Appendix C

HYDRAULICS AND HYDROLOGY

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Hydraulics and Hydrology Appendix C

1. INTRODUCTION

1.1. Study Area Description

The Middle Mississippi River National Wildlife Refuge (MMRNWR) is dispersed along 195 miles of the Mississippi River between St. Louis, Missouri and the confluence with the Ohio River; it includes approximately 7,000 acres of river islands and bottomland forest. The U.S. Fish and Wildlife Service (USFWS) manages the MMRNWR. The portion of the MMRNWR included in this Upper Mississippi River Restoration Program (UMRR) Habitat Rehabilitation and Enhancement Project (HREP) is Crains Island (553 Acres).

Crains Island is located on the right descending bank of the Mississippi River between river miles 103.5 and 105.5, approximately 4 miles southeast of the City of Chester, in Randolph County, IL. Figure 1 and Figure 2 provide a vicinity map and a specific location map for the Crains Island HREP. Crains Island is also located in the Middle Mississippi River (MMR), which is the 195-mile stretch of the Mississippi River from the confluence of the Missouri River near St. Louis, Missouri south to the confluence of the Ohio River at Cairo, Illinois (Figure 2). The MMR is often referred to as the “Open” or “Unimpounded” river because it is first section of free-flowing river below the lock-and-dam navigation system on the Upper Mississippi River.

Crains Island is adjacent to the Bois Brule levee, which was originally completed in 1937 and completed to its current state in 1968. The levee is currently operated and maintained by the Bois Brule Levee District.

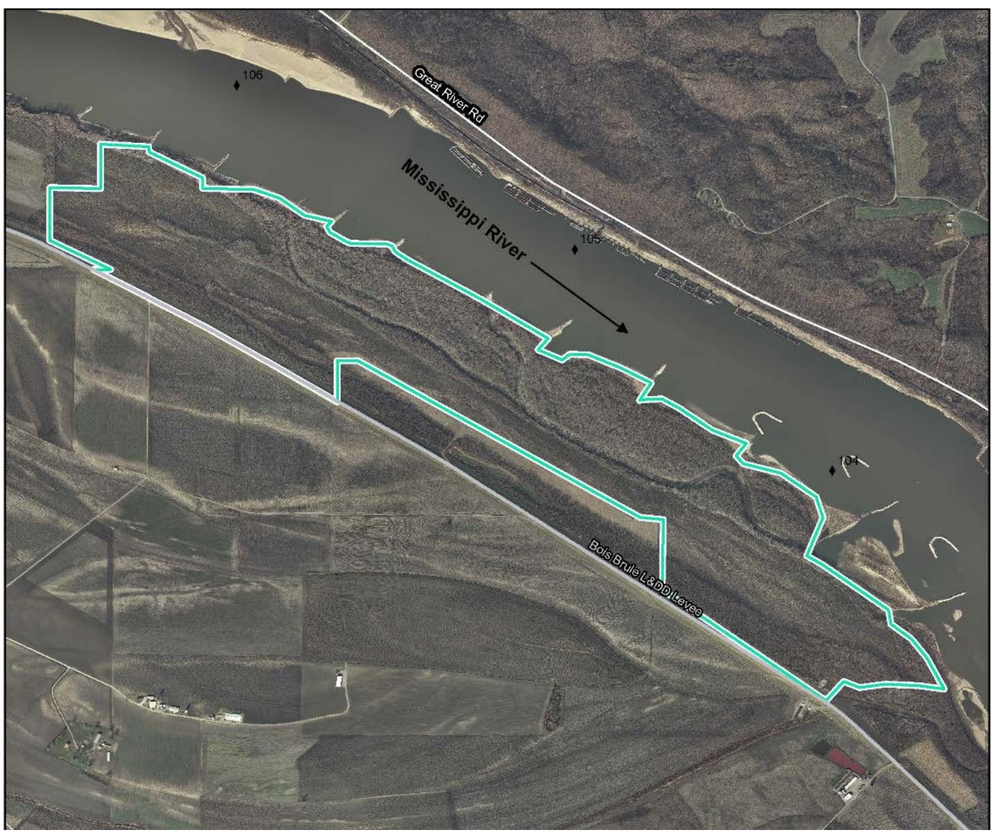

Figure 1. Project Area Crains Island.

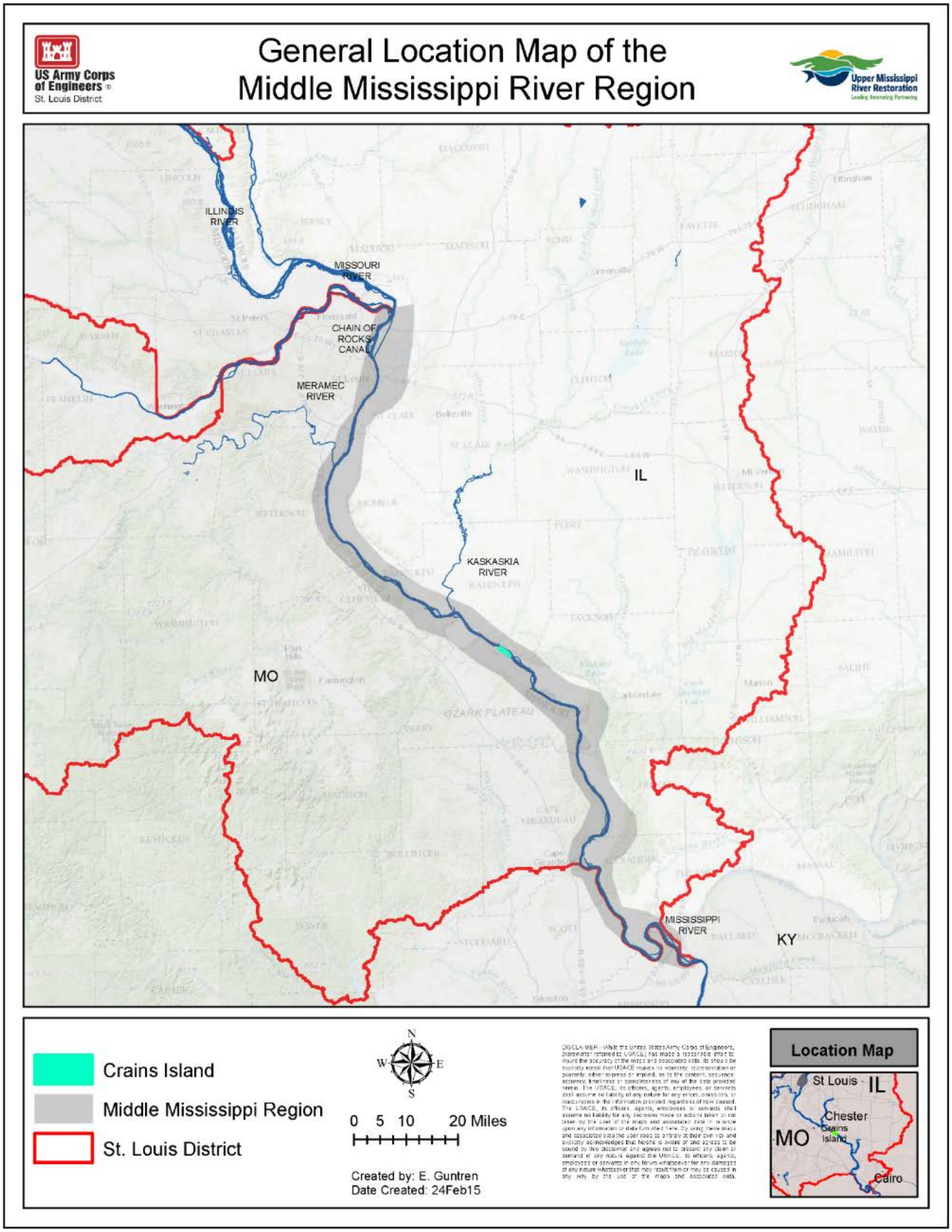

Figure 2. Middle Mississippi River Region.

1.2. Purpose and Need

The Corps proposes to rehabilitate and enhance Crains Island through construction of measures which will increase floodplain forest community diversity, restore function of flowing side channels, increase emergent wetland habitat, and improve the overall structure and function of Crains Island habitat. One key aspect of restoration includes deepening and realigning the exiting side channel. The existing side channel lacks depth and is often blocked by debris. The current channel bottom at Crains Island is exceeded only 33% of the time (250,000 cfs). The average flows though the months of August through February are well below the value's needed to inundate the current channel. Table 1 shows a list of average monthly discharges for each month during 1967 – 2016 and 1990 – 2016. Deepening the side channel to the proposed depth of zero ft LWRP will allow the bottom to be exceeded 98% of the time (66,700 cfs). See Table 2 for details.

Table 1. Average monthly discharges for each month during 1967 – 2016 and 1990 – 2016

	1967 - 2016 Average (CFS)	***1990 - 2016 Average (CFS)***
Jan	150,874	114,615
Feb	176,220	122,100
Mar	263,343	168,446
Apr	334,307	231,638
May	352,213	285,000
Jun	321,744	280,577
Jul	265,895	217,892
Aug	184,013	151,208
Sep	163,508	136,042
Oct	168,261	119,036
Nov	178,127	126,736
Dec	169,311	121,123

Table 2. Key elevations, discharges, stages, and percent exceedance values based on USGS rating curve and duration of exceedance.

	LWRP	*Design Channel Bottom*	*+5 LWRP*	*Existing Channel Bottom*	*Island Innundated*	*2yr*	*5yr*	*Berm Crown*	*100yr*
Current Discharge from USGS Rating Curve	66,700	69,000	103,000	250,000	485,000	504,000	631,000	758,000	1,030,000
Discharge from flow Freq Study						480,000	622,000		948,000
RM 105 Elevation (NAVD 88)	337.39	337.75	342.39	355.00	368.00	369.08	374.48	378.50	385.48
Chester RM 109.9 (Stage)	-0.40	-0.04	4.60	17.21	30.21	31.15	36.65	40.67	47.95
Chester RM 109.9 Elevation (NAVD 88)	340.33	340.69	345.33	357.94	370.94	371.88	377.38	381.40	388.68
Daily Percent Excceedence	98.33	97.85	85.05	33.14	6.48	5.34	1.52	0.45	

Photo 1. Debris accumulation in Crains Island side channel. Photo taken by USACE personnel in March, 2015.

