LDB) with depths between -40 ft and -20 ft MINPOOL.
214.0 - 213.0	Scour was observed on the main channel side of Portage Island with depths ranging between -40 ft and -30 ft MINPOOL. A crossing from the LDB to the Right Descending Bank (RDB) was observed between RM 214.0 and RM 213.0.
213.0 - 212.0	The thalweg remained along the RDB of the main channel with confluence scour observed where the Portage Island side channel meets the main channel flow.
212.0 - 211.0	The thalweg continued along the RDB while higher bed elevations ranging from -15 ft to 0 ft MINPOOL were observed in the dike field along the LDB.
211.0 - 209.5	The thalweg remained along the Missouri bankline with depths ranging between -40 ft and -20 ft MINPOOL. The area immediately upstream of Eagle's Nest Island and between Eagle's Nest and the Illinois bankline had elevations ranging between -15 ft to -5 ft MINPOOL. A large amount of the flow entering the side channel complex between Eagle's Nest Island and the Illinois bankline returns to the main channel flow between Eagle's Nest and Piasa Islands.

209.5 - 207.5	A crossing from the RDB to the LDB was observed between RM 209.0 and RM 207.5 with depths ranging between -35 ft to -10 ft MINPOOL. Higher elevations, ranging between -10 ft to +5 ft MINPOOL were observed along the main channel side of Piasa Island and within Piasa Chute.
207.5 - 205.0	The thalweg remained along the LDB with depths ranging between -45 ft and -20 ft MINPOOL while higher elevations ranging between -15 ft to 0 ft MINPOOL were observed among the dike field located on the RDB.

2.3 Scales and Bed Materials

The model employed a horizontal scale of 1 inch = 600 feet, or 1:7,200, and a vertical scale of 1 inch = 65 feet, or 1:780, for a 9 to 1 distortion ratio of linear scales. This distortion supplied the necessary forces required for the simulation of sediment transport conditions similar to those observed in the prototype. The bed material was granular plastic urea, Type II, with a specific gravity of 1.40.

2.4 Appurtenances

The HSR model planform insert was constructed according to the 2012 high-resolution aerial photography of the study reach. The insert was then mounted in a standard HSR model flume. The riverbanks of the model were routed into dense polystyrene foam and modified during calibration with clay. Rotational jacks located within the hydraulic flume controlled the slope of the model. The measured slope of the insert and flume was approximately .012 inch/inch. River training structures in the model were made of galvanized steel mesh to generate appropriate scaled roughness.

2.5 Flow Control

Flow into the model was regulated by customized computer hardware and software interfaced with an electronic control valve and submersible pump. This interface was used to control the flow of water and sediment into the model. For all model tests, flow entering the model was held steady at 2.6 Gallons per Minute (GPM). This served as the average expected energy response of the river. Because of the constant variation experienced in the river, this steady state flow was used to replicate existing general conditions and empirically analyze the ultimate expected sediment response that could occur from future alternative actions.

2.6 Data Collection

Data from the HSR model was collected with a three dimensional (3D) laser scanner. The river bed in the model was surveyed with a high definition, 3D laser scanner that collects a dense cloud of xyz data points. Using ArcGIS computer software, these xyz data points were then georeferenced to real world coordinates and triangulated to create a 3D surface. The surface was then color coded by elevation using standard color tables that were also used in color coding prototype surveys. This process allowed a direct comparison between HSR model bathymetry surveys and prototype bathymetry surveys.

2.7 Model Replication

Once the model adequately replicated general prototype trends, the resultant bathymetry served as a benchmark for the comparison of all future model alternative tests. In this manner, the actions of any alternative, such as new channel improvement structures, realignments, etc., were compared directly to the replicated condition. General trends were evaluated for any major differences positive or negative between the alternative test and the replication test by comparing the surveys of the two and also carefully observing the model while the actual testing was taking place.

Bathymetric trends were recorded from the model using a 3-D Laser Scanner. Calibration was achieved after numerous favorable bathymetric comparisons of the prototype surveys were made to several surveys of the model. The resultant bathymetry served as the bathymetry base test for the model. Plate 13 compares the model replication, or base test, to a prototype hydrographic survey.

The model was considered calibrated between RM 212.5 and RM 207.0, which excluded entrance and exit conditions of the model. Results of the HSR model base test bathymetry and a comparison to the 2006 through 2015 prototype surveys indicated that the model replication and prototype bed responses were within the natural variation observed in the river and produced the following trends:

Table 2-2. HSR Bathymetric Trends

River Miles	Description
212.5 - 212.0	The thalweg was located along the RDB of the main channel with confluence scour observed where the Portage Island side channel meets the main channel flow.
212.0 - 211.0	The thalweg continued along the RDB while higher bed elevations ranging from -15 ft to 0 ft MinPool were observed in the dike field along the LDB.
211.0 - 209.5	The thalweg remained along the Missouri bankline with depths ranging between -20 ft and -40 ft MINPOOL. The area immediately upstream of Eagle's Nest Island and between Eagle's Nest and the Illinois bankline had elevations ranging between -15 ft to -5 ft MINPOOL. A large amount of the flow entering the side channel complex between Eagle's Nest Island and the Illinois bankline returns to the main channel flow between Eagle's Nest and Piasa Islands.
209.5 - 207.5	A crossing from the RDB to the LDB was observed between RM 209.0 and RM 207.5 with depths ranging between -35 ft to -10 ft MINPOOL. Higher elevations, ranging between -10 ft to +5 ft MINPOOL were observed along the main channel side of Piasa Island and within Piasa Chute.
207.5 - 207.0	The thalweg remained along the LDB with depths ranging between -45 ft and -20 ft MINPOOL while higher elevations ranging between -15 ft to 0 ft MINPOOL were observed among the dike field located on the RDB.

2.8 Design Alternative Testing

The testing process consisted of modeling alternative measures in the HSR model followed by an analyses of the bathymetry results. The goal was to identify the most effective and economical plan to enhance environmental diversity in the Piasa Island Complex reach while having no negative impact to the existing navigation channel. Evaluation of each alternative was accomplished through a qualitative comparison to the model replication test bathymetry. Plates 14 -36 compare the alternative bathymetric results with the base test bathymetry of HSR model. See Chapter 4 for the full list of plates.

2.9 HSR Results and Path Forward

Throughout testing, a number of alternative measures visibly increased the amount of flow entering the side channel, but the shear stress forces, which determines bed scour, were not great enough to create any significant bathymetry changes. After testing 23 alternatives and repeatedly seeing an increase in flow but little bathymetric changes with alternative tests, engineers determined the HSR model's calibrated flowrate was lower than Piasa Chute's channel forming discharge. In other words, the calibration of the Piasa HSR model accurately replicated the bathymetry within the overall study reach, but a higher model discharge rate was necessary to see bathymetric changes due to alternative designs within Piasa Chute.

HSR models are calibrated by manipulating entrance and exit conditions, flow rate, model slope, tail gate height, and sediment volume until the model bathymetry replicates the prototype river. Furthermore, HSR models are qualitatively analyzed in that the bathymetric trends in the model match average bathymetric trends of the prototype over the course of multiple years. Simply, the HSR model replicates an average condition of the reach, not a high discharge event, which occurs much less frequently. Site visits confirmed that during typical stages, there is very little flow entering the side channel complex, which is what the calibrated HSR model replicated.

In order to test alternatives at a higher flowrate, or higher channel forming discharge, the PDT decided to utilize an Adaptive Hydraulics (AdH) numerical model. AdH is a finite element modeling package that evaluates two-dimensional shallow water calculations and was designed to solve water problems within riverine systems and estuaries. AdH works in conjunction with Surface Water Modeling System (SMS), which is used for mesh generation and visualization of results calculated in AdH. AdH model development, calibration, and results are discussed in Chapter 3. The AdH model allowed the PDT to analyze alternatives at different flow conditions as well as quantitatively measure discharge through Piasa Chute, changes in bed shear, and changes in velocity.

3 AdH Modeling

3.1 Geometry

The elevation data used to create the AdH computational mesh was compiled using several datasets that covered both above and below the waterline. The sources include a combination of Light Detection and Ranging surveys (LiDAR) and hydrographic surveys, which consisted of single beam and multi-beam survey data. LiDAR data is collected above the water surface while hydrographic or bathymetric surveys are used to collect elevation data below the water surface. Data in NAVD88 was converted to NGVD29 using a datum shift of approximately +0.5 feet. The surveys were merged together to create a single elevation dataset representing all areas above and below the waterline within the numerical model mesh domain. Table 3-1 lists the elevation datasets used to create the mesh. The merged elevation data is shown in Figure 3-1.

Table 3-1. Source of Elevation Datasets

Survey	Survey Type	Vertical Datum	Year
Structure Survey	Multi Beam Hydrographic Survey	(NGVD29)	2015
Piasa Chute Side Channel Survey	Multi Beam Hydrographic Survey	(NGVD29)	2013
Main Channel Survey	Single Beam Hydrographic Survey	(NGVD29)	2011
Upper Mississippi River LiDAR	LiDAR	(NAVD88)	2013

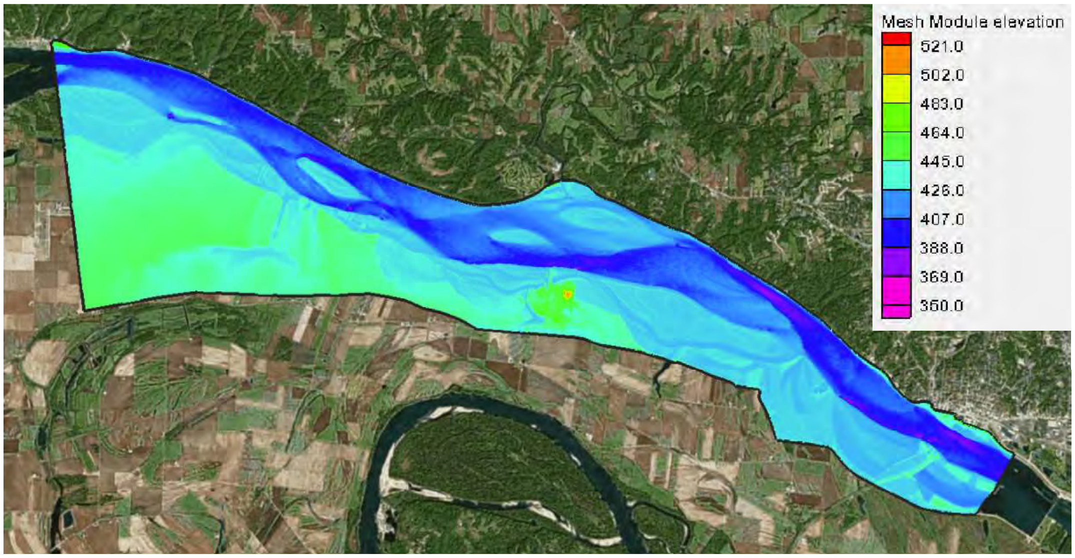


Figure 3-1. Piasa Island Complex AdH Elevation Map

3.2 Calibration

To develop and calibrate an AdH model, multiple items are necessary. These items include boundary conditions, a numerical mesh file, a hot start file, roughness values, a computational environment, and calibration results.

3.2.1 Boundary Conditions: Discharge and Water-surface Elevation Data

The Piasa & Eagle's Nest Islands HREP AdH model included the reach between the gage at Grafton, Illinois (UMR 218.6) and the gages at Alton Marina (UMR 203.0) and Mel Price (Pool, UMR 201.1) near Alton, Illinois (RM 218.60-201.50). However, the gage at Grafton, Alton, and Mel Price (Pool) were not rated for discharge. In order to determine discharge through the study reach, a calculation was made by subtracting the Herman, MO gage discharge on the Missouri River from the St. Louis, MO gage discharge on the Mississippi River. Furthermore, there is a time lag of approximately 1 day between the Herman, MO gage and the St. Louis, MO gage, so this was also factored into the discharge calculations. Engineers chose a range of discharges based on historical hydrograph data that represented a range of river conditions including normal pool, pool drawdown, and flood flows. The discharge entering the model was distributed from the Illinois bluff to a backwater area approximately 1 mile to the south of the Illinois bluff. The entrance and exit discharge boundaries were chosen based on typical inundation for the discharges to be tested and have been highlighted in yellow on Figure 3-2. Table 3-2, Table 3-3, and Table 3-4 show the relevant gage information, discharge data, and stage data, respectively.

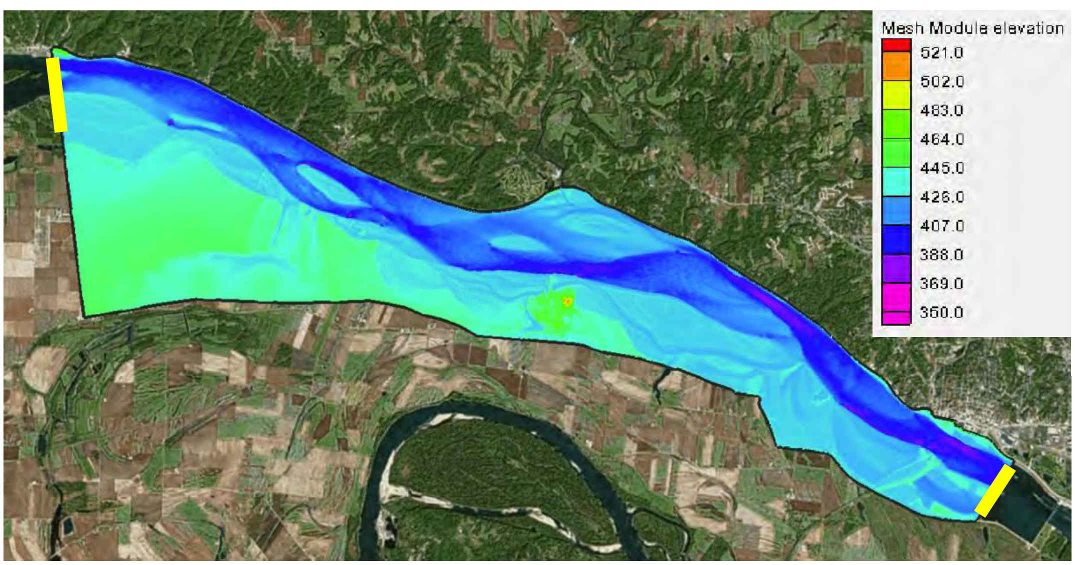


Figure 3-2. AdH Discharge Entrance and Exit boundaries

Table 3-2. Gage Locations

Gage Name	River	River Mile	Gage Latitude	Gage Longitude	Gage Zero (elevation – feet NAVD88)	Minimum Pool (elevation – feet NAVD88)
Grafton	Mississippi	218.60	38°58'05"	90°25'44"	403.22	417.43
Mel Price Pool	Mississippi	201.10	38°52'18"	90°09'27"	395.04	412.06
Alton	Mississippi	203.0	38°53'14"	90°11'02"	399.66	413.66
Herman	Missouri	97.9	38°42'35"	91°26'19"	481.50	-
St. Louis	Mississippi	179.60	38°37'44"	90°10'47"	379.94	-

Table 3-3. Discharge Data

River Condition	St. Louis Gage Discharge (ft^3/s)		Hermann Gage Discharge (ft3/s)		8AM Difference (ft3/s)	5PM Difference (ft3/s)	Average Discharge (ft3/s)
Pool	3-20-14		3-19-14		158,300	159,500	3-20-14
	8AM	5PM	8AM	5PM			158,900
	203,000	204,000	44,700	44,500			
Pool	4-24-14		4-23-14		202,900	201,600	4-24-14
	8AM	5PM	8AM	5PM			202,250
	257,000	255,000	54,100	53,400			
Pool Drawdown	5-15-14		5-14-14		245,900	249,700	5-15-14
	8AM	5PM	8AM	5PM			247,800
	304,000	307,000	58,100	57,300			
Flood	7-03-14		7-02-14		301,000	302,000	7-03-14
	8AM	5PM	8AM	5PM			301,500
	427,000	429,000	126,000	127,000			
Flood	4-21-13		4-20-13		386,000	403,000	4-21-13
	8AM	5PM	8AM	5PM			394,500
	591,000	600,000	205,000	197,000			
Flood	4-25-13		4-24-13		447,000	453,000	4-25-13
	8AM	5PM	8AM	5PM			450,000
	652,000	650,000	205,000	197,000			

Table 3-4. Stage Data

Date	Grafton Gage Reading (elevation in feet NAVD88)	RM 201.5 WSE (elevation in feet NAVD88)
3-20-14	419.08	416.57
4-24-14	419.31	413.36
5-15-14	421.29	413.37
7-03-14	424.16	416.24
4-21-13	429.43	423.98
4-25-13	432.64	426.93

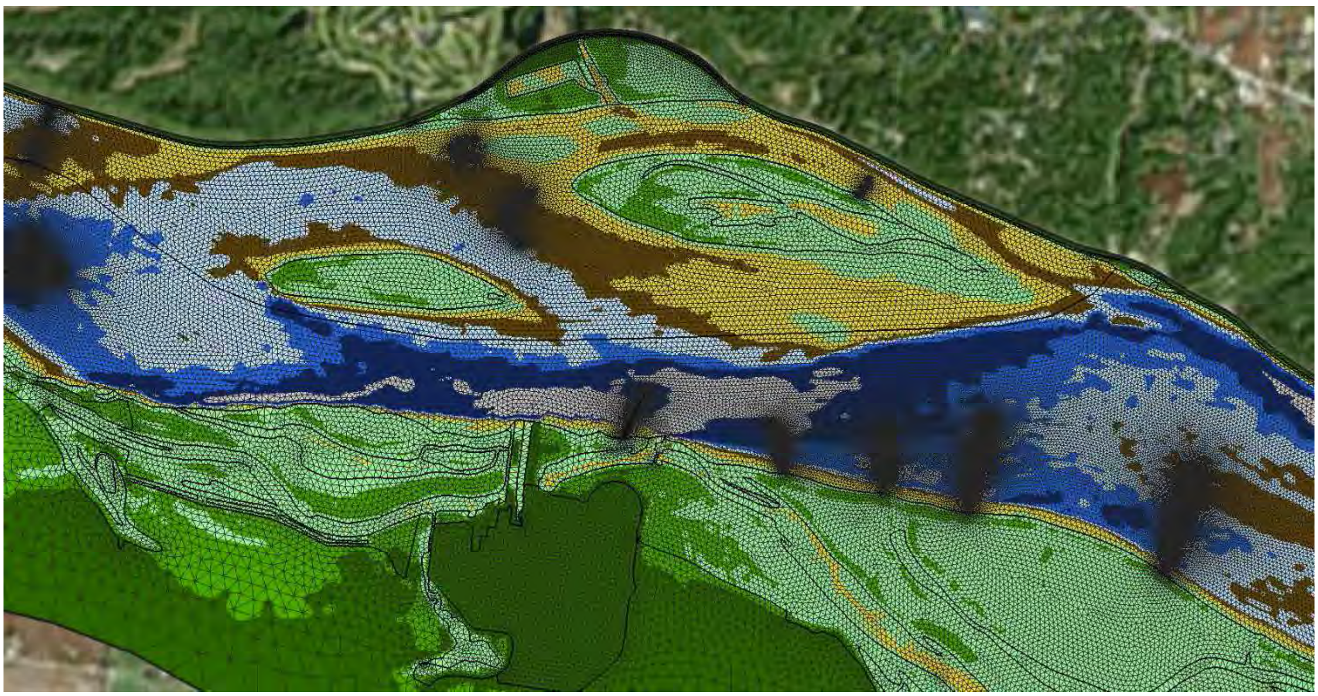
Table 3-5. Grafton Gage Flow Frequency

Frequency	Discharge (cfs)	Stage (elevation in feet NAVD88)
2 yr	212,000	423.92
5 yr	271,000	429.12
10 yr	312,000	430.92

25 yr	372,000	433.82
50 yr	406,000	436.32
100 yr	445,000	438.62
200 yr	491,000	440.72
500 yr	547,000	442.52

3.2.2 Mesh Development

A numerical model mesh was created in order to utilize an AdH model. The mesh file was generated using SMS 11.1.16. The mesh covers the extents of the area being evaluated and is used to define the surface and all features. The extents of the mesh were from approximately RM 218.00 – 201.50. The study area was from approximately RM 212.00 – 207.00 (see Figure 3-3), meaning the AdH model had 6 river miles of entrance conditions and 5.5 river miles of exit conditions. The upstream and downstream



limits of the mesh were far enough away from the study area so that any effects of boundary conditions would be dissipated before reaching the study area. The mesh is generated by using triangular elements and nodes at various spacing. Then, the mesh elements are draped onto an elevation data set to create a surface mesh. The space between nodes were adjusted to change the size of the triangular elements, thus increasing detail as needed in areas such as the structures in the river. See Figure 3-4 for an example of triangular elements and nodes created in SMS.

Figure 3-3. Piasa Island Complex AdH Mesh

Figure 3-4. Surface Mesh Elements

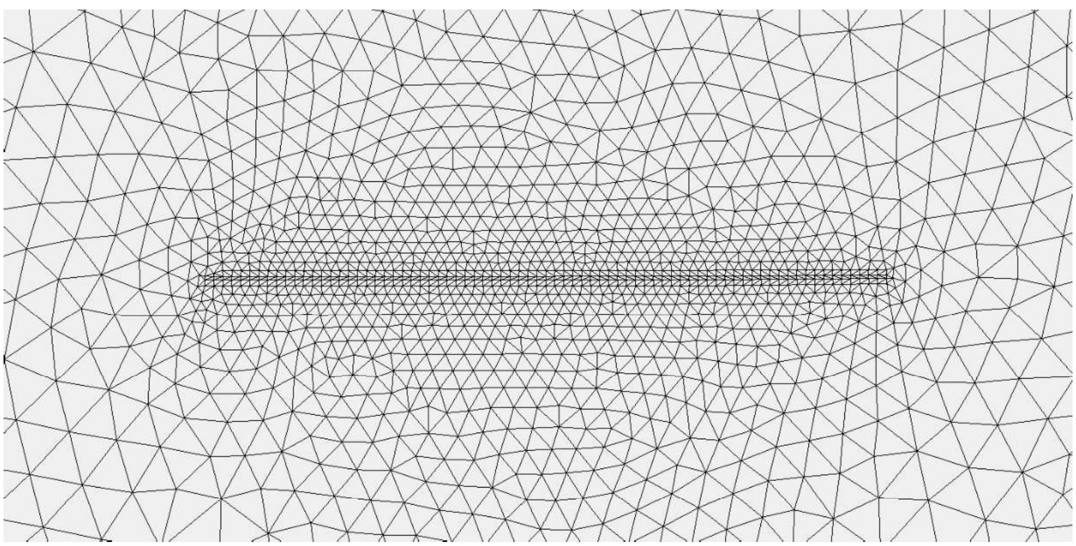
3.2.3 Hot Start Initial Conditions

The hot start initial conditions is used for initial setup and stability of the model. The hot start establishes an initial depth of water and velocity when available. The hot start file used initial depth of water and was established by interpolating between the gage at Grafton and the interpolated WSE at RM 201.5.

3.2.4 Roughness Values

Following the creation of the numerical model mesh file, roughness values were assigned to all elements based on the element's corresponding prototype material type. The material boundaries were based on aerial photography, LiDAR elevation data, and hydrographic survey data. Two roughness types were used to define the friction within the reach: unsubmerged rigid vegetation (URV) and Manning's n-values.

URV is used to compute a shear stress coefficient for computing shear stress through a rigid, unsubmerged vegetation. URV takes into account roughness height, average stem diameter, and



average stem density per unit area.

The initial Manning's n-values were obtained from Open-Channel Hydraulics, (Chow 1959), and were adjusted within acceptable ranges to achieve model calibration. The roughness values used in the model study can be seen in Table 3-5 and Table 3-6, and a map of the materials used in the study can be seen in Figure 3-5 (note: dike rock, revetment rock, road, and bridge pier are difficult to see in the image due to the features' small size).

Table 3-6. Unsubmerged Rigid Vegetation

AdH Material	**Roughness Height (ft)**	**Average Stem Diameter (ft)**	**Average Stem Density (stems/ft^2)**
Trees	0.5	1.5	0.02

Table 3-7. Manning's n-values

AdH Material	Manning's n Roughness Coefficient	Equivalent Roughness Height (feet)
River Channel	0.028	N/A
Backwater Area	0.04	N/A
Farmland	0.028	N/A
Residential Development	0.05	N/A
Commercial Development	0.06	N/A
Dike Rock	N/A	3.0
Revetment Rock	N/A	3.0
Road	0.05	N/A
Bridge Pier	0.025	N/A
Side Channel	0.03	N/A

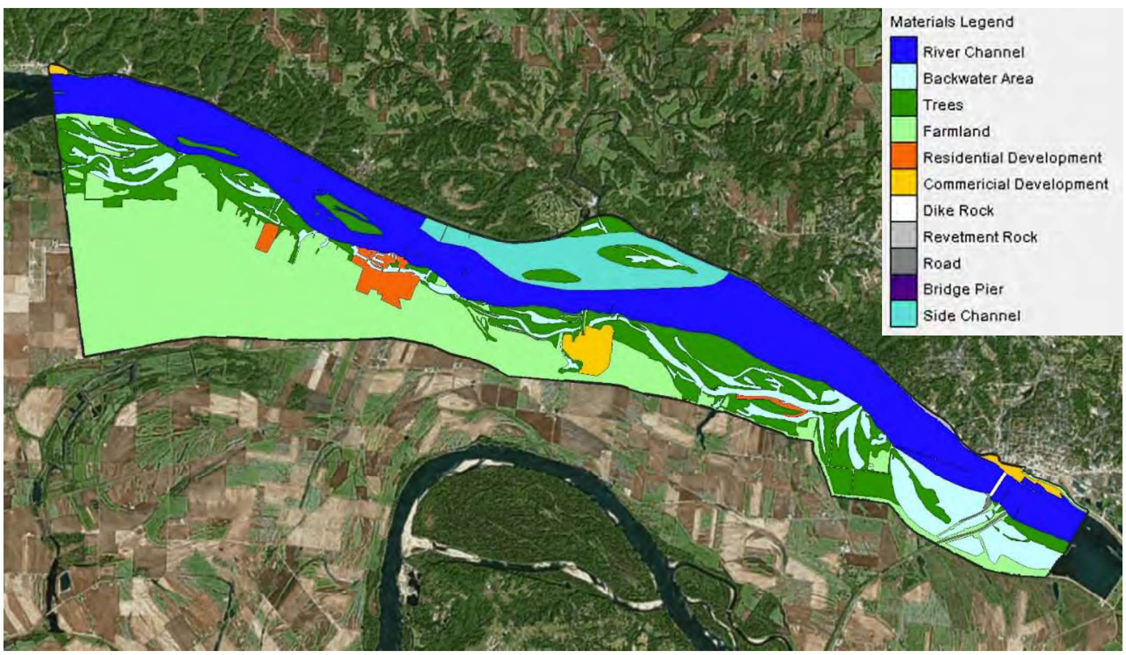


Figure 3-5. Bed Material Map

3.2.5 Computational Environment

The numerical modeling was executed on the U.S. Army Engineer Research and Development Center's (ERDC) High-Performance Computing (HPC) Cray XE6 (Garnet) and SGI ALtix ICE X (Topaz) parallel processing supercomputers. The numerical model was computed with both HPC platforms due to time restrictions and long wait times.

3.2.6 Calibration Results

The AdH model was calibrated by making small adjustments to the roughness values in order to achieve water surface elevations that closely matched those of the same prototype discharges and elevations.

The adjustments to the roughness values were within the range of acceptable use for a river channel of this type. The elevations were compared at the Grafton gage. This comparison of data was used to verify the calibration of the AdH model. Table 3-7 shows that the AdH model's water surface elevations closely matched the elevations observed in the prototype at the various flow conditions. Plate 37 shows the SMS base test for the model.

Table 3-8. Water Surface Elevation Verification

Discharge (ft^3/s)	Gage	Prototype (elevation – ft NAVD88)	AdH (elevation – ft NAVD88)	Difference (ft)
158,900	Grafton	419.08	419.57	-0.49
202,250	Grafton	419.31	419.64	-0.33
247,800	Grafton	421.29	421.35	-0.06
301,500	Grafton	424.16	423.95	0.21
394,500	Grafton	429.43	429.45	-0.02
450,000	Grafton	432.64	432.12	0.52

3.3 Alternative Testing

The alternative tests for the AdH model were heavily informed from the earlier HSR model tests. Each of the 22 AdH alternatives were run a total of 6 times – one for each flow condition, which were 158,900 cfs, 202,250 cfs, 247,800 cfs, 301,500 cfs, 394,500 cfs, and 450,000 cfs. The goal of each alternative was to utilize dredging, river training structures, and strategic placement of dredge material to create both island and shallow water habitat within the Piasa Chute complex. In order to determine if an alternative was successful, engineers analyzed the increase or decrease of discharge through Piasa Chute. A description of each alternative and the representative results can be found on the following pages.

3.3.1 Alternative 1

Alternative 1 (Plate 38) consisted of a 200 foot wide dredge cut through Piasa Chute, multiple dredge disposal locations, and two river training structures. The dredge cut through Piasa Chute consisted of removing bed material until an elevation of 405.11 ft was achieved. The dredge cut started and ended at the upper and lower ends of Piasa Chute where existing bathymetry matched the desired 405.11 ft elevation of the dredge cut. The dredge material was placed within Piasa Chute where high elevation areas already existed in the prototype leading to island habitat creation. A chevron was placed near RM 209.8 along the LDB at the upper end of Piasa Chute to protect the new island habitat from erosion. Furthermore, a dike was placed along the RDB of Piasa Chute near RM 208.50 to help protect the downstream disposal location within Piasa Chute. Figure 3-6 compares the Alternative and base test discharges within Piasa Chute.

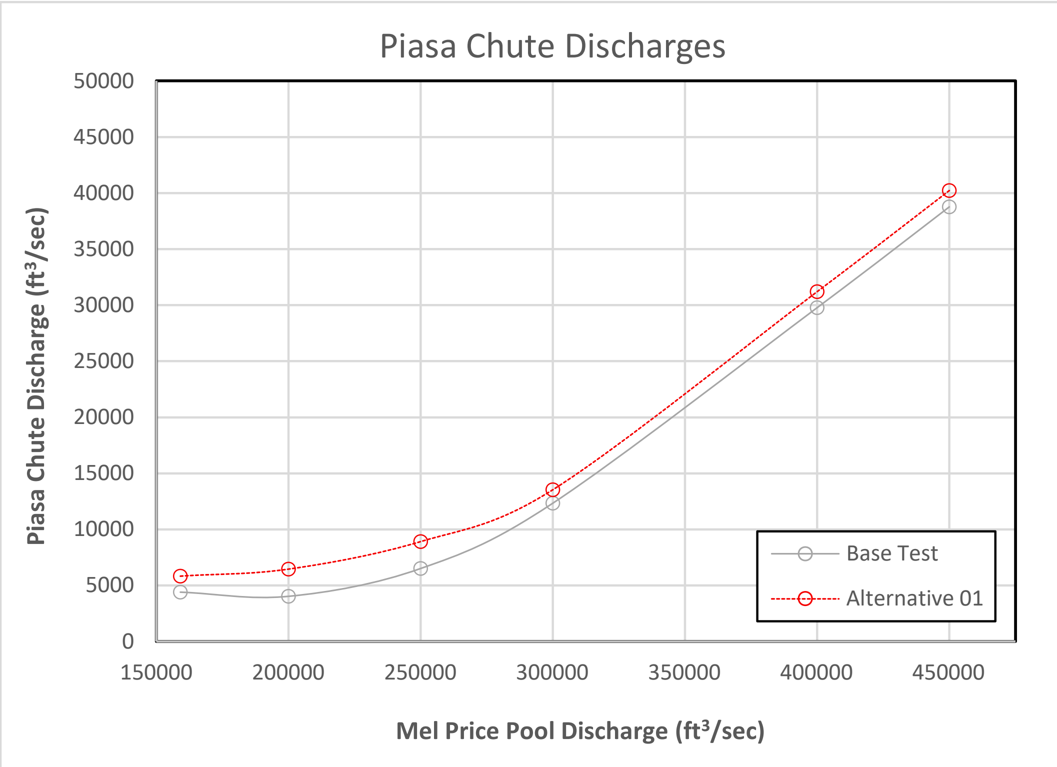


Figure 3-6. Piasa Chute Discharge (Alternative 01 vs Base Test)

3.3.2 Alternative 2

Alternative 2 (Plate 39) consisted of a 200 foot wide dredge cut through Piasa Chute and multiple dredge disposal locations. The dredge cut through Piasa Chute consisted of removing bed material until an elevation of 405.1 ft was achieved. The dredge cut started and ended at the upper and lower ends of Piasa Chute where existing bathymetry matched the desired 405.1 ft elevation of the dredge cut. The dredge material was placed within Piasa Chute where high elevation bars already existed in the prototype leading to island habitat creation. Figure 3-7 compares the Alternative and base test discharges within Piasa Chute.

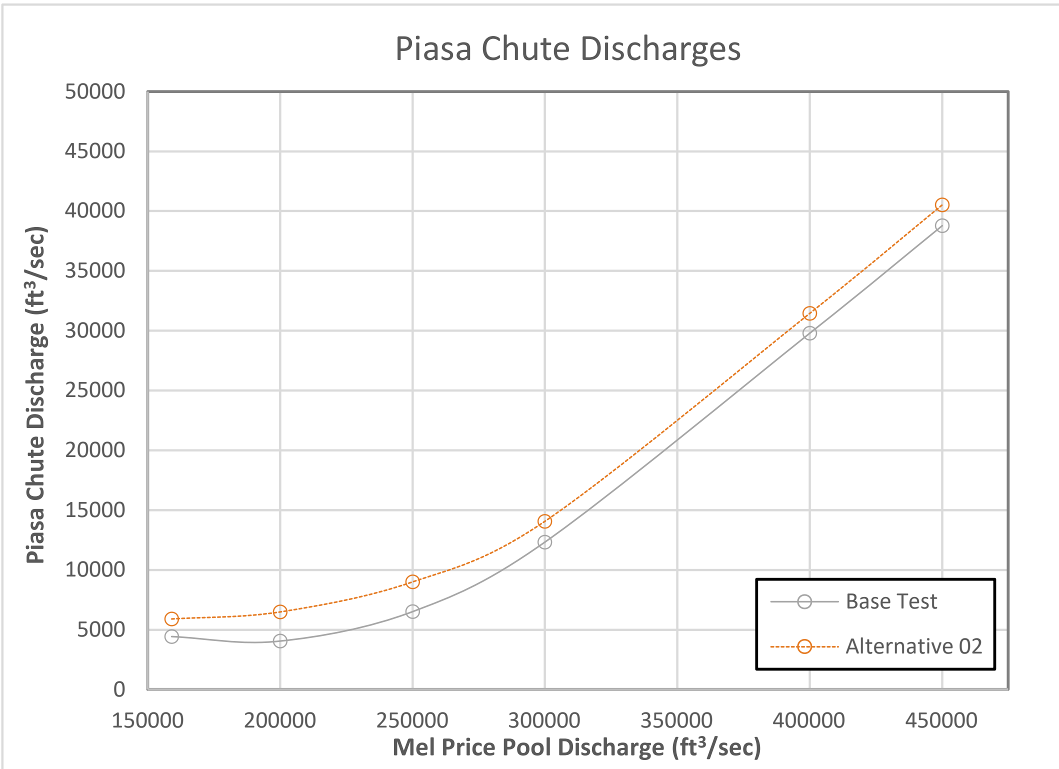


Figure 3-7. Piasa Chute Discharge (Alternative 02 vs Base Test)

3.3.3 Alternative 3

Alternative 3 (Plate 40) consisted of a 200 foot wide dredge cut through Piasa Chute and a single dredge disposal location. The dredge cut through Piasa Chute consisted of removing bed material until an elevation of 405.1 ft was achieved. The dredge cut started and ended at the upper and lower ends of Piasa Chute where existing bathymetry matched the desired 405.1 ft elevation of the dredge cut. The dredge material was placed between Piasa and Eagle's Nest Islands leading to island habitat creation. A chevron structure was placed upstream of the new island habitat in order to protect it from erosion. Figure 3-8 compares the Alternative and base test discharges within Piasa Chute.