1.3. Historical Analysis

The Mississippi River near Crains Island has been dramatically altered over the years as a result of the construction of river training structures. The structures were constructed as part of the U.S. Army Corps of Engineers authority to provide a safe and dependable navigation channel. The flood plain has been disconnected as a result of the construction of the Bois Brule levee originally completed in 1937 and completed to its current state in 1968. The levee is currently operated and maintained by the Bois Brule Levee District.

Figure 3. Historic River Training Structures and Revetment

River training structures have had a significant impact on the topography in the project area, especially those constructed and modified between 1928 -1960. Table 3 displays the list of structures built, the date of construction, and the type of construction based on the best available data compiled by USACE. Highlighted in yellow in this table are the structures primarily responsible for forming Crains Island. Prior to the 1960's almost all of the structures placed in the Middle Mississippi River were of the woody pile type. Logs were driven into the river bed to create roughness and formed into a river training structure. Due to the higher maintenance of these woody structures, river training structures began to be constructed from stone during the 1960s.

Photo 2 – Example of woody pile structures on the Upper Mississippi River.

Figure 4 illustrates that remnant pile structures and mattress revetment may be partially responsible for the excessive debris that accumulates in the existing channel. Historic structures were never removed by the Corps, but may have been degraded over time from flows and ice. Most likely they are still there but buried in sediment. Pile Dike 105.5 R is in the same location as a large woody debris build up. It is also possible that these historic structures act as a grade control which does not allow the channel to deepen.

Figure 4. Debris Accumulation due to Historic Pile Structures

Figures 5, 7, and 8 demonstrate how the construction of river training structures has changed what was once 2 channels with split flow into a single channel in this area of the river. Later, in the 1930's the Bois Brule levee was constructed and cut the river off from its floodplain.

Figure 5: 1870 Hand drawn map overlaid on 2012 Aerial photo of Crains Island Complex. C0urtesy of USACE St. Louis District.

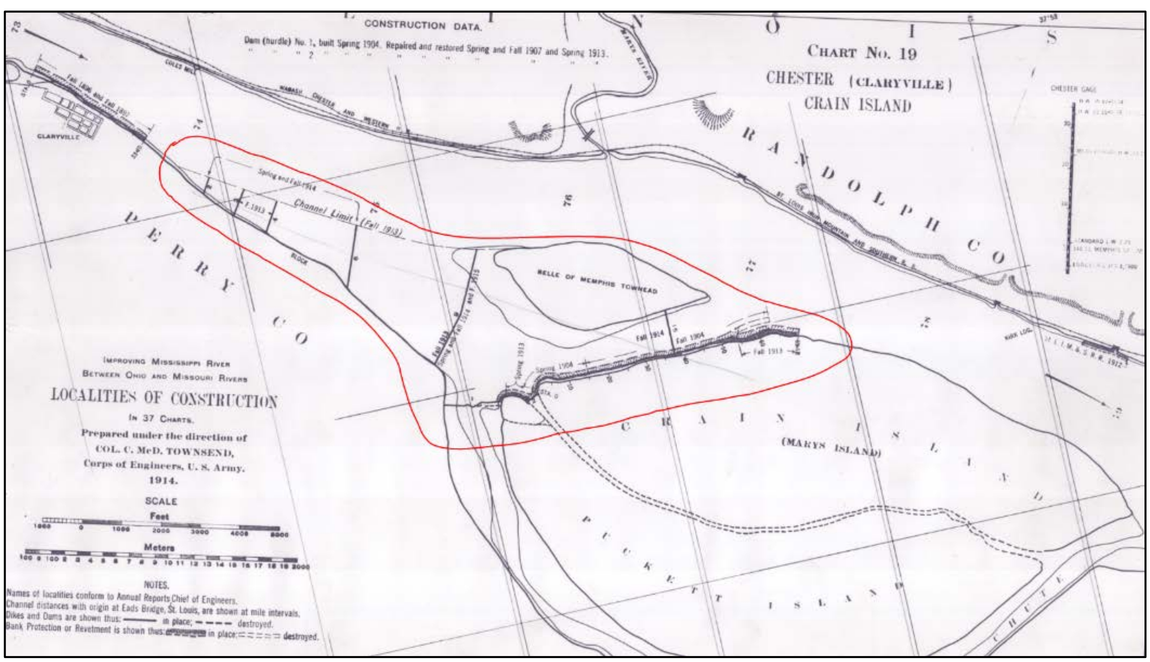

Figure 6: 1914 Localities of Construction near Crains Island. Courtesy of USACE St. Louis District.

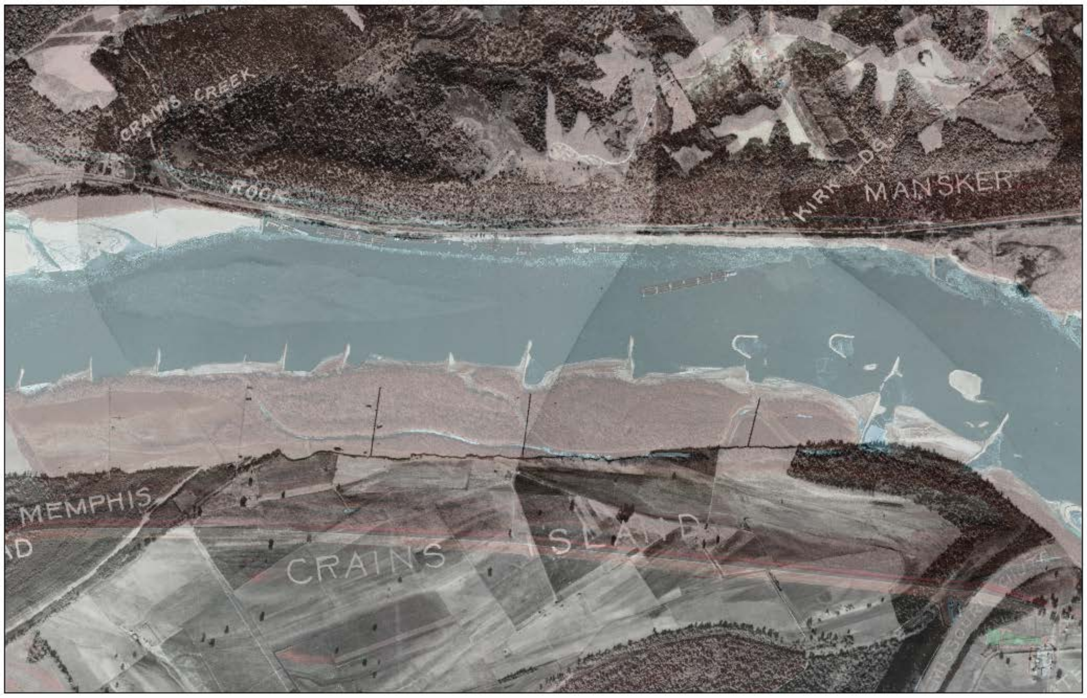

Figure 7: 1929 Aerial photo overlaid on 2012 Aerial photo of Crains Island Complex. Courtesy of USACE St. Louis District.

Table 3. Index of River Training Structures

ID	Structure Name	Contract Number	Date Start	Date End	Stone Type	Tons Placed (Removed)
	Historic Revetment		1904	1915		
3403	Trail Dike 105.90 R			1940	Pile	
3404	Spur Dike 105.80 R		1942	1968	Pile	
2687	Spur Dike 105.70 R			1928	Pile	
				1932	Pile	
				1933	Pile	
2592	Spur Dike 105.60 R		1942	1968	Pile	
		72-C-0128		9/13/1972	A	12,329
		77-C-0155		7/12/1978	A	17,645
2593	Spur Dike 105.50 R			1920	Pile	
		78-C-0156	10/19/1978	7/21/1979	A	14,145
2744	Pile Dike 105.40 R			1928	Pile	
				1932	Pile	
2594	Spur Dike 105.20 R	72-C-0128		3/1/1973	A	4,962
		78-C-0156	10/20/1978	7/23/1979	A	11,177
2595	Spur Dike 105.00 R			1928	Pile	
				1931	Pile	
				1932	Pile	
				1937	Pile	
		78-C-0156		7/24/1979	A	23,926
		89-C-0071	2/19/1990	2/24/1990	A	9,958
2596	Spur Dike 104.70 R			1931	Pile	
		72-C-0128		9/12/1973	A	10,077
		75-C-0131	1/18/1975	8/2/1975	A	5,848
		78-C-0156	10/24/1978	6/13/1979	A	11,698
		89-C-0071	2/19/1990	2/24/1990	A	19,321
2963	Spur Dike 104.40 R			1928	Pile	
				1931	Pile	
				1936	Pile	
				1937	Pile	
		75-C-0131	7/31/1975	8/8/1975	A	10,713
		78-C-0156	6/14/1979	7/24/1979	A	12,877
		10-C-0411	10/4/2011	10/21/2011		(12,967)
		13-D-0518 0002	5/28/2014	5/29/2014		(900)
3067	Chevron 104.40 R	10-C-0411	10/13/2011	12/1/2011	A	49,918
2982	Chevron 104.10 R	10-C-0411	10/4/2011	11/15/2011	A	42,549
		12-D-0503 0002	8/2/2013	8/2/2013	A	1,334
2983	Spur Dike 104.00 R			1931	Pile	
				1932	Pile	
				1936	Pile	
				1937	Pile	
		72-C-0128		9/13/1973	A	21,950
		75-C-0131	8/8/1975	8/16/1975	A	11,818
		78-C-0156	6/13/1979	7/27/1979	A	11,849
		10-C-0411	9/15/2011	10/27/2011	A	21,696
		13-D-0518 0002	5/29/2014	6/4/2014	A	(3,662)
2981	Chevron 103.70 R	10-C-0411	9/14/2011	10/14/2011	A	34,940
		12-D-0503 0002	8/1/2013	8/2/2013	A	2,774

1.4. Navigation Dredging

Upper Mississippi River Mile 103 just downstream of the project area has had a significant amount of dredging for navigation purposes. Table 4 shows that over the 10 year period of 2004 – 2014 over 5 million cubic yards have been dredged from the navigation channel.