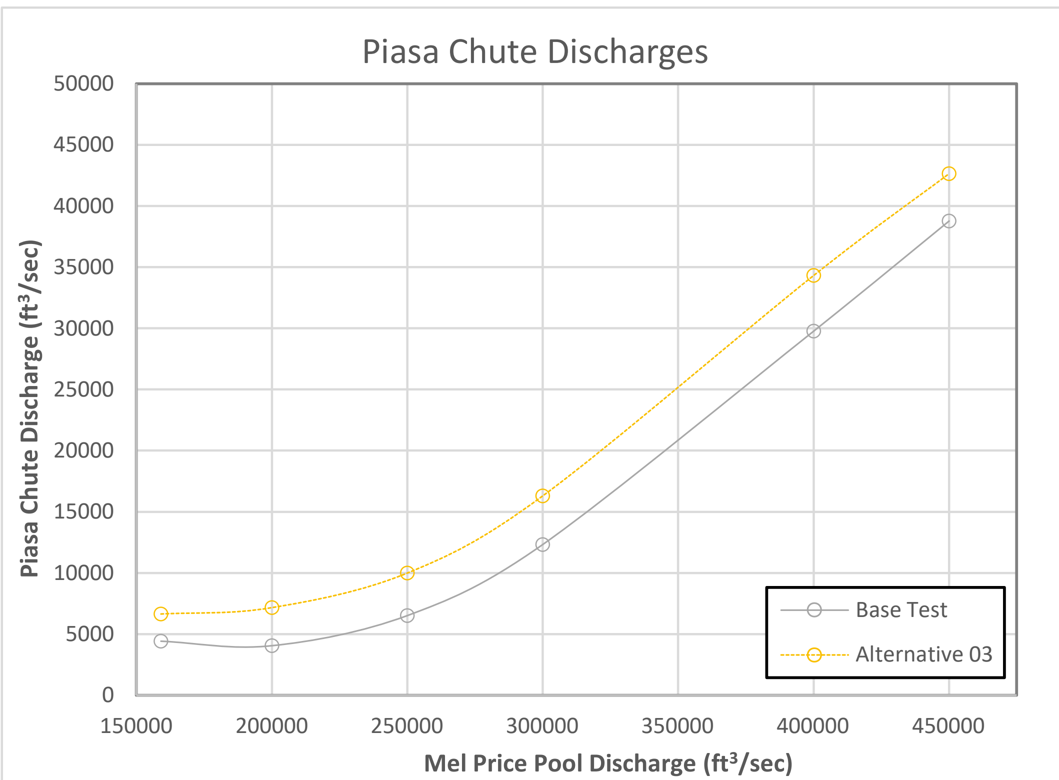


Figure 3-8. Piasa Chute Discharge (Alternative 03 vs Base Test)

3.3.4 Alternative 4

Alternative 4 (Plate 41) consisted of a 200 foot wide dredge cut through Piasa Chute and a single dredge disposal location. The dredge cut through Piasa Chute consisted of removing bed material until an elevation of 405.1 ft was achieved. The dredge cut started and ended at the upper and lower ends of Piasa Chute where existing bathymetry matched the desired 405.1 ft elevation of the dredge cut. The dredge material was placed on the lower end of the main channel side of Piasa Island leading to the creation of island habitat. Figure 3-9 compares the Alternative and base test discharges within Piasa chute.

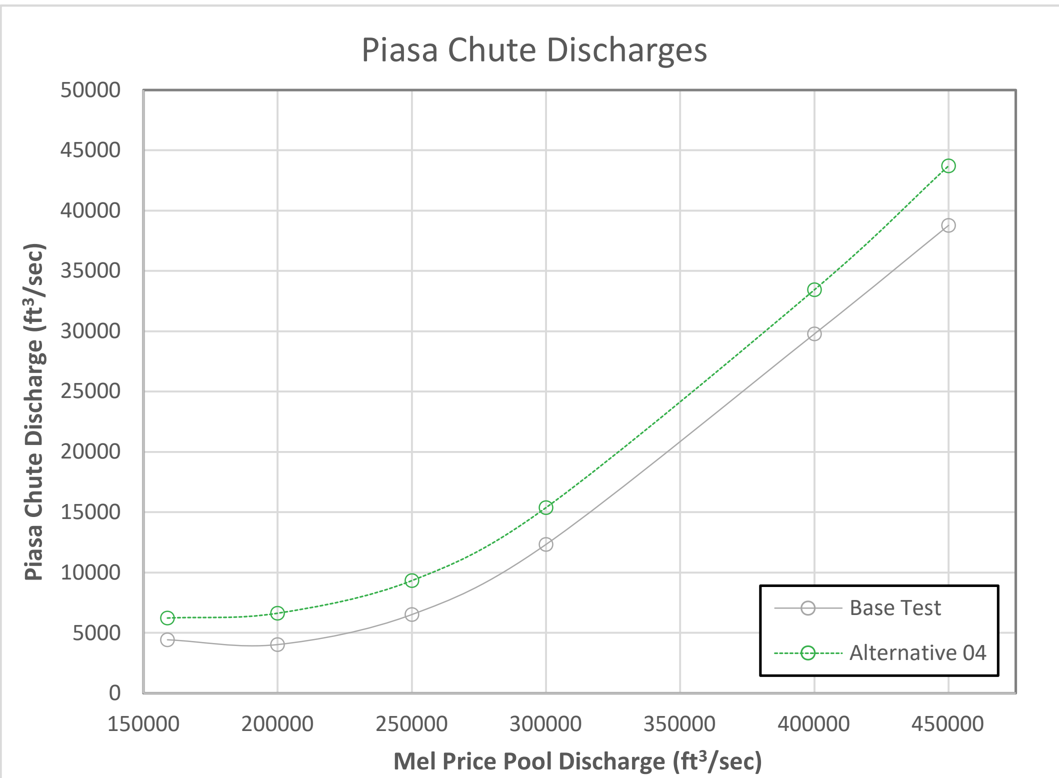


Figure 3-9. Piasa Chute Discharge (Alternative 04 vs Base Test)

3.3.5 Alternative 5

Alternative 5 (Plate 42) consisted of a 300 foot wide dredge cut through the sediment wave located along the LDB upstream of the Piasa Island complex. The dredge cut consisted of removing bed material until an elevation of 405.1 ft was achieved. The dredge cut started and ended at the upper and lower ends of sediment wave where existing bathymetry matched the desired 405.1 ft elevation of the dredge cut. The dredge material was placed between Piasa and Eagle's Nest Islands leading to island habitat creation. A chevron was placed upstream of the new island habitat in order to protect it from erosion. Figure 3-10 compares the Alternative and base test discharges within Piasa chute.

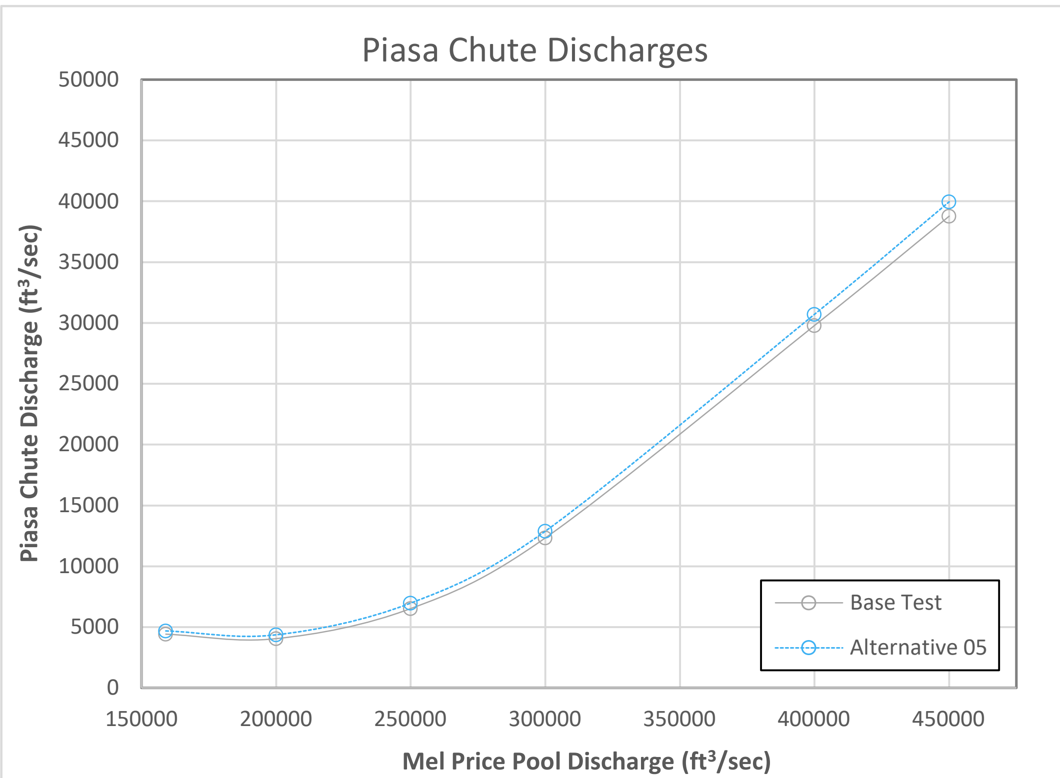


Figure 3-10. Piasa Chute Discharge (Alternative 05 vs Base Test)

3.3.6 Alternative 6

Alternative 6 (Plate 43) consisted of a 300 foot wide braided dredge cut through Piasa Chute and multiple dredge disposal locations. The 'braided' term describes the way the dredge cut exists between high elevation areas creating a more natural braided channel. The dredge cut consisted of removing bed material until an elevation of 405.1 ft was achieved. The dredge cut started and ended at the upper and lower ends of Piasa Chute where existing bathymetry matched the desired 405.1 ft elevation of the dredge cut. The dredge material was placed to create island habitat in multiple locations: within Piasa Chute where high elevation areas already existed, on the lower end of the main channel side of Piasa Island, and upstream of the Piasa Island complex along the LDB. Structures were placed on the downstream side of the new island habitat on the upper end of the Piasa Island Complex and within Piasa Chute to assist in stabilizing and retaining the shape of the new habitat feature. The island habitat created on the main channel side of Piasa Island was not protected since that location was a low bed shear area, meaning less erosion and scour is expected. Figure 3-11 compares the Alternative and base test discharges within Piasa chute.

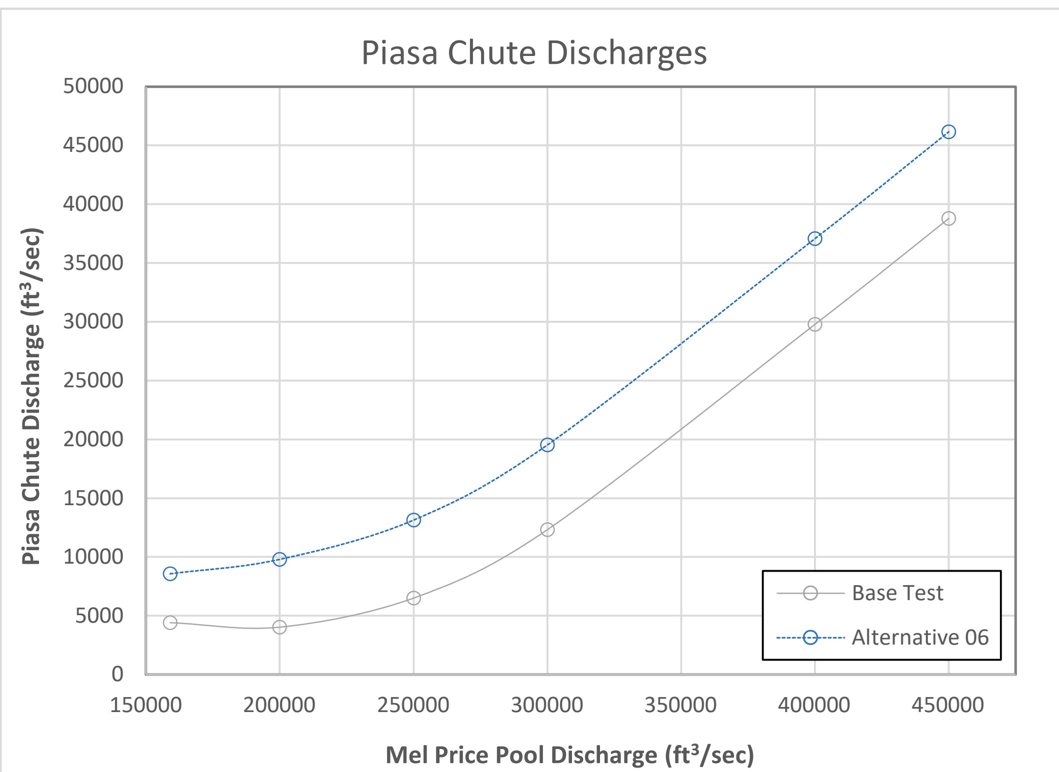


Figure 3-11. Piasa Chute Discharge (Alternative 06 vs Base Test)

3.3.7 Alternative 7

Alternative 7 (Plate 44) consisted of a 200 foot wide braided dredge cut through Piasa Chute and multiple dredge disposal locations. The 'braided' term describes the way the dredge cut exists between high elevation areas creating a more natural braided channel. The dredge cut consisted of removing bed material until an elevation of 405.1 ft was achieved. The dredge cut started and ended at the upper and lower ends of Piasa Chute where existing bathymetry matched the desired 405.1 ft elevation of the dredge cut. The dredge material was placed to create island habitat in multiple locations: within Piasa Chute where high elevation areas already existed, on the lower end of the main channel side of Piasa Island, and upstream of the Piasa Island complex along the LDB. Structures were placed on the downstream side of the new island habitat on the upper end of the Piasa Island Complex and within Piasa Chute to assist in stabilizing and retaining the shape of the new habitat feature. The island habitat created on the main channel side of Piasa Island was not protected since that location was a low bed shear area, meaning less erosion and scour is expected. Figure 3-12 compares the Alternative and base test discharges within Piasa chute.

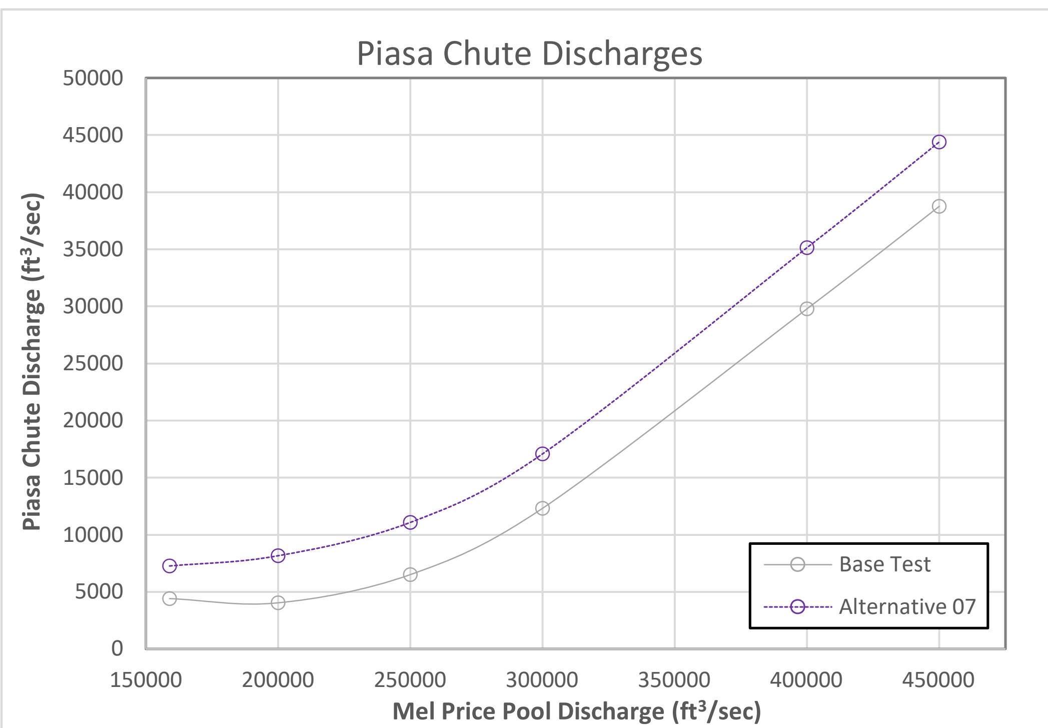


Figure 3-12. Piasa Chute Discharge (Alternative 07 vs Base Test)

3.3.8 Alternative 8

Alternative 8 (Plate 45) consisted of a 300 foot wide dredge cut through Piasa Chute and a single dredge disposal location. The dredge cut through Piasa Chute consisted of removing bed material until an elevation of 405.1 ft was achieved. The dredge cut started and ended at the upper and lower ends of Piasa Chute where existing bathymetry matched the desired 405.1 ft elevation of the dredge cut. The dredge material was placed on the lower end of the main channel side of Piasa Island leading to the creation of island habitat. The island habitat created was not protected since that location was a low bed shear area, meaning less erosion and scour is expected. Figure 3-13 compares the Alternative and base test discharges within Piasa Chute.