Table 4. Navigation Dredging

Upper River Mile	*Lower River Mile*	*Cubic Yards*	*Date Start*	*Date end*
103	102.4	761,758	10/09/2004	10/30/2004
103.8	103.2	433,153	08/22/2005	09/04/2005
104.1	103.9	185,637	08/22/2005	09/04/2005
104	102.4	669,419	07/26/2007	08/11/2007
104	102.4	159,406	11/20/2007	11/26/2007
104	102.5	549,788	10/05/2008	10/19/2008
102.1	101.9	99,650	10/19/2008	10/22/2008
103.7	102	532,546	08/08/2009	08/21/2009
103.6	102.1	423,524	10/25/2010	11/03/2010
103.7	102.1	100,989	11/04/2011	11/16/2011
102.1	101.8	353,247	11/25/2011	12/02/2011
102.3	101.5	229,820	11/16/2012	11/21/2012
103.7	102.3	398,801	09/11/2013	09/26/2013
103.3	102.5	253,214	12/21/2014	12/26/2014

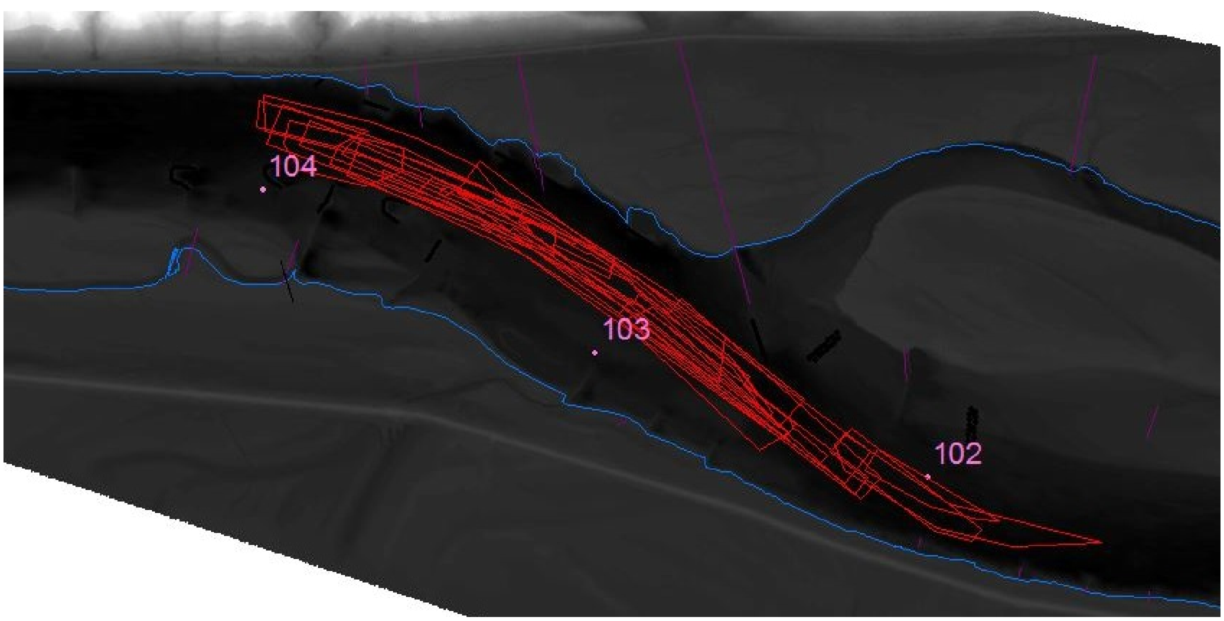

Figure 8. Dredge Locations

It is important that any proposed project at Crains Island does not negatively impact the navigation channel. This is especially true for low flow conditions where the flows are at or near the Low Water Reference Plane (LWRP). The low water reference plane, is a 3D hypothetical model of the water surface developed to approximate a common "low water" river level at all points on the Mississippi River between river miles 200 to 0. LWRP is based on a statistical analysis of 97% exceedance discharge (a discharge that is lower than 97% of flows) at key gages and water surface profiles taken at low flow conditions.

Kansas City District recommends that constructed side channels do not draw more than 10% of the flow from the main channel so that impacts to navigation are minimized. A flow split analysis was conducted using HEC-RAS to determine how much flow would be diverted to the side channel as a result of the project. It was determined at +3 LWRP that 0.12% of the flow would be diverted. Lower flows such as +0 LWRP would draw even less flow. Table 10 shows the results of this analysis.

2. DESIGN

2.1. Side Channel Design

Deepening the existing side channel is designed to improve aquatic habitat at much lower flows on the Mississippi River. This will extend the amount of time the channel is submerged. Figure 9 shows the alignment options considered for the proposed side channel.

Figure 9. Side Channel Alignment Options

For side channel alignment option 1, a curved entrance was considered which resembles that of a crain's neck. It was thought that this option would shield the side channel from debris from the main river channel. However upon further investigation, this type of curved entrance is not found naturally in this area of the river and other side channels with a crains neck entrance such as Boston Bar have had debris issues in the past. The crain's neck option also increased the sinuosity to 1.79 which is higher than that of nearby side channels such as those shown in Table 5. An increased sinuosity can actually reduce the ability of the channel to transport debris and sediment which is a primary consideration of the design. Option 1 was not considered further and was not evaluated in the HEC-RAS model.

Side channel alignment option 2 eliminated the crain's neck and decreased the sinuosity to 1.05 which is similar to other nearby side channels. When this option was modeled in HEC-RAS it was discovered that very low flows were present in the 2nd side channel entrance. The second side channel entrance was altered to provide higher water velocities to reduce sedimentation. This alteration of the second entrance resulted in the final recommended alignment option. See

Table 9 Low Flow Model Results for a comparison of the original and final side channel velocities.

Another primary considerations for design of this side channel is to allow debris and drift to pass though the chute without getting caught up and clogging it causing decreased flow velocities and sedimentation. Lessons learned from the Kansas City District dictate that a channel bottom width of greater than 75 ft and final side slopes of 3H:1V be utilized. To determine a reasonable depth, an analysis on 4 chutes in close proximity to Crains Island were analyzed. Profiles and cross sections of each side channel were completed. An example using Establishment Chute is shown in Figure 10. The results are summarized in Table 5 .

Table 5. Results of Side Channel Analysis

Side Channel	*Survey date*	*Upper River Mile*	*Lower River Mile*	*Average bottom width*	*Average top width*	*Depth (LWRP)*	*Slope*	*Sinuosity*
Jones Chute	7/17/2014	98.30	95.00	138	265	-0.8	0.0000%	1.01
Liberty Chute	7/16/2014	102.80	99.90	236	447	0.3	0.0286%	1.11
Kaskaskia Chute	7/9/2014	118.00	115.80	101	199	2.0	0.0268%	1.11
Establishment Chute	6/15/2014	132.50	130.10	90	227	0.7	0.0083%	1.05
Average				**141**	**284**	**0.6**	**0.0158%**	**0.82**

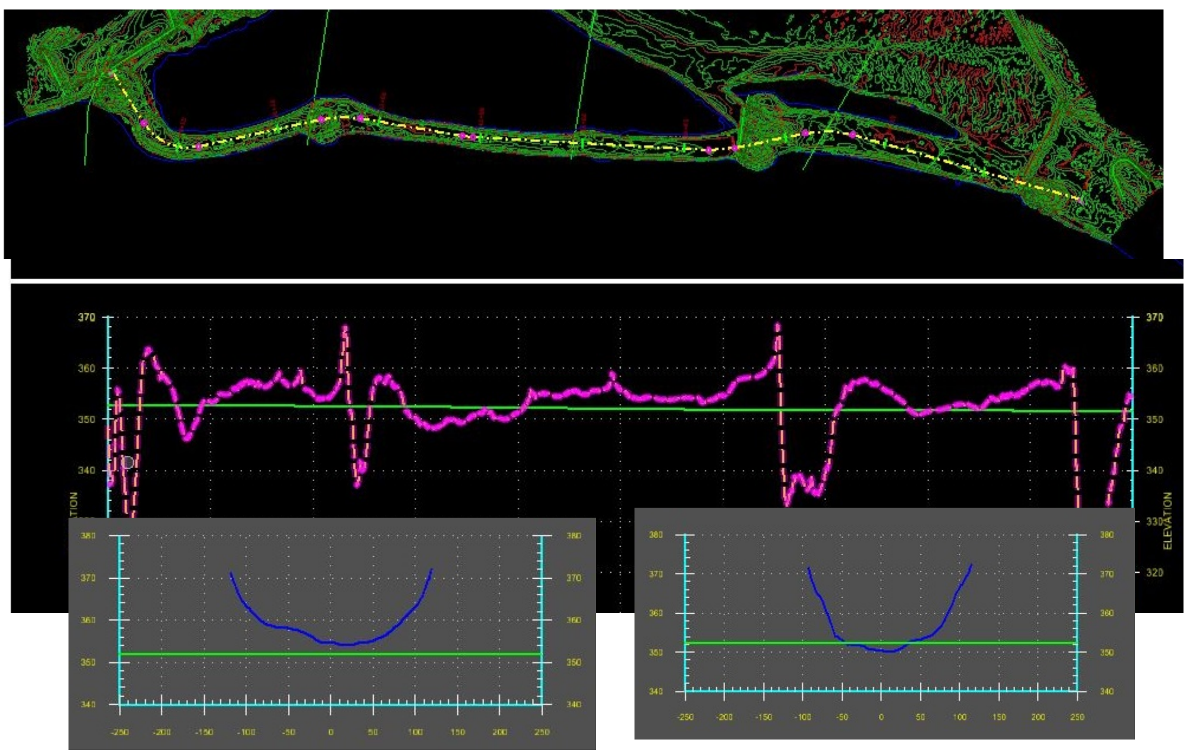

Figure 10. Profiles and cross sections of Establishment Chute. The green line in profile and cross section represents LWRP.

The final typical cross section of the side channel is shown in Figure 11. The final bottom width is 80 ft and average top width is 300 ft. The side final design has a sinuosity of 1.05.