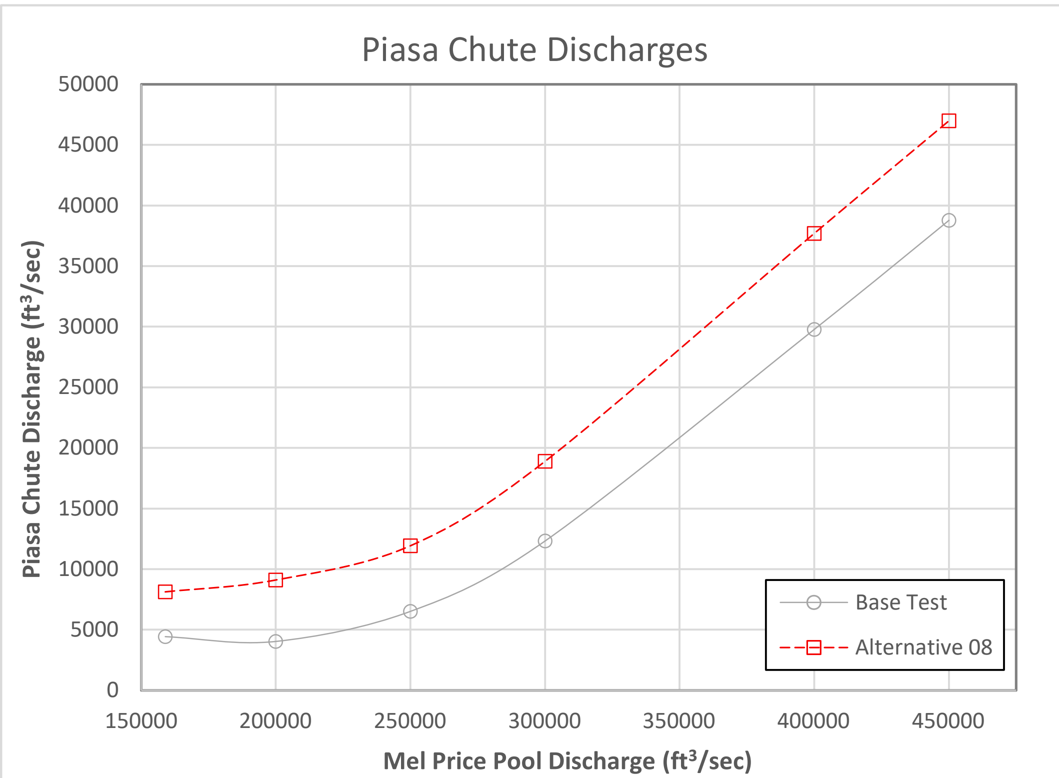


Figure 3-13. Piasa Chute Discharge (Alternative 08 vs Base Test)

3.3.9 Alternative 9

Alternative 9 (Plate 46) consisted of a structure to contain the existing sediment wave upstream of the Piasa Island complex. Furthermore, the structure would provide a disruption to any additional sediment entering the project area in the future. Figure 3-14 compares the Alternative and base test discharges within Piasa Chute.

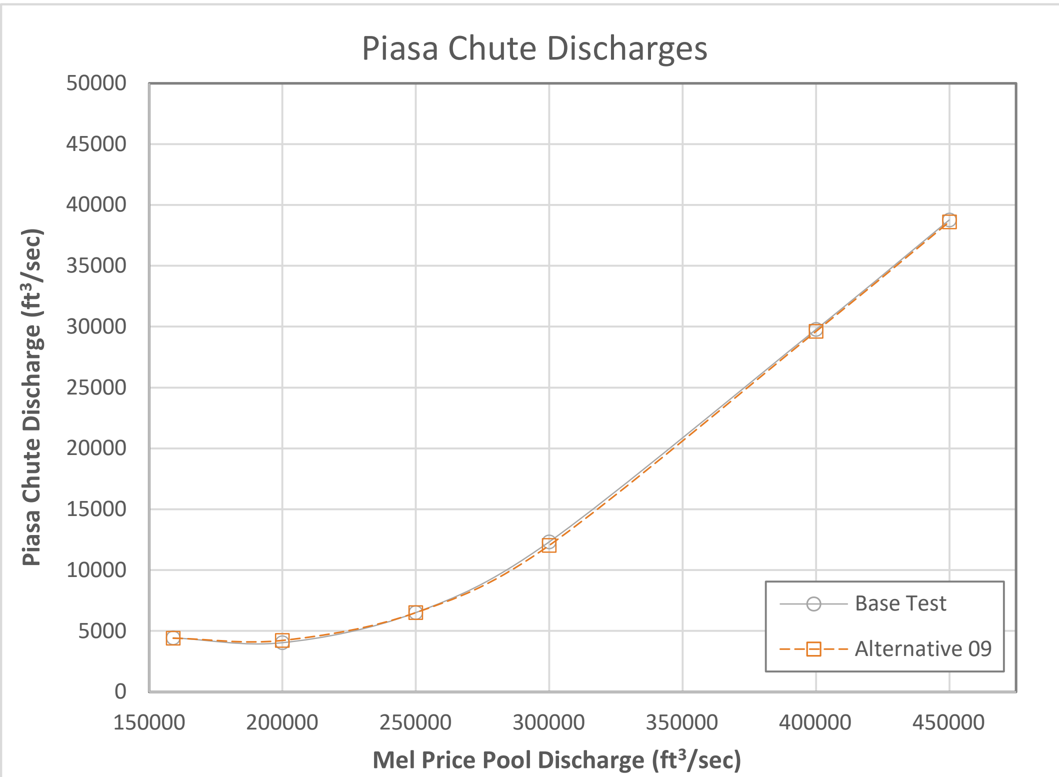


Figure 3-14. Piasa Chute Discharge (Alternative 09 vs Base Test)

3.3.10 Alternative 10

Alternative 10 (Plate 47) consisted of a notched structure between Piasa and Eagle's Nest Islands. A majority of the discharge through the Piasa Island complex exits between the two islands, so the goal of the notched structure was to direct more discharge through Piasa Chute while still allowing a small amount of flow to exit the complex between the islands. Figure 3-15 compares the Alternative and base test discharges within Piasa Chute.

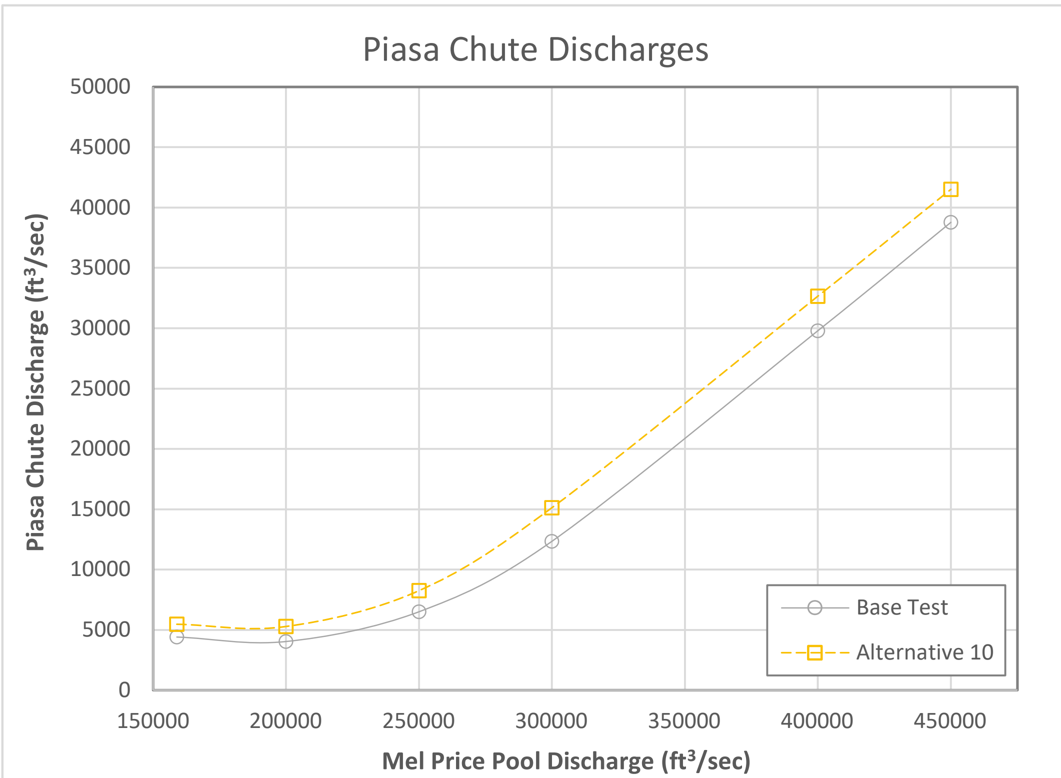


Figure 3-15. Piasa Chute Discharge (Alternative 10 vs Base Test)

3.3.11 Alternative 11

Alternative 11 (Plate 48) consisted of a 200 foot braided dredge cut with multiple dredge disposal locations. The 'braided' term describes the way the dredge cut exists between exist-ing high elevation areas creating a more natural braided channel. The dredge cut through Piasa Chute consisted of removing bed material until an elevation of 405.1 ft was achieved. The dredge cut started and ended at the upper and lower ends of Piasa Chute where existing bathymetry matched the desired 405.1 ft elevation of the dredge cut. The dredge material was placed to create island habitat in multiple loca-tions: within Piasa Chute where high elevation areas already existed, on the lower end of the main channel side of Piasa Island, and upstream of the Piasa Island complex along the LDB. Structures were placed on the downstream side of the new islands to assist in stabilizing and retaining the shape of the new habitat feature. The island habitat created on the main channel side of Piasa Island was not protected since that location was a low bed shear area, meaning less erosion and scour is expected. Figure 3-16 compares the Alternative and base test discharges within Piasa Chute.

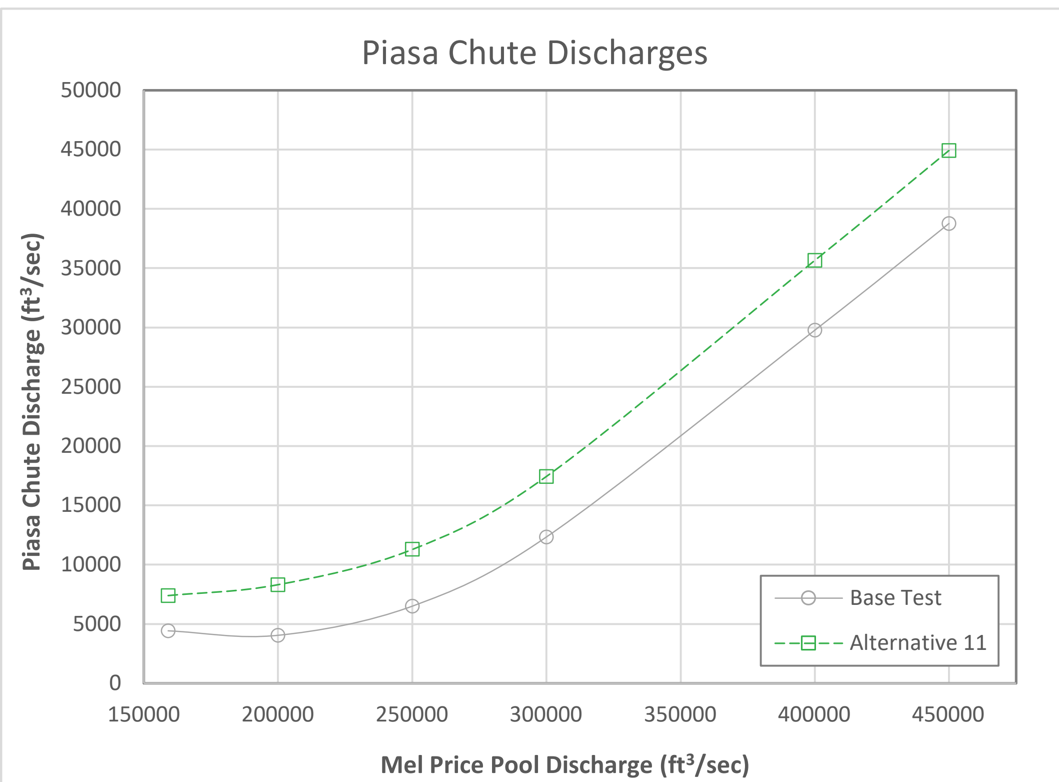


Figure 3-16. Piasa Chute Discharge (Alternative 11 vs Base Test)

3.3.12 Alternative 12

Alternative 12 (Plate 49) consisted of a 300 foot dredge cut within Piasa Chute, a dredge cut within the Piasa Island backwater area, and a disposal location. The dredge cut through Piasa Chute consisted of removing bed material until an elevation of 405.1 ft was achieved while the dredging in the Piasa Island backwater area was dredged to an elevation of 414.6 ft. The Piasa Chute dredge cut started and ended at the upper and lower ends of Piasa Chute where existing bathymetry matched the desired 405.1 ft elevation of the dredge cut. The backwater dredging started from the 414.6 ft elevation in the Piasa Island backwater area and cut through the existing island to meet a 414.6 ft elevation on the main channel side of Piasa Island. The dredge material was placed on the lower end of the main channel side of Piasa Island leading to the creation of island habitat. The island habitat created on the main channel side of Piasa Island was not protected since that location was a low bed shear area, meaning less erosion and scour is expected. Figure 3-17 compares the Alternative and base test discharges within Piasa Chute.

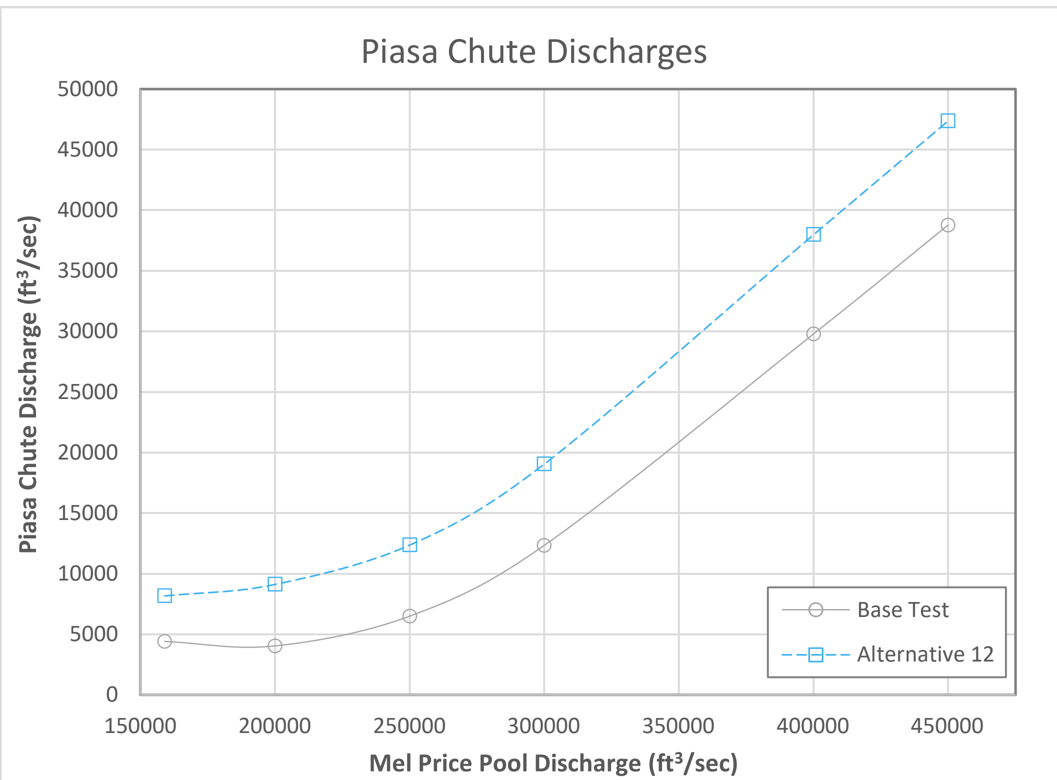


Figure 3-17. Piasa Chute Discharge (Alternative 12 vs Base Test)

3.3.13 Alternative 13

Alternative 13 (Plate 50) consisted of a 300 foot braided dredge cut within Piasa Chute, a dredge cut within the Piasa Island backwater area, and multiple disposal locations. The dredge cut through Piasa Chute and within the Piasa Island backwater area consisted of removing bed material until an elevation of 405.1 ft was achieved. The Piasa Chute dredge cut started and ended at the upper and lower ends of Piasa Chute where existing bathymetry matched the desired 405.1 ft elevation of the dredge cut. The backwater dredging started where the backwater area meets the Piasa Chute dredging and continued through the backwater area where backwater is typically present. The dredge material was placed to create island habitat in multiple locations: on the lower end of the main channel side of Piasa Island and upstream of the Piasa Island complex along the LDB. A structure was placed on the downstream side of the upstream island habitat to assist in stabilizing and retaining the shape of the new habitat feature. The island habitat created on the main channel side of Piasa Island was not protected since that location was a low bed shear area, meaning less erosion and scour is expected. Figure 3-18 compares the Alternative and base test discharges within Piasa Chute.

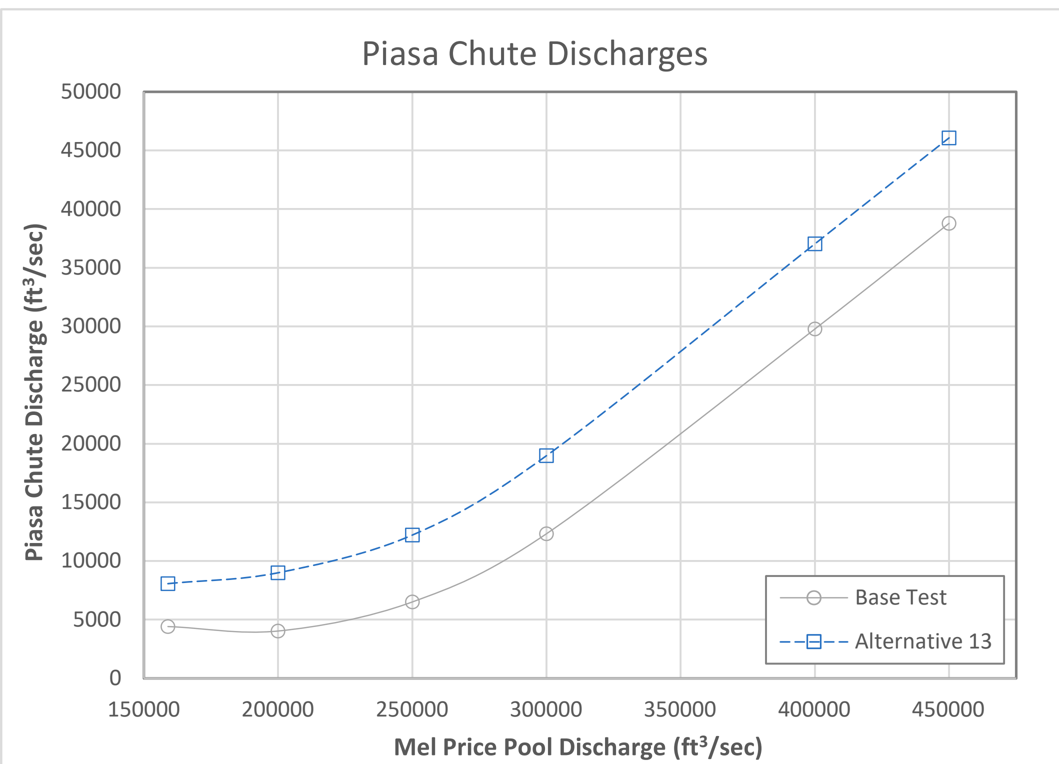


Figure 3-18. Piasa Chute Discharge (Alternative 13 vs Base Test)

3.3.14 Alternative 14

Alternative 14 (Plate 51) consisted of a structure between Piasa and Eagle's Nest Islands. A majority of the discharge through the Piasa Island complex exits between the two islands, so the goal of the notched structure was to direct more discharge through Piasa Chute. Figure 3-19 compares the Alternative and base test discharges within Piasa Chute.

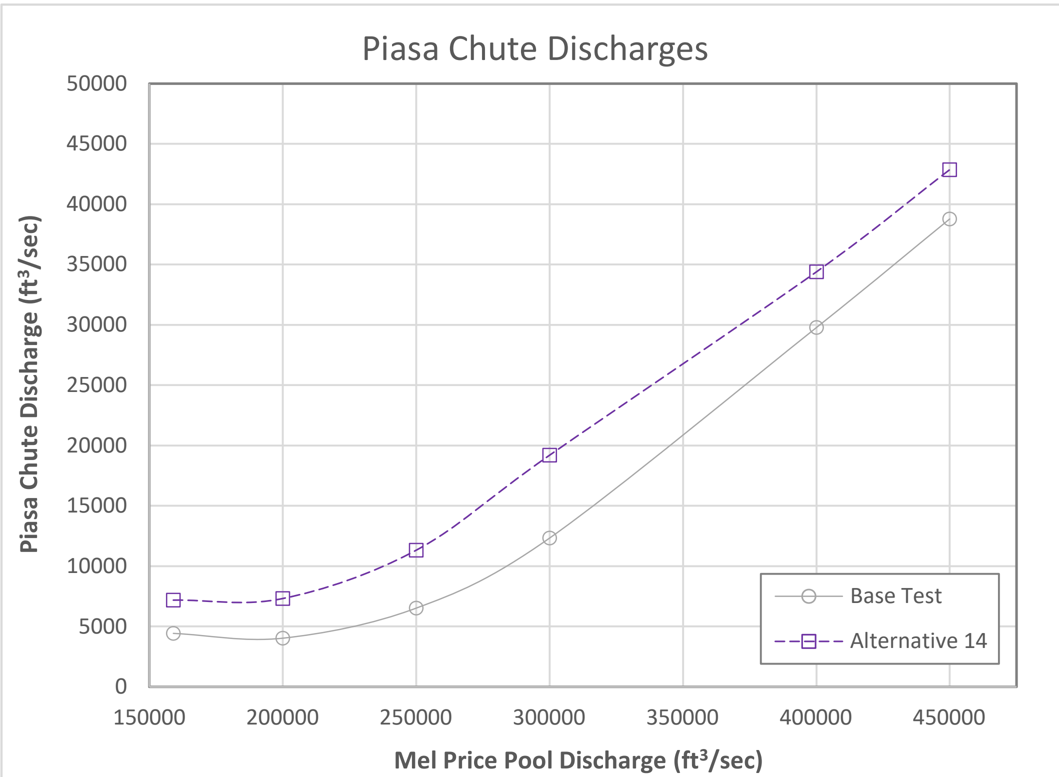


Figure 3-19. Piasa Chute Discharge (Alternative 14 vs Base Test)

3.3.15 Alternative 15

Alternative 15 (Plate 52) consisted of two low elevation structures placed on the side channel side of Eagle's Nest Island. A majority of the discharge through the Piasa Island complex exits between the two islands, so the goal of the low structures was to divert some of the discharge through Piasa Chute while allowing the rest of the flow to continue between the two islands. Figure 3-20 compares the Alternative and base test discharges within Piasa Chute.

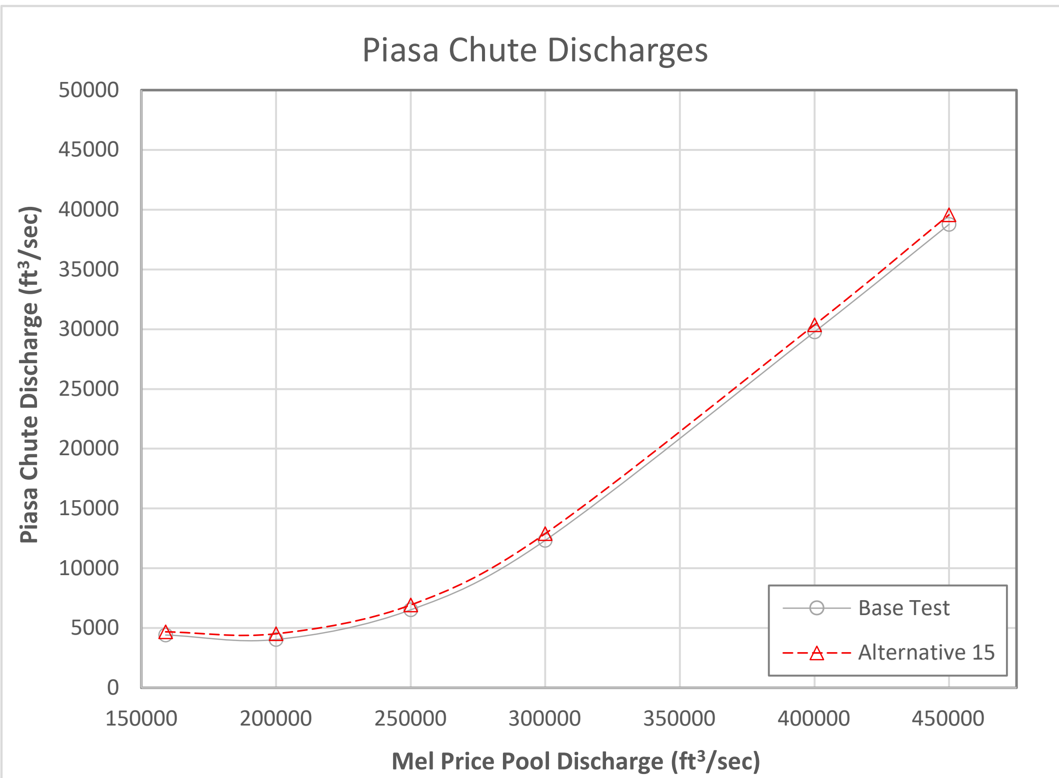


Figure 3-20. Piasa Chute Discharge (Alternative 15 vs Base Test)

3.3.16 Alternative 16

Alternative 16 (Plate 53) consisted of a low elevation structure placed between Eagle's Nest Island and the Illinois bankline. The structure was tested in order to inform the PDT of the discharge impacts through Piasa Chute if a low elevation structure were placed at the entrance to the Piasa Island complex in order to disrupt any future sediment waves entering the project area. Figure 3-21 compares the Alternative and base test discharges within Piasa Chute.

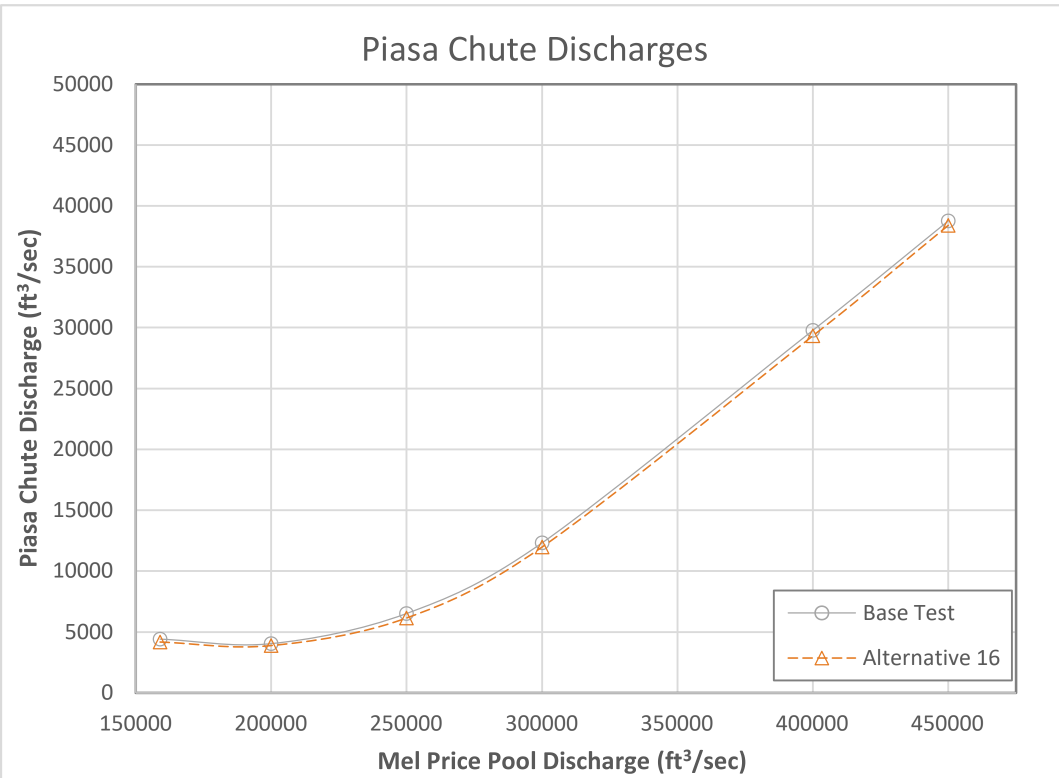


Figure 3-21. Piasa Chute Discharge (Alternative 16 vs Base Test)

3.3.17 Alternative 17

Alternative 17 (Plate 54) consisted of a curved structure placed between the head of Eagle's Nest Island and the Illinois bankline. The structure was placed to create a backwater area in the Piasa Island complex which would block off flow and any sediment entering Piasa Chute. The PDT was determining if a dredge cut in Piasa Chute could be expected to last longer with a drastic change to the amount of flow entering the side channel. However, during the test, water from the main channel entered the side channel complex between Piasa and Eagle's Nest Islands and then went through Piasa Chute. However, the discharge through Piasa chute was less than in the base condition, leading the PDT to believe that any sediment being carried in with the water would fall out in the side channel causing increased elevations. Figure 3-22 compares the Alternative and base test discharges within Piasa Chute.

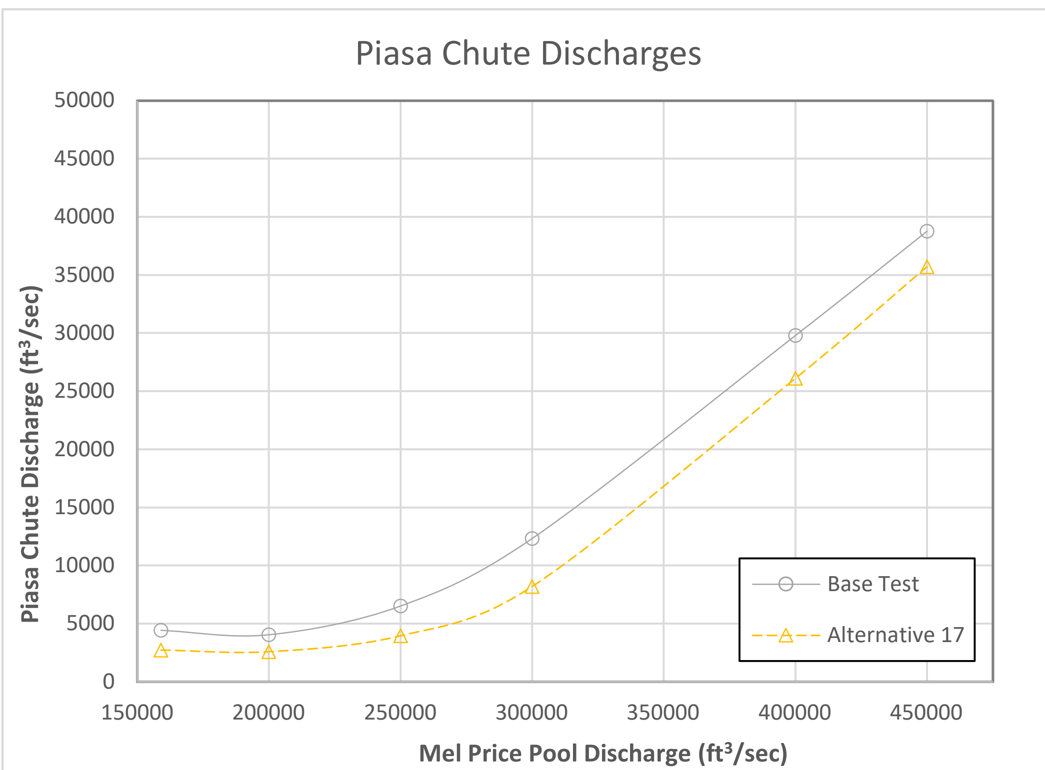


Figure 3-22. Piasa Chute Discharge (Alternative 17 vs Base Test)

3.3.18 Alternative 18

Alternative 18 (Plate 55) consisted of a structure placed between the head of Eagle's Nest Island and the Illinois bankline. The structure was placed to create a backwater area in the Piasa Island complex which would block off flow and any sediment entering Piasa Chute. The PDT was determining if a dredge cut in Piasa Chute could be expected to last longer with a drastic change to the amount of flow entering the side channel. However, during the test, water from the main channel entered the side channel complex between Piasa and Eagle's Nest Islands and then went through Piasa Chute. However, the discharge through Piasa chute was less than in the base condition, leading the PDT to believe that any sediment being carried in with the water would fall out in the side channel causing increased elevations. Figure 3-23 compares the Alternative and base test discharges within Piasa Chute.