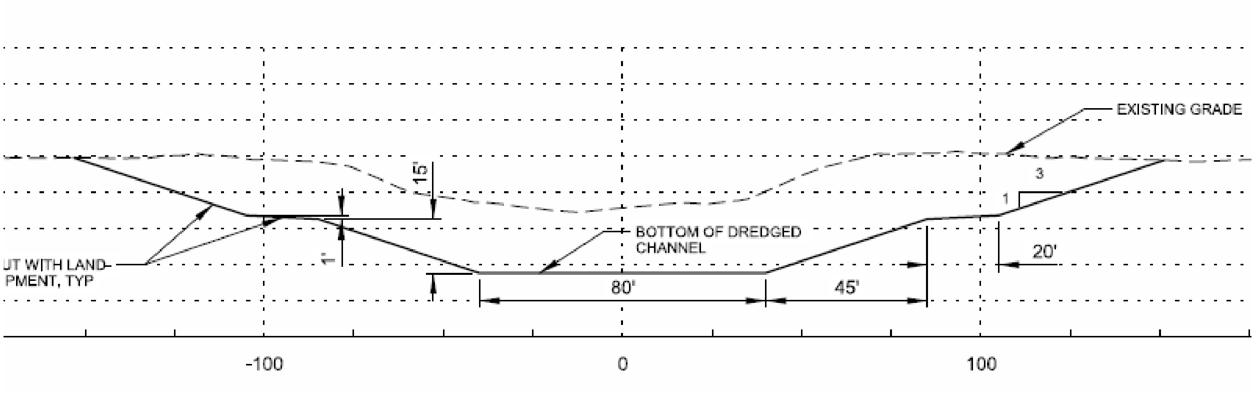

Figure 11. Final typical cross section of the side channel.

2.2. Sediment Deflection Berm Design

The sediment deflection berm is designed to improve aquatic and floodplain forest habitat by deflecting course sediment material (i.e., sand) and reducing high flows in the Project Area, which is located within the regulatory floodway. Currently, high sand deposition limits forest diversity by preventing hardmast tree species establishment. The sediment deflection berm would also improve backwater from the lower end of the island during high flow events, which would increase the amount of fine sediment deposition (i.e., silt/clay), thereby improving the soils overtime for hard mast tree establishment.

The original alignment and height of the sediment deflection berm was modified though the study process to account for impacts to the 1% annual chance exceedance (ACE) flood. Originally a berm height equal to a 10% ACE flow was considered but this did not meet the State of Illinois 1% ACE flood impact requirements. Several alternatives were considered but ultimately a berm height equal to a 20% ACE flow was selected and the alignment was altered to minimize flood impacts. The final berm height and alignment maximized the area shielded from high velocity flow while still meeting 1% ACE flood requirements. See Figure 12 for the original and final berm alignments.

Figure 12. Original and final berm alignments.

A typical cross section of the final sediment deflection berm design is shown in Figure 13. The riverside slope shown on the right of Figure 13 is a 4H:1V slope. The crown is 12' wide and landside slope is 8H:1V which will help eliminate scour from overtopping and to allow additional area for plant hard and soft mast trees.

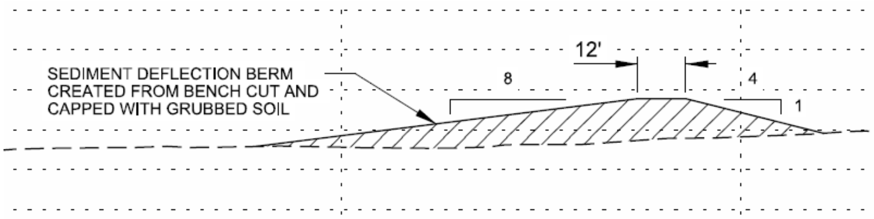

Figure 13. Typical berm cross section.

3. GAGE INFORMATION (CHESTER, IL)

3.1. Duration of exceedance

Figure 14 shows the percent exceedance using 50 years of daily flow data from USGS. Figure 14 represents the percent of days which are at or exceed a given flow. A 50 year return period (2% ACE) was used to represent current hydrologic conditions since it will include the effects of the large reservoirs constructed on the Missouri River..

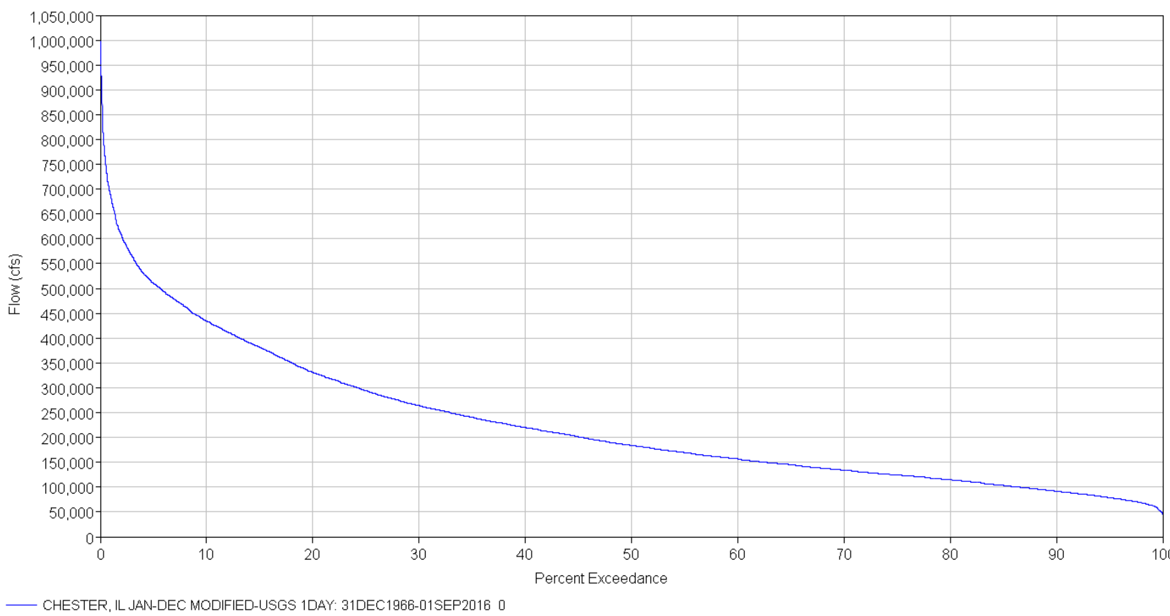

Figure 14. Chester Gage Duration of Exceedance from 1966 – 2016

3.2. Comparative stage hydrograph

Figure 15 shows the max, min, and average stage at Chester for the entire period of record 1891 – 2017. On average low stages are expected from August through February.

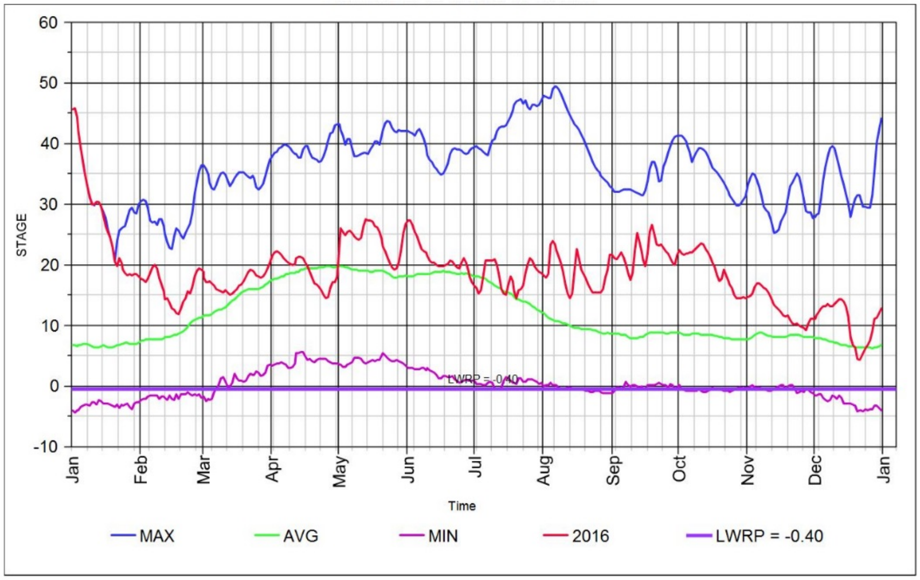

Figure 15. Comparative Stage Hydrograph

4. HEC-RAS MODELING

4.1. Geometry

For the numerical models, HEC-RAS was used as a tool to develop the models. HEC-RAS is a software developed by the Hydrologic Engineering Center (HEC) from USACE. The version used in the following models is 5.0.3, which includes 2D modeling. This new capability of the software will be used in this project to determine the effects of the proposed side channels, and the sediment deflection berm. The geometry created in HEC-RAS was imported from ArcGIS shapefiles. See Figure 16 for the imported shapefiles which show the Dikes, Islands and the Mississippi River bankline. The St. Louis Enterprise GIS database was used to obtain these shapefiles. See Figure 17 for the proposed features that were edited in ArcGIS using the data editor tool. The x,y coordinates of the shapefiles were used to draw the RAS breaklines along the model. The extent of the RAS model starts at the Chester gage, 5 miles upstream of Crain's Island (RM 105.6 to RM 103.8). The 1% ACE flow condition was modeled from Chester gage to the old Bishop landing gage, located at RM 100.7. For calibration purposes all of the other flow stages were modeled from Chester to Red Rock gage, 9.8 miles downstream of Crain's Island. The width of the model was limited by the Bois Brule Levee on the right side (looking downstream). Since there is a cliff (high ground elevation) on the left side, the model was limited by IL Highway #3.

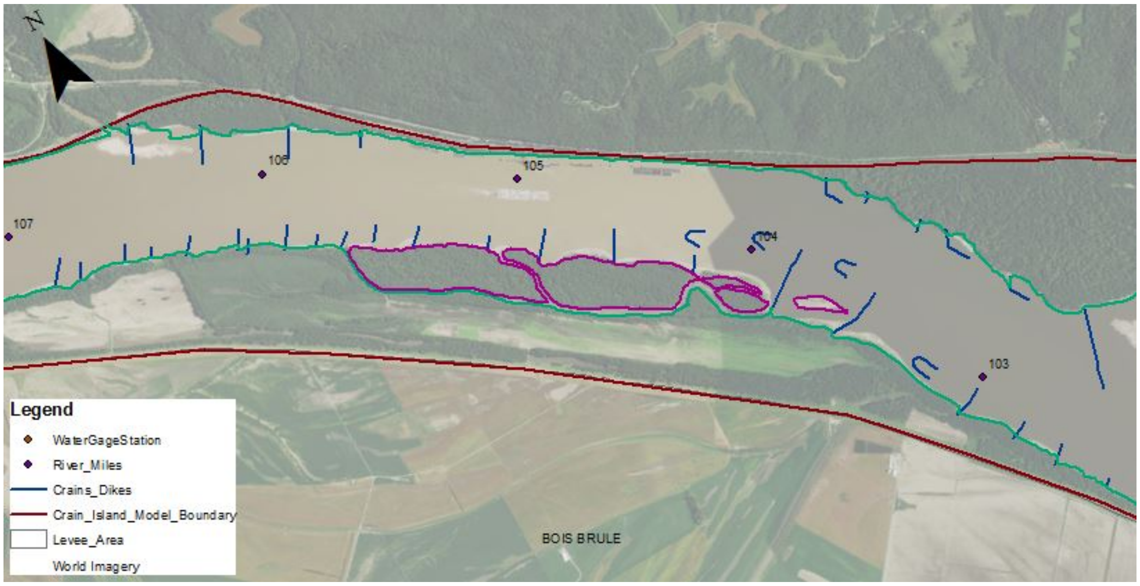

Figure 16. Existing GIS Layers

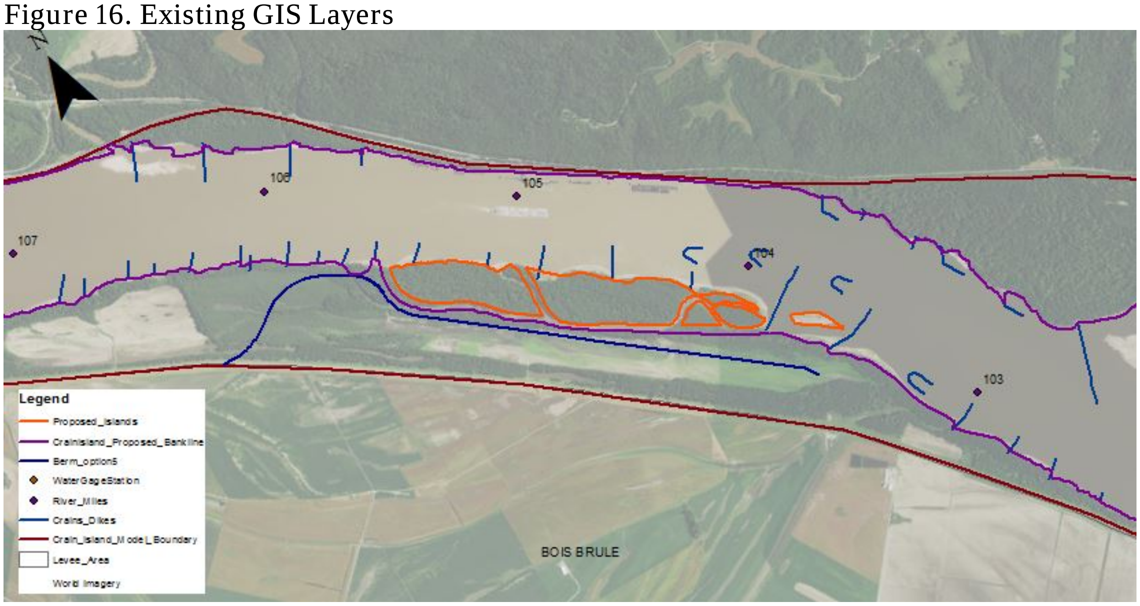

Figure 17. Proposed GIS Layers

4.1.1. Existing Condition Surveys

A wide range of datasets was used to develop the existing conditions for the HEC-RAS model. Multibeam and Singlebeam hydrosurveys were used dating from 2013 to 2015 in order to provide the coverage needed for this model.

Main channel cross sections, or Hydrosurveys, were the least detailed and have a 250' cross sectional spacing. Hydrosurveys were used to develop the main channel only. A combination of LiDAR and multibeam surveys were used to provide enhanced detail over most of the river structures and Crains Island. The LiDAR was collected in 2012 during very low water. LiDAR points had 3'x3' spacing with 1' vertical accuracy. Multibeam surveys were used to represent some of the river structures where available. Multibeam surveys are very dense and accurate with less than 1' spacing and the vertical accuracy is less than 0.5'.

The hydrosurveys were then combined with a Light Detection and Ranging survey (LiDAR) collected in 2012. Hydrosurveys are all collected in National Geodetic Vertical Datum of 1929 (NGVD 29) whereas the LiDAR is collected in North American Vertical Datum of 1988 (NAVD 88). The National Geodetic Survey shows no shift in this area between the two datums. In many cases surveys from different years overlapped and engineering judgement was used as to determine which was incorporated based on density, coverage and date. The final combined raster used for the HEC-RAS model had a 10'x10' cell size. This is adequate for the HEC-RAS model which has 100 ft x 100 ft mesh size with 50 ft x 50 ft breaklines.

4.1.2. Mesh Development

The general cell spacing throughout the model mesh was set to be 100 ft by 100 ft. Breaklines were used to generate smaller mesh sizes over the areas of interest. All of the breaklines had a minimum cell spacing of 50 ft and a maximum of 100 ft. The mesh was then edited by manually so that final cells had the proper number of sides. The mesh generated for the existing model conditions can be seen Figure 18. The main differences in the mesh for the existing and proposed conditions is the second side channel entrance, expansion of the side channels, and the addition of a berm (identified with as brown line on the right image of Figure 17. These differences on the mesh can be appreciated in Figure 18 and Figure 19.

Figure 18. Existing Model Conditions

Figure 19. Proposed Model Conditions

For the land cover, a 2011 National Land Cover Dataset (NLCD) was used as a base. See Figure 20 for the manning's n values used to calibrate the model. See Figure 21 for the additional polygons used for the proposed conditions. Table 6 shows the Manning's n values for the different regions. For the additional polygons on the proposed conditions, the n vales for the Berm and the side channels were 0.1 and 0.025, respectively.

Table 6. Manning's n values by Land Cover

Region Description	***Base manning's n values***	***Adjusted manning's n values***
Barren Land Rock/Sand/Clay	0.025	0.025
Cultivated Crops	0.04	0.04
Deciduous Forest	0.1	0.1
Developed, high intensity	0.1	0.1
Developed, low intensity	0.05	0.05
Developed, medium intensity	0.08	0.08
Developed, open space	0.03	0.03
Emergent herbaceous wetlands	0.045	0.045
Evergreen forest	0.1	0.1
Grassland/herbaceous	0.03	0.03
Mixed forest	0.08	0.08
Open water	0.025	0.041
Pasture/hay	0.035	0.035
Shrub/scrub	0.05	0.05
Woody wetlands	0.04	0.04

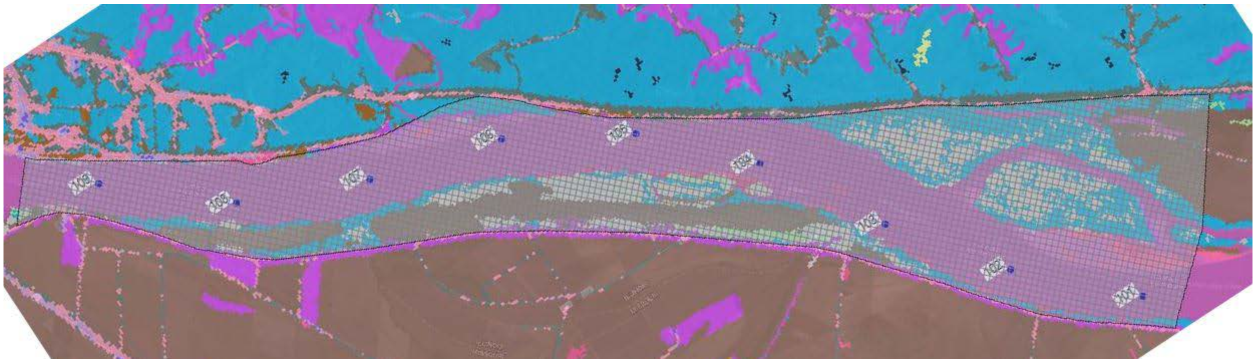

Figure 20. Land Cover Regions for the Model Existing Condition

Color	Value	Name	Default Manning's n
	0	nodata	
	1	255	
	2	barren land rock/sand/clay	0.025
	3	cultivated crops	0.04
	4	deciduous forest	0.1
	5	developed, high intensity	0.1
	6	developed, low intensity	0.05
	7	developed, medium intensity	0.08
	8	developed, open space	0.03
	9	emergent herbaceous wetla...	0.045
	10	evergreen forest	0.1
	11	grassland/herbaceous	0.03
	12	mixed forest	0.08
	13	open water	0.025
	14	pasture/hay	0.035
	15	shrub/scrub	0.05
	16	woody wetlands	0.04

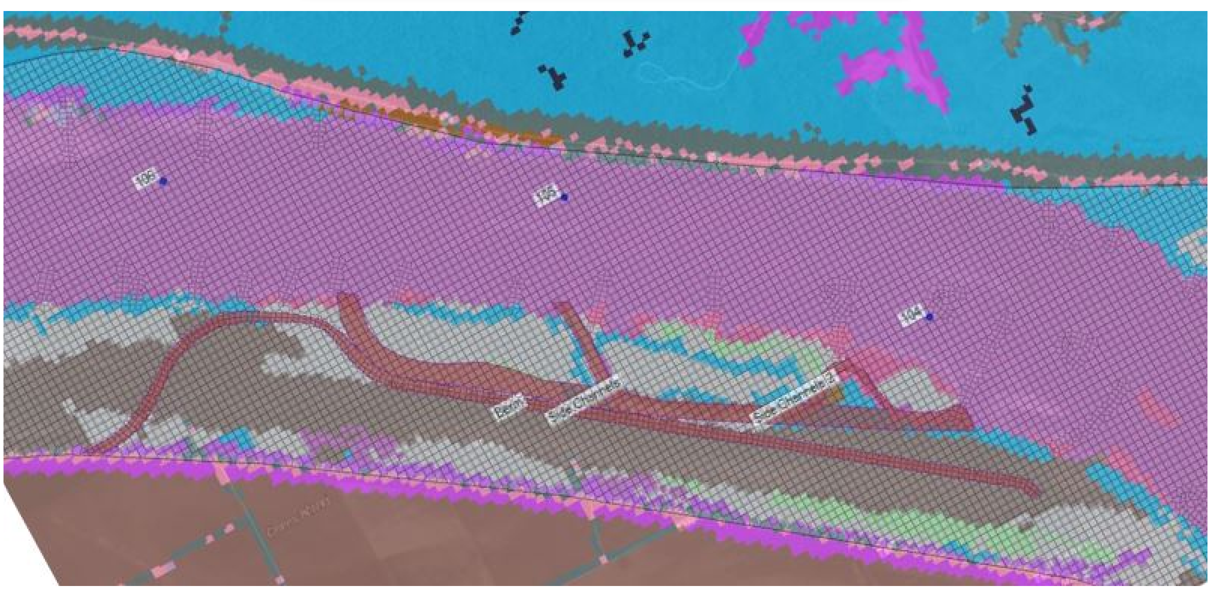

Figure 21. Land Cover Regions for the Model Proposed Condition

4.2. Boundary Conditions for High Flow

For all of the models an upstream boundary condition was set at Chester Gage. The downstream boundary condition for the 1% annual chance exceedance (ACE) flood model was set to the old Bishop Landing Gage rather than the Red Rock gage because there was a 1% ACE water surface elevation from Upper Mississippi River System Flow Frequency Study by the St. Louis District (USACE, 2004). Both of the time series for the 1% ACE flow models were set to a constant Flow (at Chester) and a WSE (Water Surface Elevation) simulating a steady state run. The 1% ACE flow for Chester Gage is 948,000 cfs and the WSE at Bishop Landing is 383.1 ft.