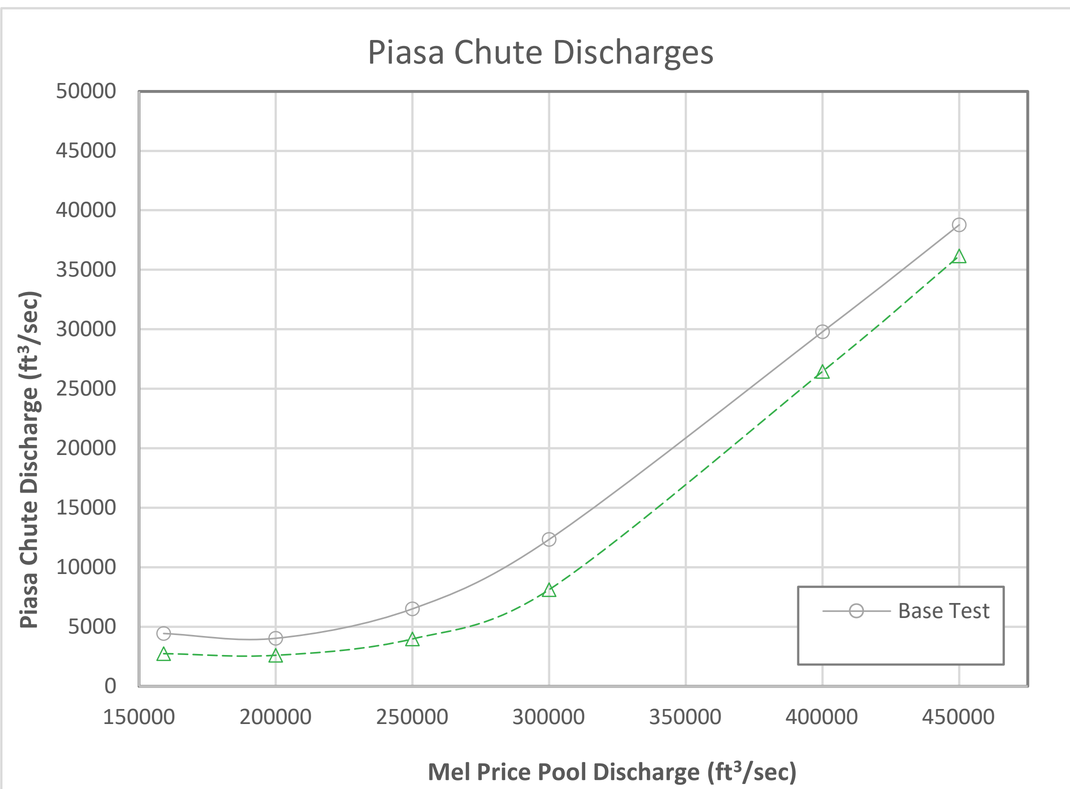


Figure 3-23. Piasa Chute Discharge (Alternative 18 vs Base Test)

3.3.19 Alternative 19

Alternative 19 (Plate 56) consisted of a 200 foot wide braided dredge cut through Piasa Chute, a notched rock structure, and multiple dredge disposal locations. The 'braided' term describes the way the dredge cut exists between existing high elevation areas creating a more natural braided channel. The dredge cut through Piasa Chute consisted of removing bed material until an elevation of 405.1 ft was achieved. The dredge cut started and ended at the upper and lower ends of Piasa Chute where existing bathymetry matched the desired 405.1 ft elevation of the dredge cut. The notched structure was placed between Piasa and Eagle's Nest Islands to direct more discharge through Piasa Chute while still allowing a small amount of flow to exit the complex between the islands. The dredge material was placed to create island habitat in multiple locations: within Piasa Chute where high elevation areas already existed, on the lower end of the main channel side of Piasa Island, and upstream of the Piasa Island complex tied into the LDB. Structures were placed on the downstream side of the new islands to assist in stabilizing and retaining the shape of the new habitat feature. The island habitat created on the main channel side of Piasa Island was not protected since that location was a low bed shear area, meaning less erosion and scour is expected. Figure 3-24 compares the Alternative and base test discharges within Piasa Chute.

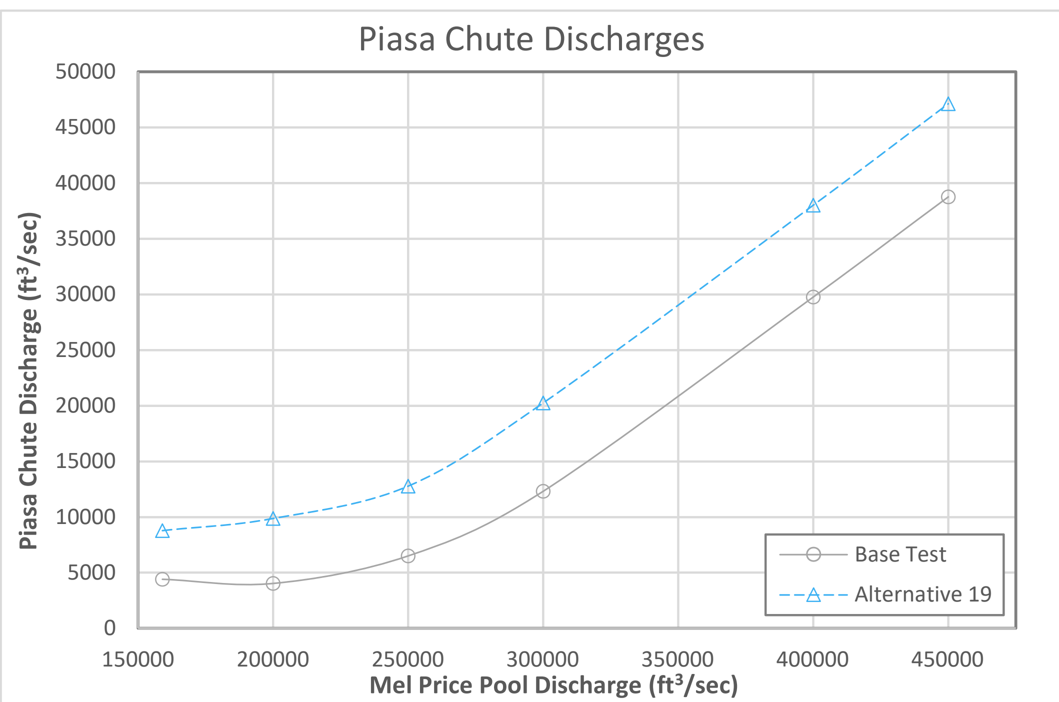


Figure 3-24. Piasa Chute Discharge (Alternative 19 vs Base Test)

3.3.20 Alternative 20

Alternative 20 (Plate 57) consisted of a 300 foot wide braided dredge cut through Piasa Chute, a notched rock structure, and multiple dredge disposal locations. The 'braided' term describes the way the dredge cut exists between existing high elevation areas creating a more natural braided channel. The dredge cut through Piasa Chute consisted of removing bed material until an elevation of 405.1 ft was achieved. The dredge cut started and ended at the upper and lower ends of Piasa Chute where existing bathymetry matched the desired 405.1 ft elevation of the dredge cut. The notched structure was placed between Piasa and Eagle's Nest Islands to direct more discharge through Piasa Chute while still allowing a small amount of flow to exit the complex between the islands. The dredge material was placed to create island habitat in multiple locations: within Piasa Chute where high elevation areas already existed, on the lower end of the main channel side of Piasa Island, and upstream of the Piasa Island complex tied into the LDB. Structures were placed on the downstream side of the new islands to assist in stabilizing and retaining the shape of the new habitat feature. The island habitat created on the main channel side of Piasa Island was not protected since that location was a low bed shear area, meaning less erosion and scour is expected. Figure 3-25 compares the Alternative and base test discharges within Piasa Chute.

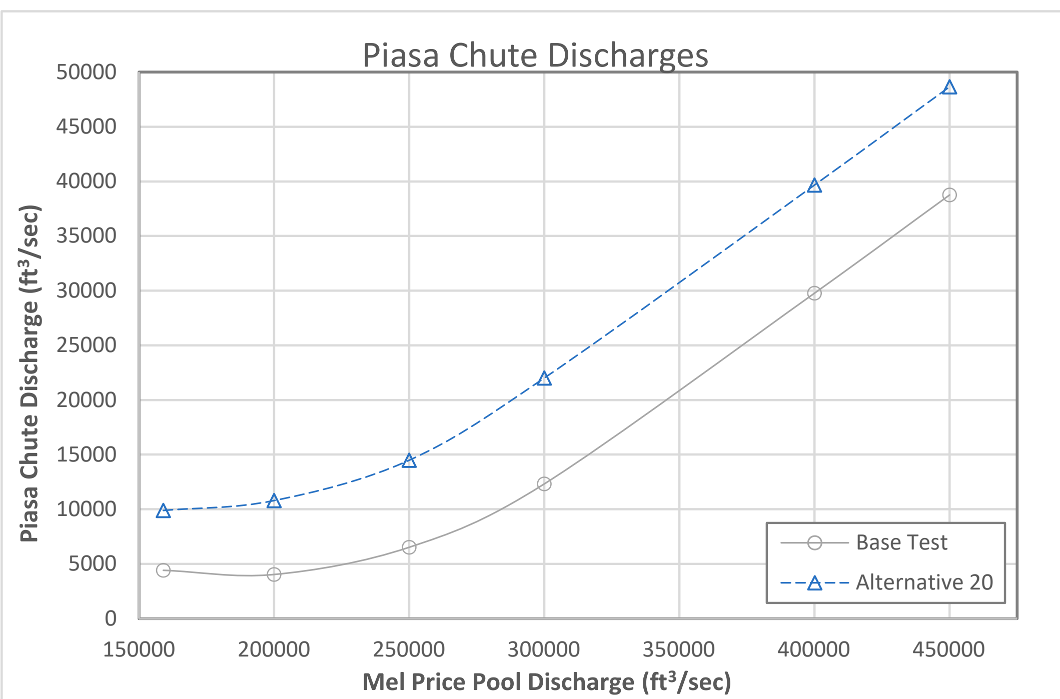


Figure 3-25. Piasa Chute Discharge (Alternative 20 vs Base Test)

3.3.21 Alternative 21

Alternative 21 (Plate 58) consisted of a 200 foot wide braided dredge cut through Piasa Chute, a notched rock structure, and multiple dredge disposal locations. The 'braided' term describes the way the dredge cut exists between existing high elevation areas creating a more natural braided channel. The dredge cut through Piasa Chute consisted of removing bed material until an elevation of 405.1 ft was achieved. The dredge cut started and ended at the upper and lower ends of Piasa Chute where existing bathymetry matched the desired 405.1 ft elevation of the dredge cut. The notched structure was placed between Piasa and Eagle's Nest Islands to direct more discharge through Piasa Chute while still allowing a small amount of flow to exit the complex between the islands. The dredge material was placed to create island habitat in multiple locations: within Piasa Chute where high elevation areas already existed, on the lower end of the main channel side of Piasa Island, and upstream of the Piasa Island complex along the LDB. Structures were placed on the downstream side of the new islands to assist in stabilizing and retaining the shape of the new habitat feature. The island habitat created on the main channel side of Piasa Island was not protected since that location was a low bed shear area, meaning less erosion and scour is expected. Figure 3-26 compares the Alternative and base test discharges within Piasa Chute.

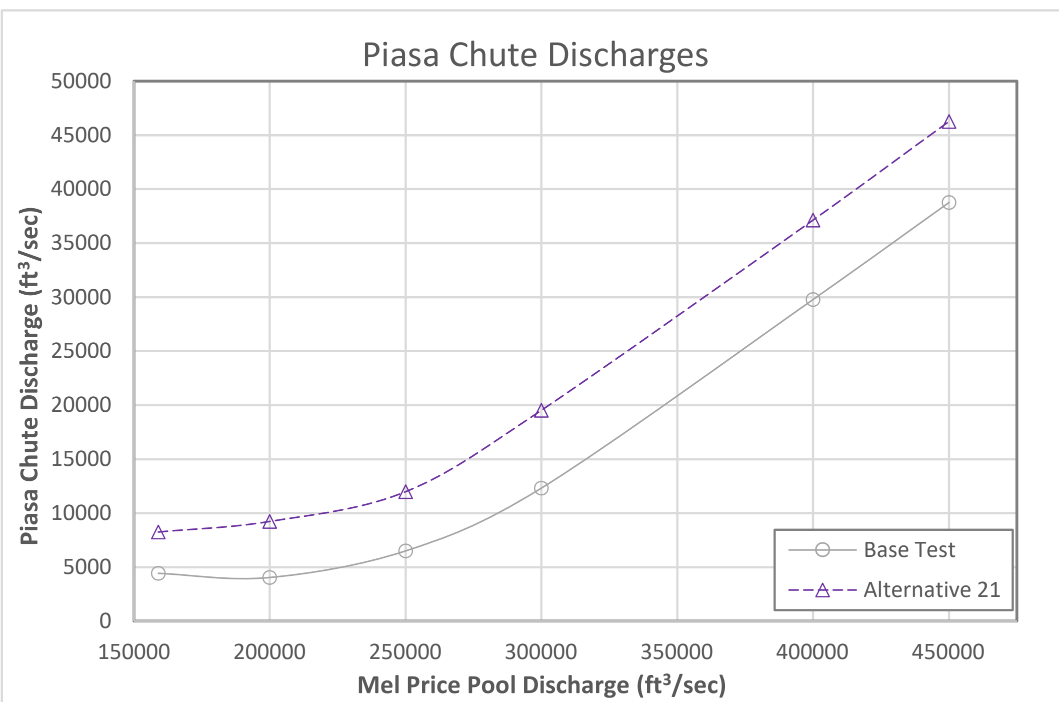


Figure 3-26. Piasa Chute Discharge (Alternative 21 vs Base Test)

3.3.22 Alternative 22

Alternative 22 (Plate 59) consisted of a 300 foot wide braided dredge cut through Piasa Chute, a notched rock structure, and multiple dredge disposal locations. The 'braided' term describes the way the dredge cut exists between existing high elevation areas creating a more natural braided channel. The dredge cut through Piasa Chute consisted of removing bed material until an elevation of 405.1 ft was achieved. The dredge cut started and ended at the upper and lower ends of Piasa Chute where existing bathymetry matched the desired 405.1 ft elevation of the dredge cut. The notched structure was placed between Piasa and Eagle's Nest Islands to direct more discharge through Piasa Chute while still allowing a small amount of flow to exit the complex between the islands. The dredge material was placed to create island habitat in multiple locations: within Piasa Chute where high elevation areas already existed, on the lower end of the main channel side of Piasa Island, and upstream of the Piasa Island complex along the LDB. Structures were placed on the downstream side of the new islands to assist in stabilizing and retaining the shape of the new habitat feature. The island habitat created on the main channel side of Piasa Island was not protected since that location was a low bed shear area, meaning less erosion and scour is expected. Figure 3-27 compares the Alternative and base test discharges within Piasa Chute.

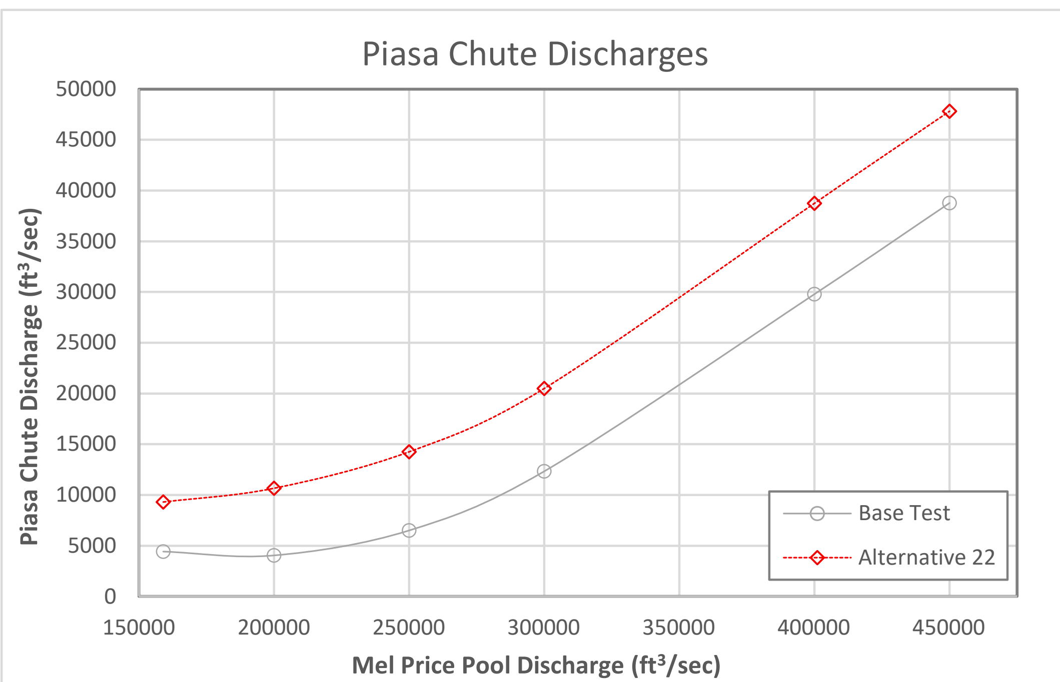


Figure 3-27. Piasa Chute Discharge (Alternative 22 vs Base Test)

3.4 AdH Results

After completing all AdH alternative tests, engineers analyzed the results to determine what measures were most successful in increasing the amount of discharge through Piasa Chute. Figure 3-28 shows a plot of all of the Piasa Chute discharges for the alternative tests.