4.3. Boundary Conditions for Low Flow

The downstream boundary condition for the low flow condition was set at Red Rock Landing Gage. The WSE at Red Rock was obtained by adding the zero gage datum (328.92 ft) to the LWRP. Table 7 shows the different low flow scenarios used to evaluate alternatives. These flows range from LWRP+3 to 2 feet above the 20% ACE flow elevation.

Table 7. Low Flows Model Scenarios

Scenario	***Stage at Chester (LWRP= - 0.4)***	***Flow at Chester***	***Stage at Red Rock Landing (LWRP= 2.1)***	***WSE at Red Rock***
LWRP +3	2.6	87,500	5.1	334.02
LWRP +4	3.6	95,200	6.1	335.02
LWRP +5	4.6	103,000	7.1	336.02
50% ACE	30	480,000	32.5	361.42
20% ACE	36.2	619,000	38.7	367.62
20% ACE +2 ft	38.2	676,000	40.7	369.62

4.4. Existing Conditions

The existing conditions model was calibrated comparing the WSE from the HEC-RAS results and Appendix D of the St. Louis District Hydrology and Hydraulics for the Upper Mississippi River System Flow Frequency Study (District Flow Frequency Study). The model was calibrated by changing Manning's n value from the National Land Cover Dataset (NLCD) 2011 version. The n-values were then adjusted to reflect actual conditions using site visit photos. An ACE of 1% was used to calibrate the model. The results of the existing conditions can be seen in Figure 22. The WSE throughout the model ranges from 383.1 downstream to 388.93 on the upstream end of the model. Table 8 compares the values from the District Flow Frequency Study and the HEC-RAS model.

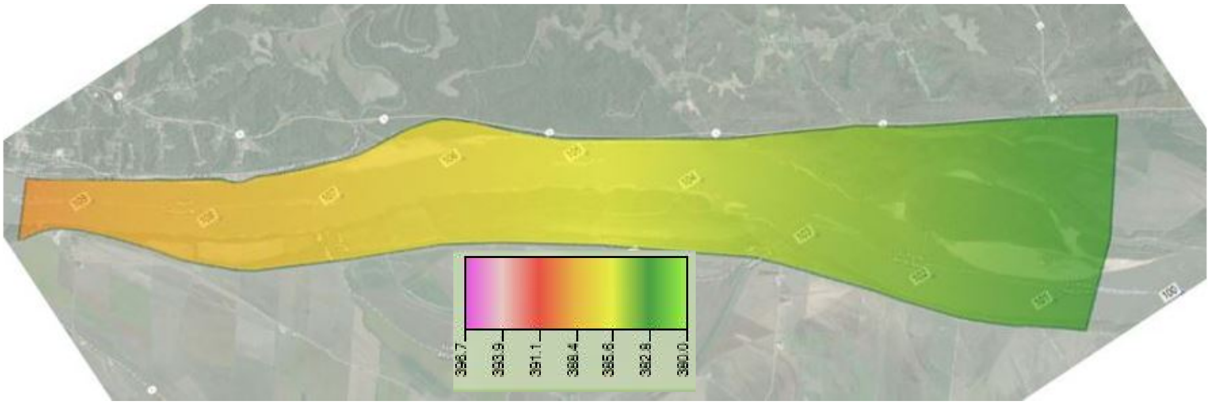

Figure 22. Existing Conditions WSE Model Results

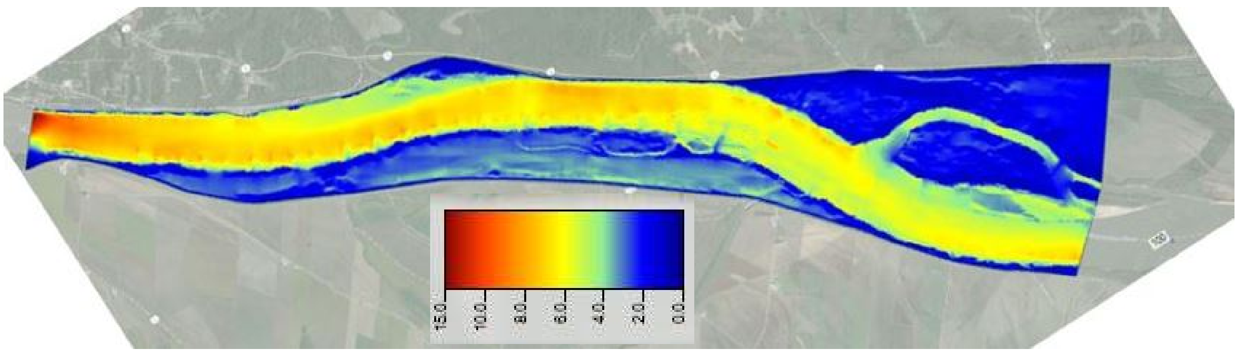

Figure 23. Existing Conditions Velocities Model Results

Table 8. Low Flows Model Scenarios

River Mile	***WSE on 2003 STL Frequency Study (ft)***	***WSE on HEC-RAS 2D model (ft)***
109.9 (Chester Gage)	389.0	388.9
108	387.6	387.5
106	386.6	386.5
105	386.0	385.9
103	384.6	384.5
102	384.0	383.9
100.80 (Bishop Landing Gage)	383.1	383.1

4.5. Proposed Conditions

4.5.1. High Flow Model Results (1% ACE)

The primary focus of the high flow model was to obtain WSE difference (from existing and proposed conditions) of less than 0.01 ft, which is the no-rise requirement for the IL Floodway Permit. For the proposed conditions, the 2D model took into account two different side channel entrances and the addition of the sediment deflection berm. A new mesh was created using HEC-RAS and a new terrain was developed using ArcGIS. The same Manning's n values were used from the calibrated existing condition model, see section 4.1.1. The boundary conditions at Chester and Bishop Landing were also unchanged from the existing condition model. The results for the proposed conditions can be seen in Figure 24.

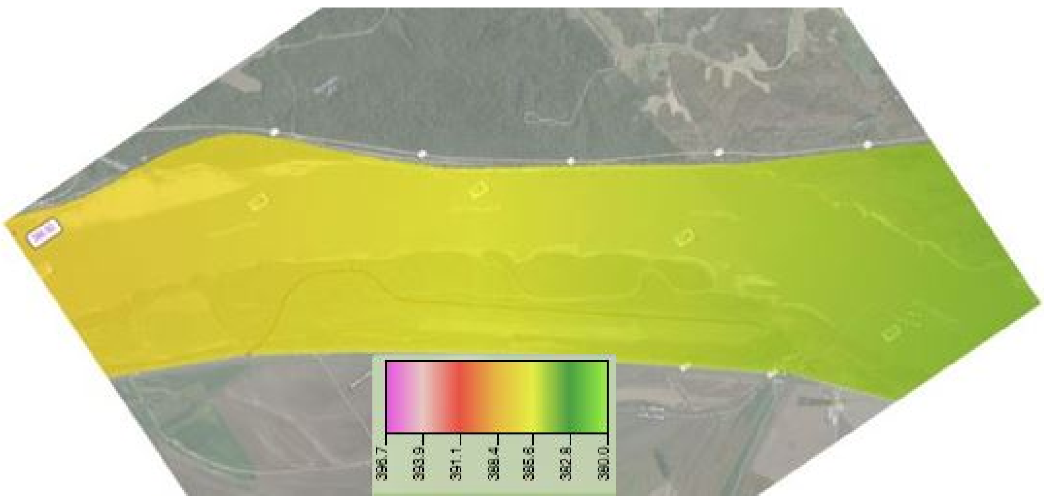

Figure 24. HEC-RAS WSE Results for Proposed Conditions

To compare the existing and proposed WSE results, WSE surfaces were exported from HEC-RAS and imported into ArcGIS. Using a surface difference tool in ArcGIS, several different berm alignments and berm heights were tested and compared to the existing condition. In order to meet the Illinois no-rise requirement it was discovered that a berm height must be less than a 20% ACE (approximately 375.9ft) and the alignment was modified slightly to ensure as little rise as possible. Figure 25 shows the initial and final berm alignments. The initial berm alignment is light blue and the final berm alignment is dark blue.