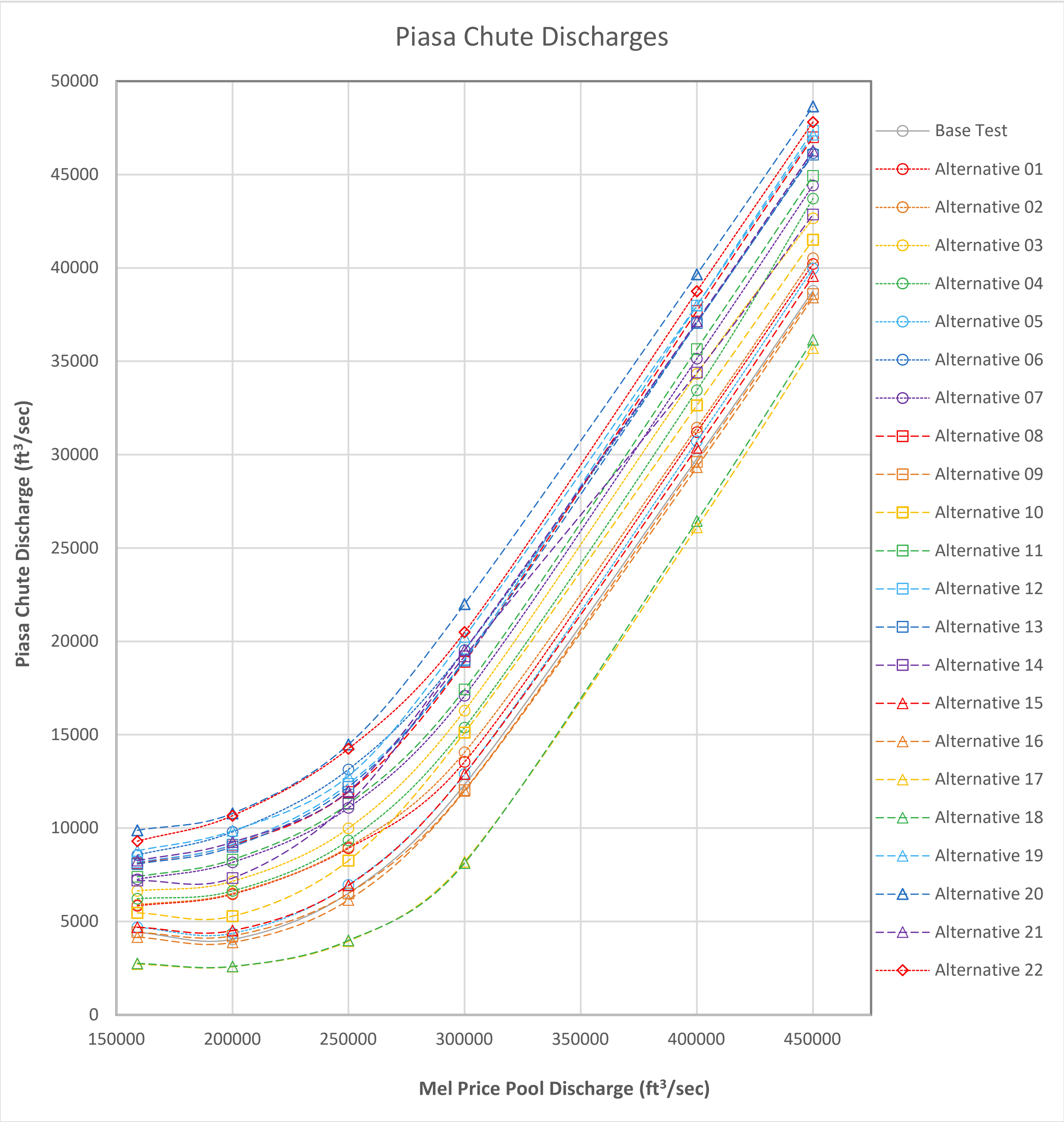


Figure 3-28. Piasa Chute Discharge for all Alternative Tests

There were a number of measures that the PDT determined to be successful. Below is a list of those measures, corresponding alternatives for each measure, and the success of the measure:

1. 200' braided dredge cut

- Alternative 7, Alternative 11
- The braided dredge cut measure provided a significant increase in discharge through Piasa Chute. Without a dredge cut, most other measures would not be as successful. Furthermore, the braided dredge cut by definition creates island habitat within Piasa Chute, but additionally, the dredge material will be used to create additional island habitat elsewhere within the study reach.

2. 300' braided dredge cut

- Alternative 6
- The braided dredge cut measure provided a significant increase in discharge through Piasa Chute. Without a dredge cut, most other measures would not be as successful. Furthermore, the braided dredge cut by definition creates island habitat within Piasa Chute, but additionally, the dredge material will be used to create additional island habitat elsewhere within the study reach.

3. Notched rock structure between Piasa and Eagle's Nest Islands

- Alternative 11
- The notched rock structure measure successfully increased discharge through Piasa Chute by diverting a majority of the flow through Piasa Chute that would normally exit between Piasa and Eagle's Nest Islands. Furthermore, the structure included two 400-ft notches, which will allow some flow to exit between Piasa and Eagle's Nest Islands creating scour holes and additional depth diversity.

4. Minimum backwater dredging

- Alternative 7
- Minimum backwater dredging at the entrance to the backwater area in the middle of Piasa Island didn't have a significant impact on discharges. However, if the PDT selects to dredge in Piasa Chute, dredging to the open the backwater area could yield habitat benefits at minimal additional cost.

5. Maximum backwater dredging

- Alternative 13

- Maximum dredging within Piasa Island didn't have a significant impact on discharges. However, if the PDT selects to dredge in Piasa Chute, dredging to open the backwater area could yield significant habitat benefits**.**

6. Island Diversity

- The creation of island habitat and diversity from dredge material is captured as part of the 200' and 300' braided dredge cut measures above.

The measures above were provided to the PDT in order to complete an environmental benefit analysis to determine the magnitude of ecosystem benefits to be expected if the measures were implemented. The evaluation was conducted by a multi-agency team which included representatives from the Illinois Department of Natural Resources (ILDNR), U.S. Fish & Wildlife Service (USFWS), and USACE. Chapter 5 of the Feasibility Report (McCain) details the feasible project measures, cost/environmental analysis, and alternative selection.

The measures the team chose to include in the recommended alternative were:

- 200' braided dredge cut in Piasa Chute
- Minimum Piasa Island backwater dredging
- Notched rock structure between Piasa and Eagle's Nest Islands
- Island creation from dredge disposal: Piasa riverside island and upstream rootless island

The selected measures are represented in the AdH test for Alternative 21 (Plate 34). Plates 60 and 61 show the SMS base test velocities and Alternative 21 velocities, respectively. Plates 62 and 63 show the SMS base test bed shear and Alternative 21 bed shear, respectively.

With implementation of the measures discussed above, including the rock river training structure, stages at average and high flows both in the vicinity of the project area and elsewhere in the Mel Price Pool reach of the Mississippi River are expected to be similar to current conditions. An abundance of research has been conducted analyzing the impacts of river training structures on water surfaces dating to the 1930s. This research includes numerical and physical models as well as analyses of historic gage data, velocity data, and cross sectional data. In addition to continued monitoring and analysis, the U.S. Army Corps of Engineers (Corps) has conducted a literature review of all available literature on the impact of river traning structures on flood levels. A summary of research on the topic is detailed in Appendix A of the *Final Environmental Assessment of the Regulating Works Project, Dogtooth Bend Phase 5, Middle Mississippi River Miles 40.0 – 20.0, Alexander County, IL, Mississippi and Scott Counties, MO* (April 2014). Based on an analysis of this research by the Corps and other external reviewers, the District has concluded that river training structures do not impact flood levels.

4 Climate Change Survey

4.1 Introduction

USACE projects, programs, missions, and operations have generally proven to be robust enough to accommodate the range of natural climate variability over their operating life spans. However, recent scientific evidence shows that in some places and for some impacts relevant to USACE operations, climate change is shifting the climatological baseline about which that natural climate variability occurs, and may be changing the range of that variability as well. This is relevant to USACE because the assumptions of stationary climatic baselines and a fixed range of natural variability as captured in the historic hydrologic record may no longer be appropriate for long-term projections of the climatologic parameters, which are important in hydrologic assessments for inland watersheds, such as the Piasa – Eagles Nest project.

4.2 Phase 1 Climate and Climate Change

4.2.1 Current Climate

Precipitation data obtained from the St. Louis Missouri Lambert International Airport, Network ID GHCND: USW00013994, Latitude 38.7525°, Longitude -90.3736°, Elevation 161.8 m. The period of record for this gage is April 1, 1938 to Jan 1, 2016.

	Precipitation All					Snowfall				
	Average (in)	Maximum (in)	Year	Minimum (in)	Year	Average (in)	Maximum (in)	Year	Minimum (in)	Year
Jan	2.1	9.0	2005	0.1	1986	5.6	23.9	1977	0.1	1989
Feb	2.2	5.0	1951	0.3	1963	4.5	20.8	1993	0.0	-
Mar	3.3	8.4	2008	0.7	1941	3.7	22.4	1960	0.0	-
Apr	3.9	10.3	1994	1.0	1977	0.3	6.5	1971	0.0	-
May	4.1	12.9	1995	0.8	2005	0.0	0.2	1973	0.0	-
Jun	4.3	13.1	2015	0.4	1991	0.0	0.0	-	0.0	-
Jul	3.7	12.7	1948	0.5	1941	0.0	0.0	-	0.0	-
Aug	3.0	14.8	1946	0.1	1971	0.0	0.0	-	0.0	-
Sep	2.9	10.0	1945	0.0	1940	0.0	0.0	-	0.0	-
Oct	2.9	12.4	2009	0.2	1975	0.0	0.0	-	0.0	-
Nov	3.2	10.0	1985	0.1	1949	1.2	11.3	1951	0.0	-
Dec	2.6	11.8	2015	0.0	1955	3.8	26.3	1973	0.0	-
Annual	**38.1**					**19.2**				

Temperature data obtained from the St. Louis Missouri Lambert International Airport, Network ID GHCND: USW00013994, Latitude 38.7525°, Longitude -90.3736°, Elevation 161.8 m. The period of record for this gage is April 1, 1938 to Jan 1, 2016.

	Temperature				
Month	**Average (°F)**	**Maximum (°F)**	**Year**	**Minimum (°F)**	**Year**
Jan	30.7	53.4	1990	6.1	1940
Feb	34.9	55.2	1976	14.0	1978
Mar	44.8	72.1	2012	22.6	1960
Apr	56.6	75.2	2010	39.4	1961
May	66.2	83.7	2012	46.9	1961
Jun	75.4	94.6	1952	59.2	1961
Jul	79.5	98.6	2012	64.8	1950
Aug	77.9	96.1	1947	61.5	1967
Sep	70.0	87.8	1939	52.0	1974
Oct	58.8	79.9	1963	39.0	1976
Nov	45.6	63.9	1999	26.1	1976
Dec	34.9	53.8	2015	13.8	1963
Annual	**56.3**				

4.2.2 Climate Change

US Army Corps of Engineers personnel have authored regional reports summarizing available scientific literature to meet the Corps goal of addressing potential climate change impacts in planning and decision making. Piasa and Eagles Nest Islands fall within Region 7, the Upper Mississippi Region, for the purposes of these reports (USACE, 2015). In the report covering the region, the following is said about the historic trends identified:

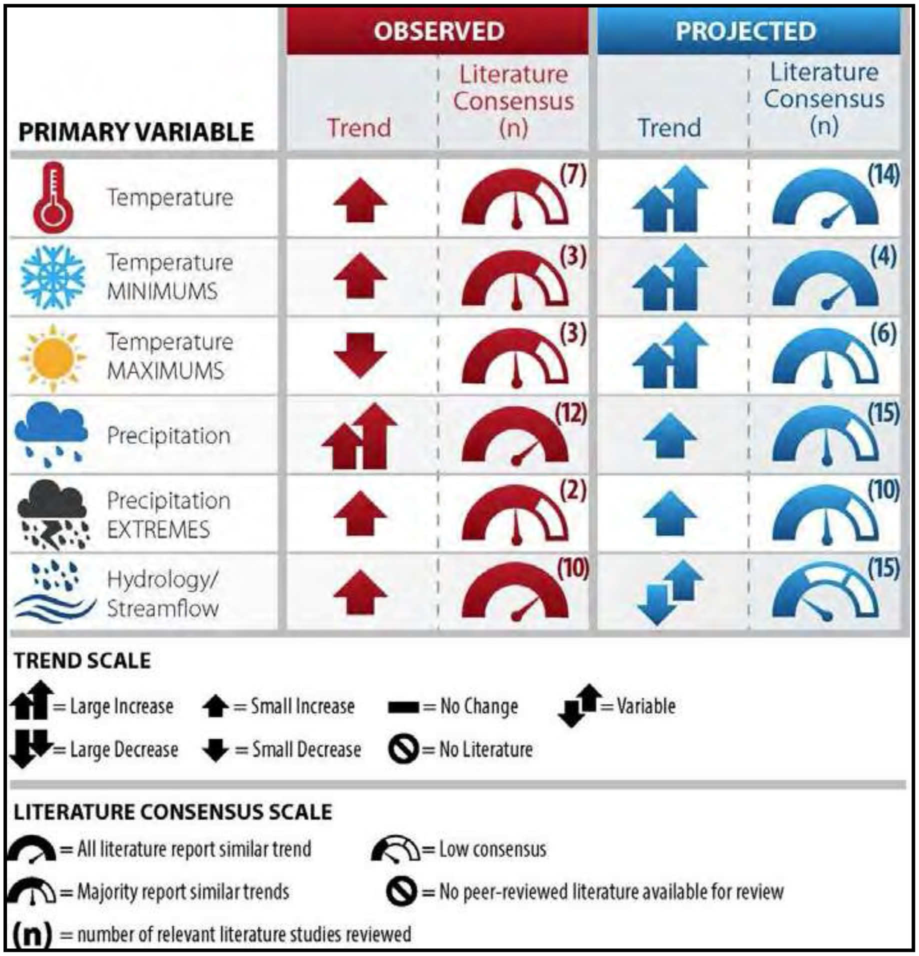


Figure 4-1 Summary matrix of observed and projected regional climate trends and literature consensus (from USACE 2015b).

4.2.3 Summary of Future Climate Projection Findings:

There is strong consensus in the literature that air temperatures will increase in the study region, and throughout the country, over the next century. The studies reviewed here generally agree on an increase in mean annual air temperature of approximately 2 to 6 ºC (3.6 to 10.8 ºF) by the latter half of the 21st century in the Upper Mississippi Region. Reasonable consensus is also seen in the literature with respect to projected increases in extreme temperature events, including more frequent, longer, and more intense summer heat waves in the long term future compared to the recent past.

Projections of precipitation found in a majority of the studies forecast an increase in annual precipitation and in the frequency of large storm events. However, there is some evidence presented that the northern portion of the Upper Mississippi Region will experience a slight decrease in annual precipitation. Additionally, seasonal deviations from the general projection pattern have been presented, with some studies indicating a potential for drier summers. Lastly, despite projected precipitation increases, droughts are also projected to increase in the basin as a result of increased temperature and [evapotranspiration] rates.

A clear consensus is lacking in the hydrologic projection literature. Projections generated by coupling [Global Climate Models] with macro scale hydrologic models in some cases indicate a reduction in future streamflow but in other cases indicate a potential increase in streamflow. Of the limited number of studies reviewed here, more results point toward the latter than the former, particularly during the critical summer months.

Given the high degree of variability and uncertainty in weather patterns in general and in predictions of future weather patterns in particular, quantifying future Project impacts is inexact. As summarized above, there is no consensus with respect to forecasts for future streamflow in the basin.

4.3 Observed Changes

The USACE Climate Hydrology Assessment Tool was used to examine observed streamflow trends in the vicinity of the example project. At the time of release of this ECB, the tool has capability only to evaluate the annual peak instantaneous streamflow; additional hydrologic variables of interest will be added in the future. The hydrologic time series of annual peak instantaneous streamflow at the gage Mississippi River at St. Louis, MO (7010000) is shown in Figure 4-2. The gage exhibits an increasing trend in annual peak instantaneous streamflow; however, this trend is not statistically significant as indicated by the high p-value. This indicates that overall, there has been no significant change in peak flows over the last 114-year period of record (1900-2014).

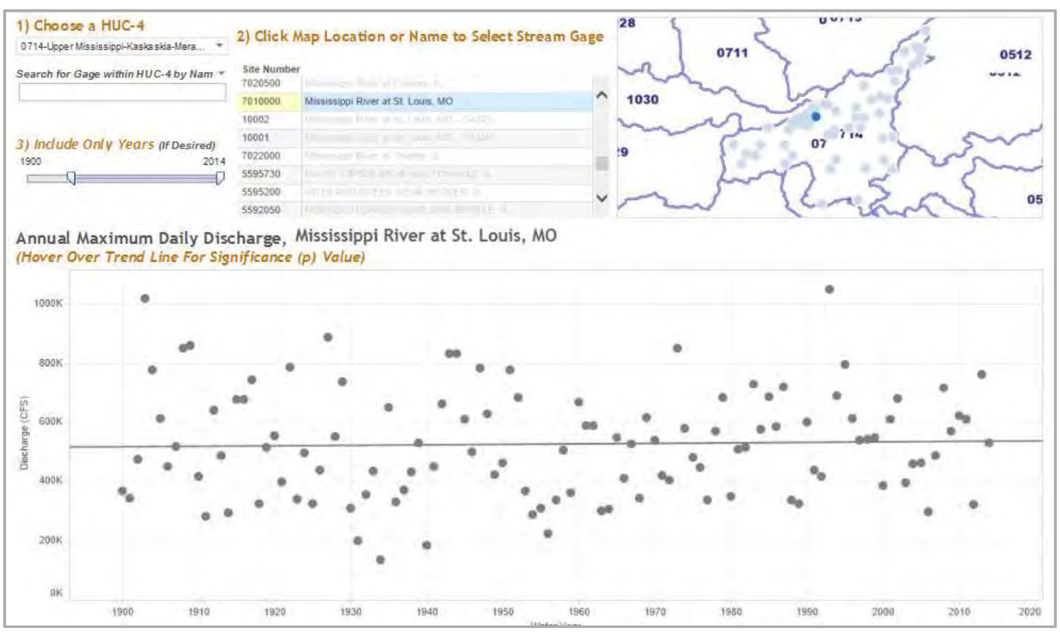


Figure 4- 2 Annual Peak Instantaneous Streamflow, Mississippi River at St. Louis, MO, Trendline Equation: Q = -219.332 * (Water Year) + 126640, p = 0.819679.

The Nonstationarity Detection Tool was also used to examine the hydrologic time series at the St. Louis, MO gage (7010000). No nonstationarity events were detected in the record (Figure 4-3), indicating that no change can be detected in the long term mean, variance, or trend in the maximum annual flow time series. A period of record of 153 years (1862 – 2015) was used. The Smooth Lombard Mood event was determined to not be an indicator of nonstationarity. Generally these 'smooth' type indicators should span at least a few consecutive years if they are genuine, whereas this one occurs very briefly. Also in this particular case, the indicator occurs right at the beginning of the period of record. The results of the nonstationarity detection analysis indicate that overall, there has been no statistically significant change in annual peak flows, as measured.