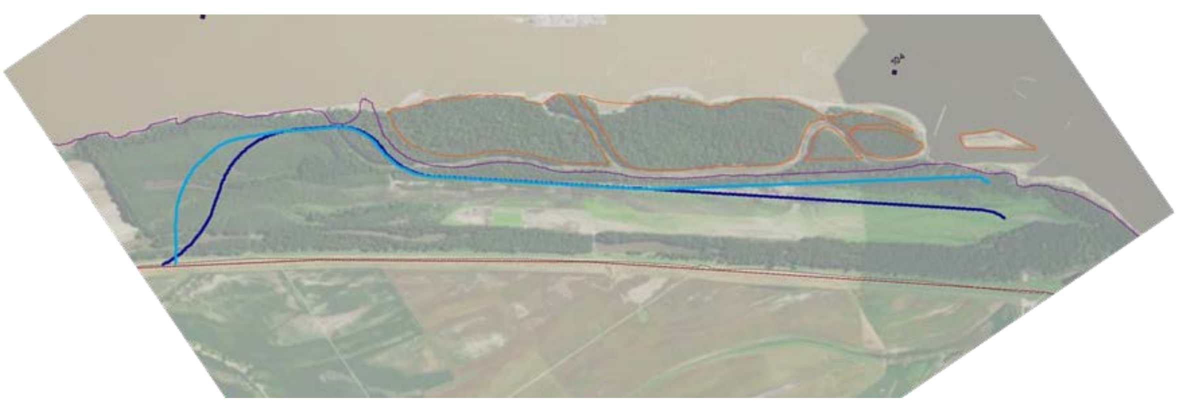

Figure 25. Berm Options Layout from ArcGIS

Figure 26 and Figure 27 show the HEC-RAS water surface elevation differences between proposed berm alignments and the existing condition. Three different shades of blue were used to identify changes in WSE in Figure 26 and Figure 27. The lighter blue represents areas where the WSE of the proposed conditions was at or below the existing condition. The medium blue represents WSE differences 0 ft to 0.01 ft and the dark blue represents areas where the difference in WSE is above 0.01 ft. Figure 26 still showed a localized area of dark blue which indicated that area is above the 0.01 ft threshold. In a 2D HEC-RAS model small areas of localized rise are acceptable provided that it is not near existing infrastructure such as a levee.

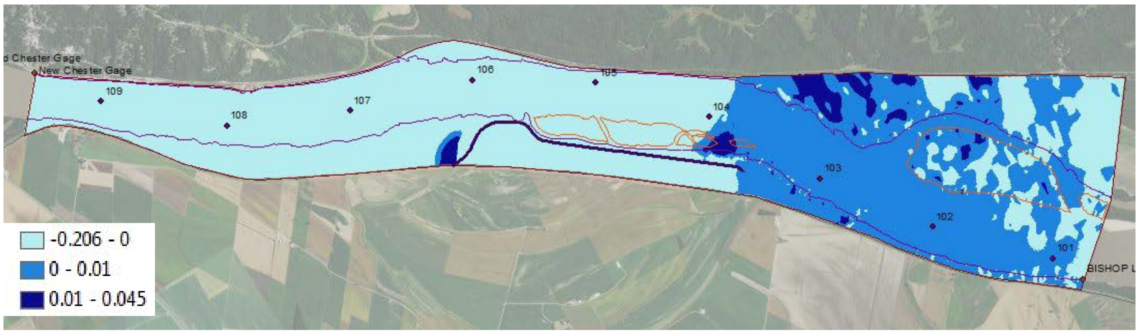

Figure 26. ArcGIS Water Surface Elevation Difference for Original Berm Alignment

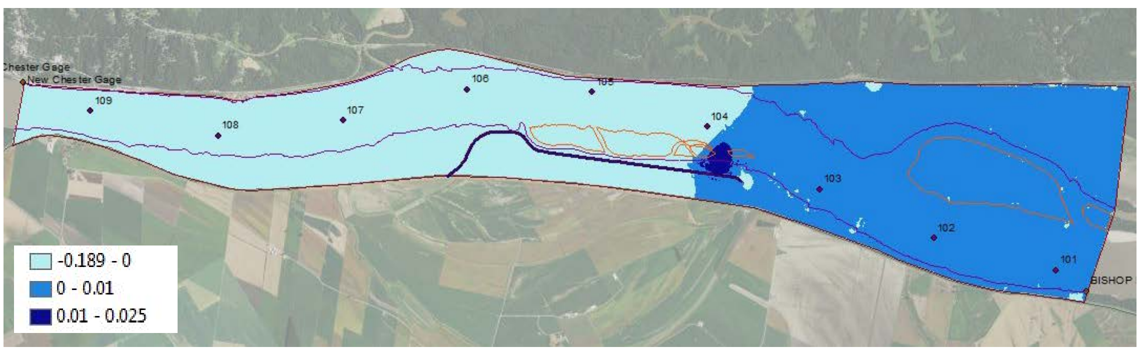

Figure 27. ArcGIS Water Surface Elevation Difference Final Berm Alignment

4.5.2. Low Flow Model Results

Low flow conditions were modeled in HEC-RAS from +0 LWRP to the 20% ACE flow which is the design elevation of the sediment deflection berm. The two main purposes of the Berm is to increase the average velocities and flow throughout the side channels, and to reduce the flow coming from upstream of the berm, allowing water to backflow from the downstream end of the Berm. The low flow model was used to illustrate how water will backflow over Crains Island and meet its intended environmental objective. It will was also used to determine the average velocities, depths and flows on the proposed side channels for a variety of flow scenarios. Also, this low flow model was used to determine the flow distribution between the main channel and proposed side channel.

See Figure 28 through Figure 30 for depth (ft) plots from the HEC-RAS that model show the progression of backwater flooding behind the berm as river stages rise. This backwater will allow increased settling time for fine sediments to deposit which will improve soils over time for hard mast tree establishment.

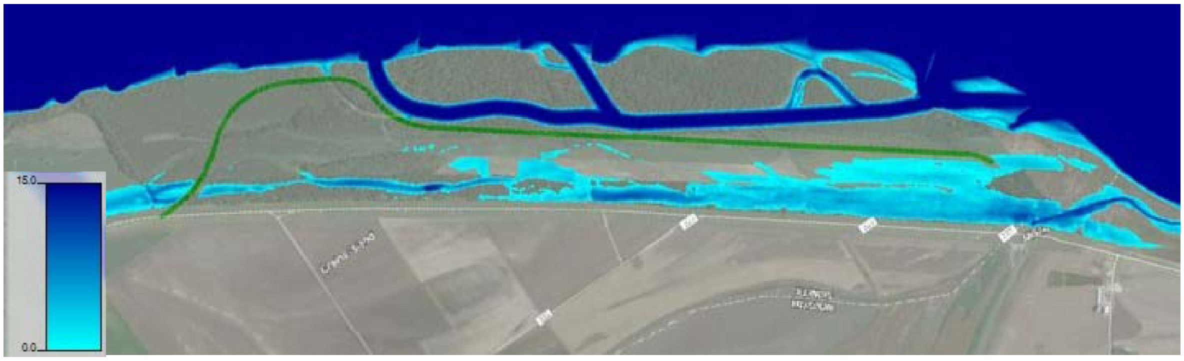

Figure 28. HEC-RAS depth (ft) plot at 24.6 on the Chester gage. (+25 LWRP)

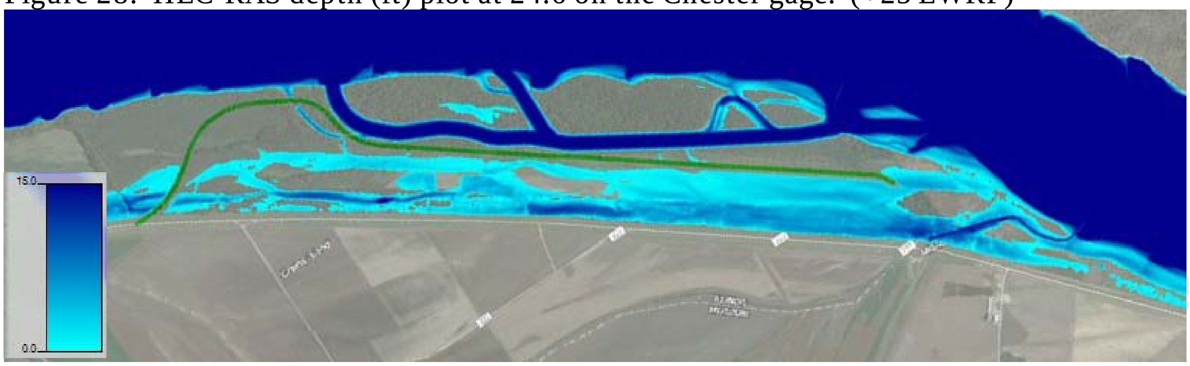

Figure 29. HEC-RAS depth (ft) plot at 26.6 on the Chester gage. (+27 LWRP)

Figure 30. HEC-RAS depth (ft) plot at 31.2 on the Chester gage. (+30.8 LWRP or 50% ACE)

Figure 31 and Figure 32 show results from the model which indicate that the berm will prevent flow entering upstream until overtopped.   Reducing flows will consequently reduce the coarse sediment from the main channel to the project area. The velocities behind the berm drop from 1-2 ft/s down to nearly 0 ft/s. The drop in velocity should allow fine sediment to deposit behind the berm.

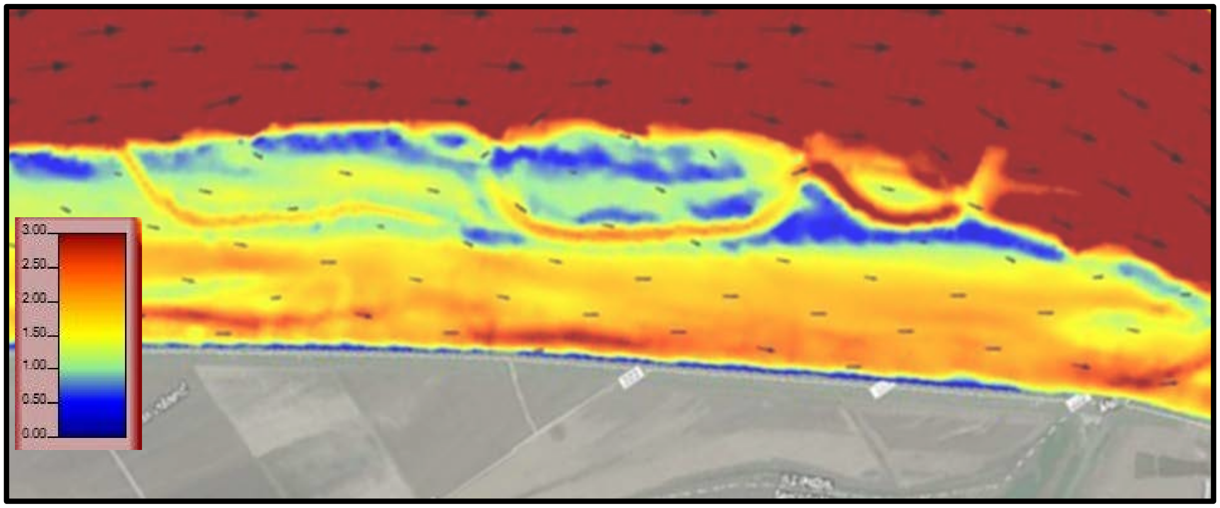

Figure 31. Existing condition velocity (ft/s) at a 20% ACE .