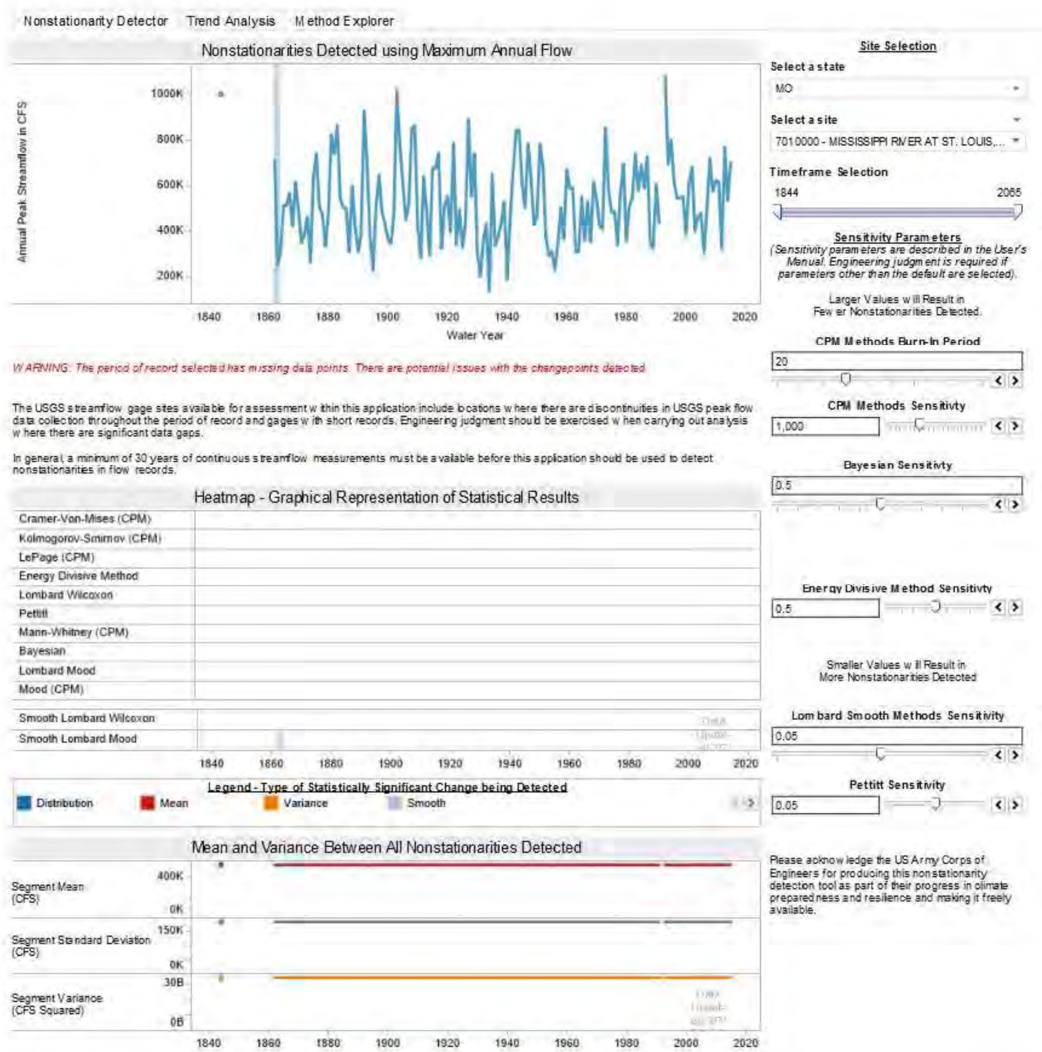


Figure 4-3 Nonstationarity Analysis of Maximum Annual Flow, Mississippi River at St. Louis, MO.

4.4 Phase II: Projected Changes to Watershed Hydrology and Assessment of Vulnerability to Climate Change.

The USACE Climate Hydrology Assessment Tool was used to examine observed and projected trends in watershed hydrology to support the qualitative assessment. As expected for this type of qualitative analysis, there is considerable but consistent spread in the projected annual maximum monthly flows (Figure 4-4), the overall projected trend in annual peak instantaneous streamflow increases over time (Figure 4-5). This increase is statistically-significant (p-value <0.0001). This finding suggests that there may be potential for higher peak streamflows in the future.

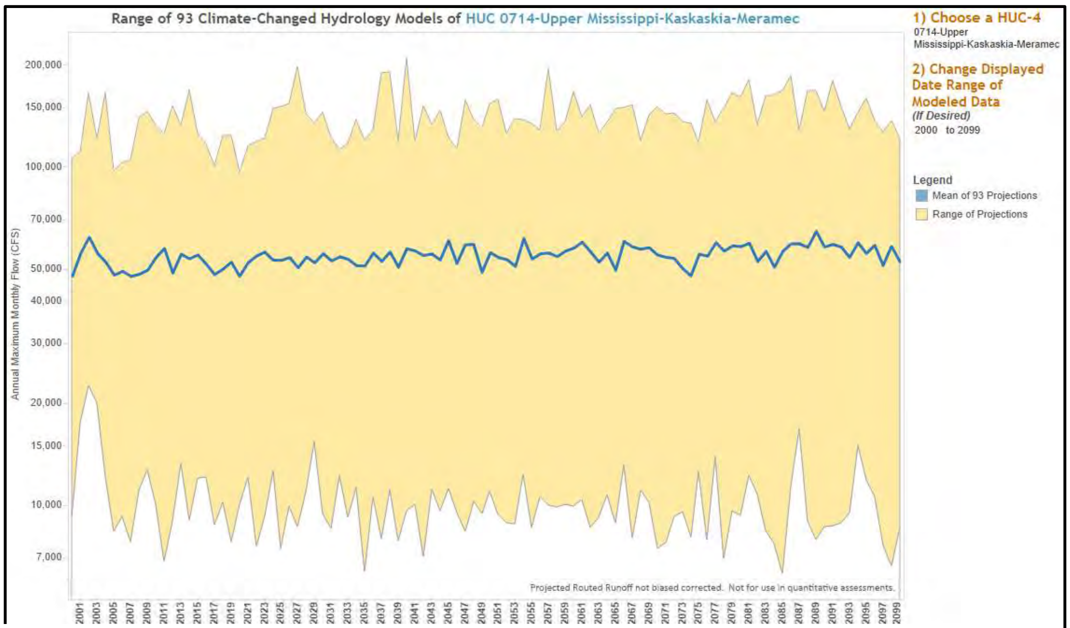


Figure 4-4 Range in the Projected Annual Maximum Monthly Flows, HUC 0714 Upper Mississippi-Kaskaskia-Meramec

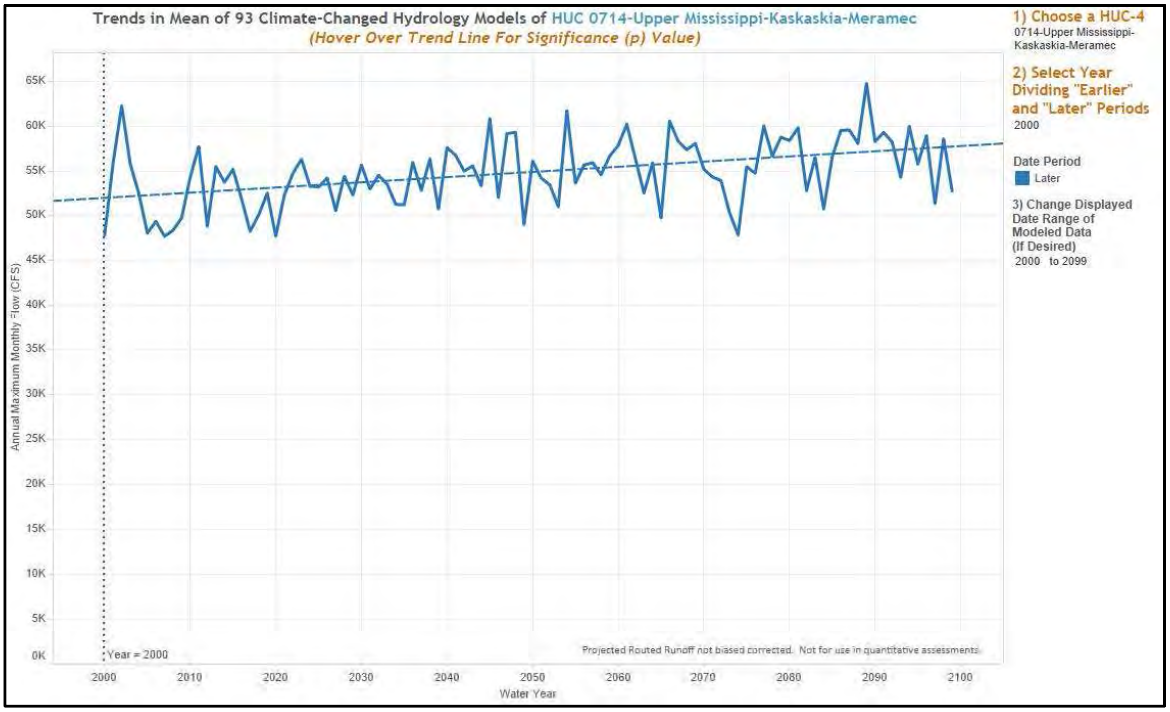


Figure 4-5 Mean Projected Annual Maximum Monthly Streamflow, HUC 0714 Upper Mississippi-Kaskaskia-Meramec. Trendline Equation: Q = 57.5719 * (Water Year) – 63194.8, $p < 0.0001$

4.5 Observed Changes in Average Daily Flow

USACE climate change tools described in the previous two sections rely on Annual Maximum Streamflow. Observed trends in average daily flows are important for Piasa and Eagles Nest Islands because it is an ecosystem restoration project, not a flood control project. Figure 4-6 shows the maximum, average, minimum and current daily flows at the St. Louis Gage for the period of record which was the best fit gage available used for all other analysis in this report.

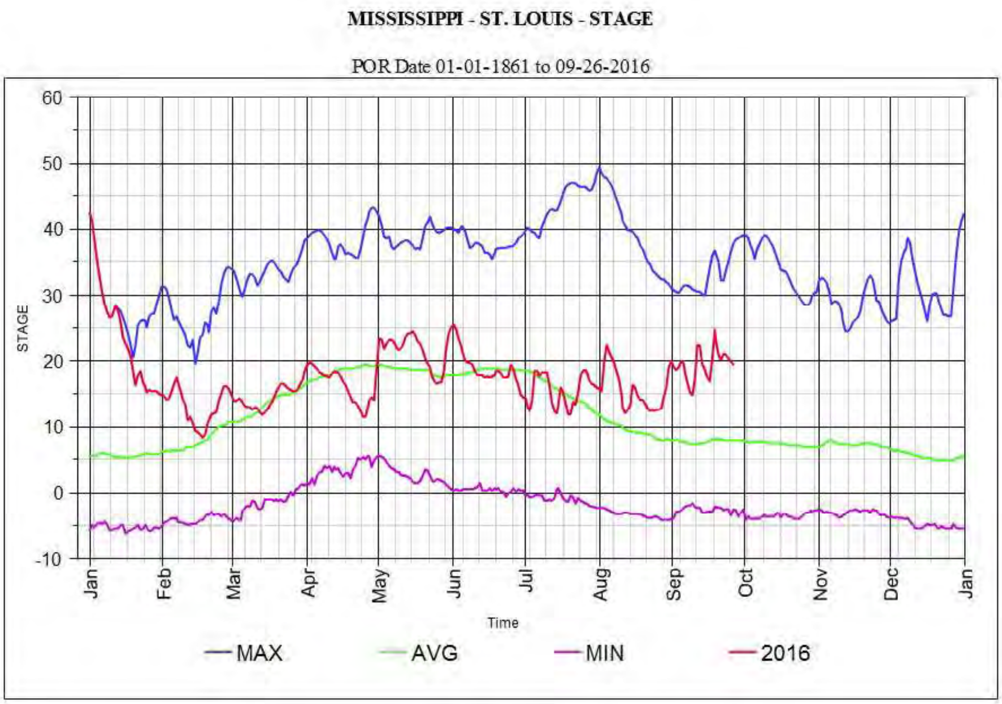


Figure 4-6 Maximum, average, minimum and current daily flows for the St. Louis, MO Gage, period of record 1861-2016.

Figure 4-8 shows the maximum, average, minimum and current daily flows at the Alton, IL Gage, which is the closest gage to the project area. The influence of the Mel Price L&D and the Missouri River which are both located between the two gage locations is evident. Figure 4-7 is the St. Louis Gage during the same time period (1990-2015) as the Alton Gage for comparison purposes.

The influence of the Mel Price L&D and Missouri River can be seen in the variability of the minimum and average results. Overall however, the results are as expected with maximums occurring during typical spring and summer rises.

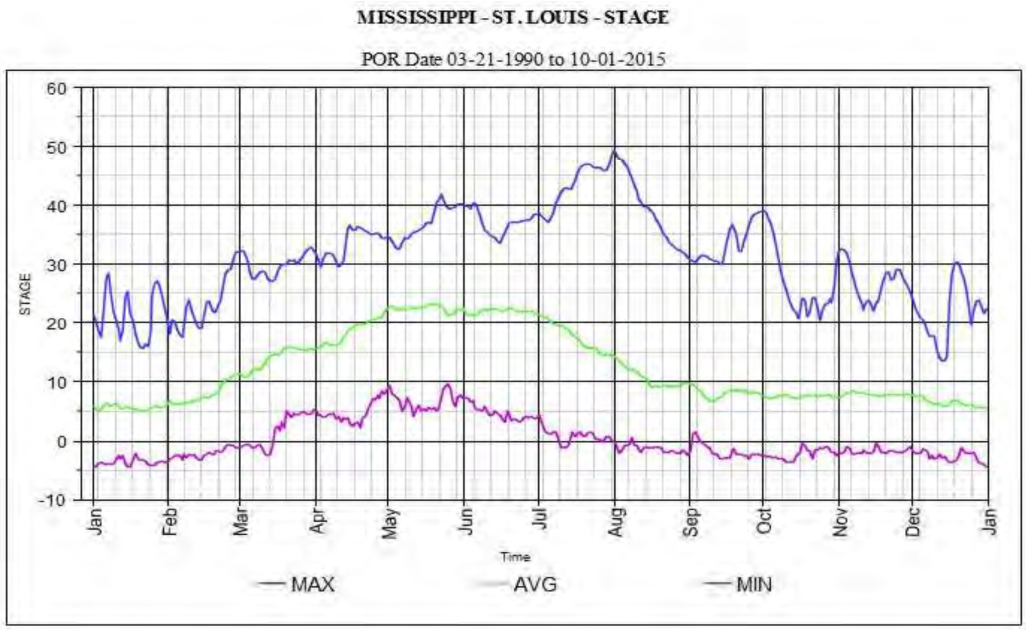


Figure 4-7 Maximum, average, minimum and current daily flows for the Alton, IL Gage period of record 1990-2015

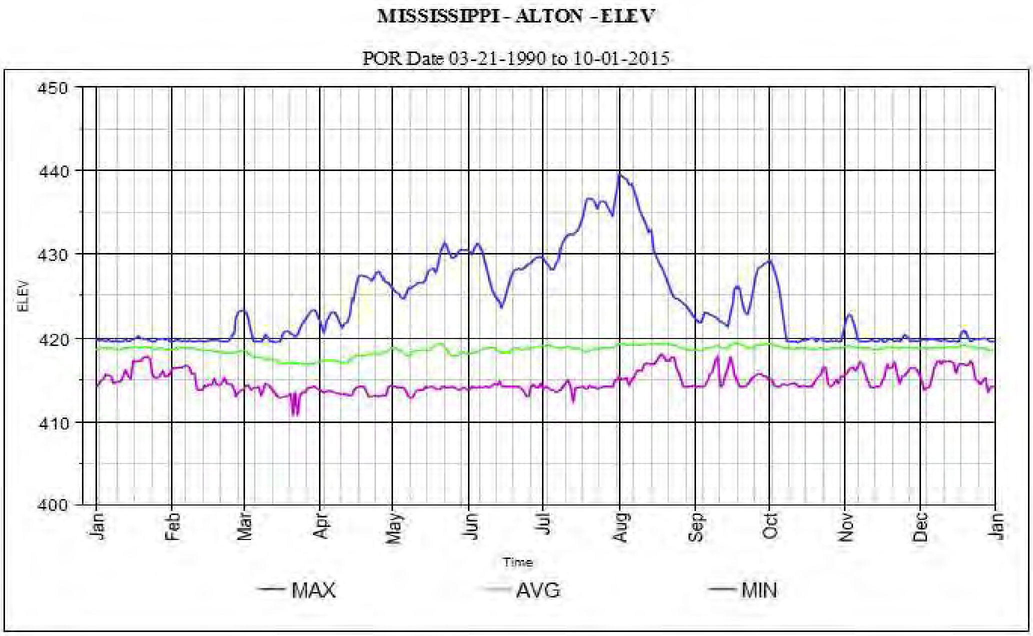


Figure 4-8 Maximum, average, minimum and current daily flows for the St. Louis, MO Gage period of 1990-2015

5 Plates

6 Acronyms

Acronym	Name
ADCP	Acoustic Doppler Current Profiler
AdH	Adaptive Hydraulics
DNR	Department of Natural Resources
ERDC	Engineer Research and Development Center
GPM	Gallons per Minute
HPC	High Performance Computing
HREP	Habitat Rehabilitation and Enhancement Project
HSR	Hydraulic Sediment Response Model
ILDNR	Illinois Department of Natural Resources
LDB	Left Descending Bank
LiDAR	Light Detection and Ranging
MINPOOL	Minimum Pool Elevation
NAVD88	North American Vertical Datum of 1988
NGVD29	National Geodetic Vertical Datum of 1929
PDT	Project Delivery Team
RDB	Right Descending Bank
RM	River Mile
SMS	Surface-water Modeling System
UMRS	Upper Mississippi River System
URV	Unsubmerged Rigid Vegetation
USACE	United States Army Corps of Engineers
USFWS	United States Fish & Wildlife Service

7 References

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