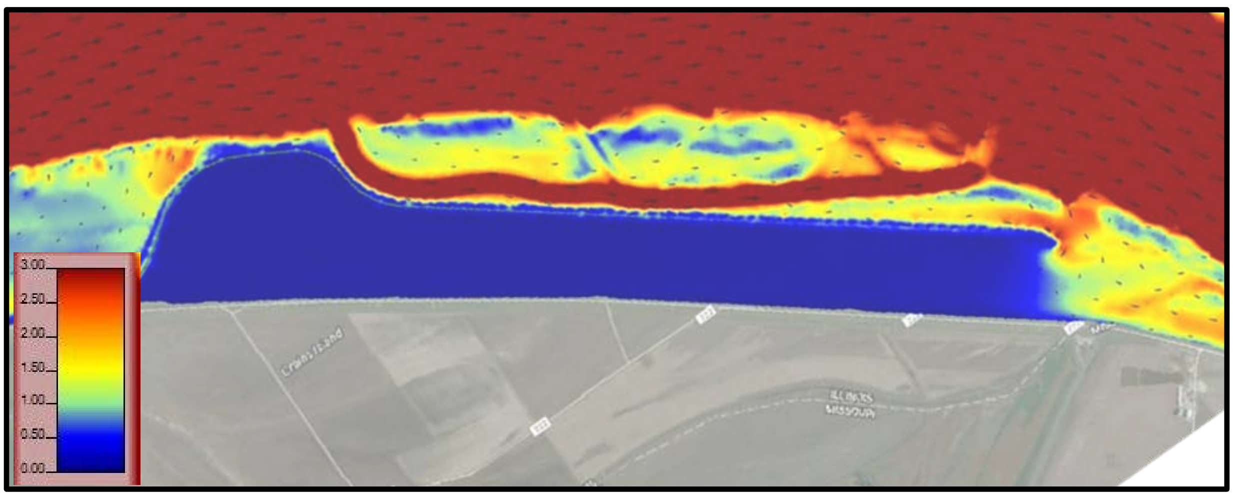

Figure 32. Proposed condition velocity (ft/s) at a 20% ACE just prior to overtopping the sediment deflection berm.

For the second analysis, two options were modeled, changing the second entrance of the side channel. The changes in the second entrance is illustrated by comparing Figure 25 and Figure 26. The main difference between the two options is the angle it which the second entrance is connected to the main channel.

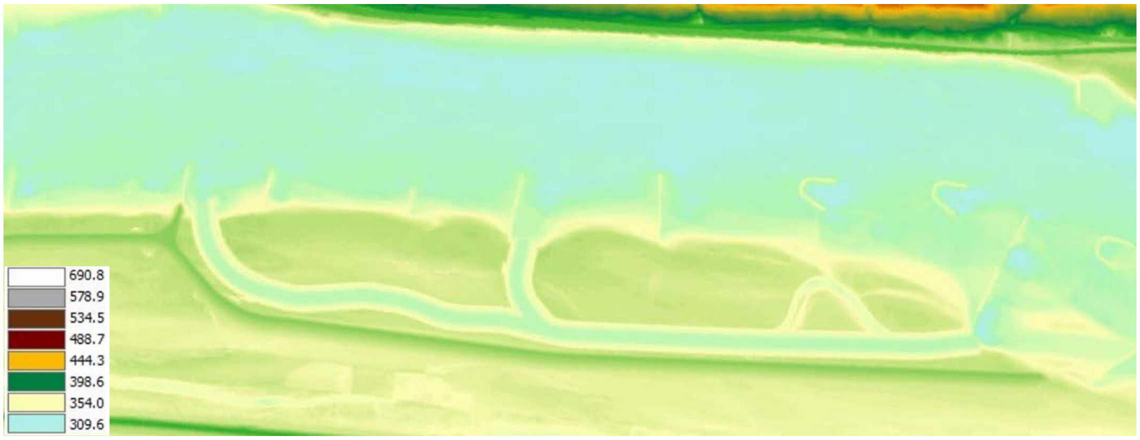

Figure 33. Side Channel Alignment Option 2

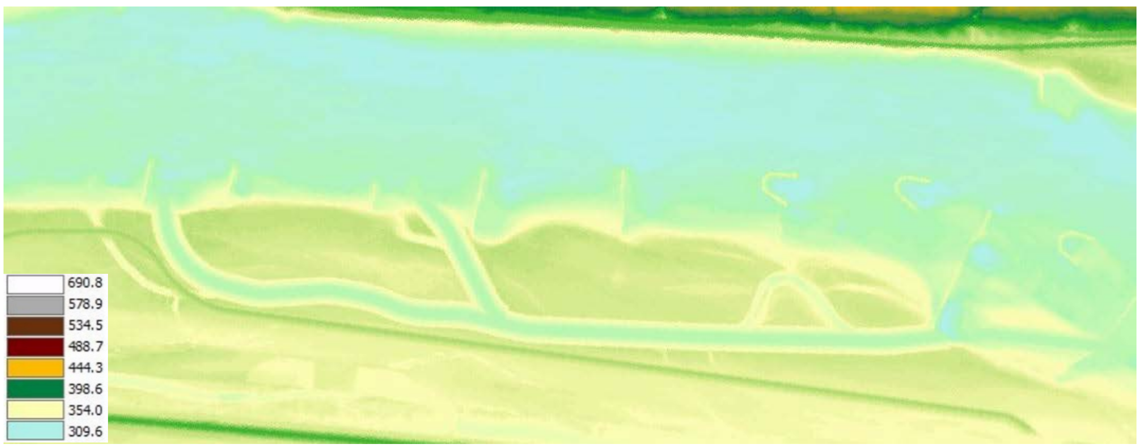

Figure 34. Recommended Side Channel Alignment

HEC-RAS model results confirmed that the recommended option will improve the velocities through the second entrance which will help avoiding sediment deposition. Table 9 shows the velocities for the recommended option were drastically increased.

Table 9. Side Channels Results for the Second Entrance

		Option 2			Recommended Option		
Flow (cfs)	Scenario	**Avg Velocity (ft/s)**	Min Velocity (ft/s)	Max Velocity (ft/s)	**Avg Velocity (ft/s)**	Min Velocity (ft/s)	Max Velocity (ft/s)
66,700	LWRP	**0.04**	0	0.16	**0.22**	0.11	0.69
103,000	+5 LWRP	**0.03**	0	0.17	**0.40**	0.19	1.00
130,000	+8 LWRP	**0.02**	0	0.16	**0.38**	0.22	0.99
480,000	50% ACE	**0.26**	0.07	1.46	**1.10**	0.86	1.89
622,000	20% ACE	**0.74**	0.37	2.25	**1.98**	1.68	2.98
707,000	10% ACE	**0.97**	0.53	2.58	**2.85**	2.60	3.79

Kansas City District recommends that constructed side channels do not draw more than 10% of the flow from the main channel so that impacts to navigation are minimized. A flow split analysis was conducted using HEC-RAS. The flow distribution for six flow conditions is shown in Table 10. It was determined at +3 LWRP that 0.12% of the flow would be diverted. Lower flows such as +0 LWRP would draw even less flow.

Table 10. Flow Distribution on Low Flows Model

	Main Channel Flow (cfs)		***Side Channel flow (cfs)***	***Flow Distribution***	
Scenario	**Upstream**	**Downstream**	**Average**	**% of Flow on Side Channels**	**% of Flow on Main Channel**
LWRP +3	87,529	87,439	102	0.12%	99.90%
LWRP +4	95,200	95,066	158	0.17%	99.86%
LWRP +5	103,000	102,809	248	0.24%	99.81%
50% ACE	478,932	456,594	23,478	4.90%	95.34%
20% ACE	595,797	558,997	34,489	5.79%	93.82%
20% ACE + 2ft	642,020	601,282	38,777	6.04%	93.65%

HEC-RAS results for low flow conditions show that the average flow in the new side channel will be between 0.32 and 5.32 feet per second depending on the scenario. See Table 11 for a full list of flow conditions and the resulting velocity in the side channel.

Table 11. Side channel results from Low Flows Model.

Scenario	***Stage at Chester (LWRP= - 0.4)***	***Stage at Red Rock Landing (LWRP= 2.1)***	***Flow at Chester (cfs)***	***Velocity (ft/s)***
LWRP +3	2.6	5.1	87,500	0.32
LWRP + 4	3.6	6.1	95,200	0.37
LWRP +5	4.6	7.1	103,000	0.47
LWRP +10	9.6	12.1	150,000	1.41
LWRP +15	14.6	17.1	212,000	2.38
LWRP +20	19.6	22.1	289,000	3.13
LWRP +25	24.6	27.1	378,000	3.91
LWRP +30	29.6	32.1	472,000	4.52
50% ACE flow	30	32.5	480,000	4.52
LWRP +35	34.6	37.1	579,000	4.94
20% ACE flow	36.2	38.7	619,000	5.09
20% ACE +2’ flow	38.2	40.7	676,000	5.32

6. CLIMATE CHANGE

6.1. Phase 1 Climate Change

6.1.1. 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.

Table 12. Precipitation data at Lambert Airport

	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.

Table 13. Temperature data at Lambert Airport

	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**				

6.1.2. Climate Change

US Army Corps of Engineers personnel have authored regional reports summarizing available scientific literature available to meet the Corps goal of addressing potential climate change impacts in planning and decision making. Crains Island falls 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:

Summary of Observed Climate Findings:

The general consensus in the recent literature points toward moderate increases in temperature and precipitation, and streamflow in the Upper Mississippi Region over the past century. In some studies, and some locations, statistically significant trends have been quantified. In other studies and locales within the Upper Mississippi Region, apparent trends are merely observed graphically but not statistically quantified. There has also been some evidence presented of increased frequency in the occurrence of extreme storm events (Villarini et al., 2013). Lastly, a transition point in climate data trends, where rates of increase changed significantly, was identified by multiple authors at approximately 1970.

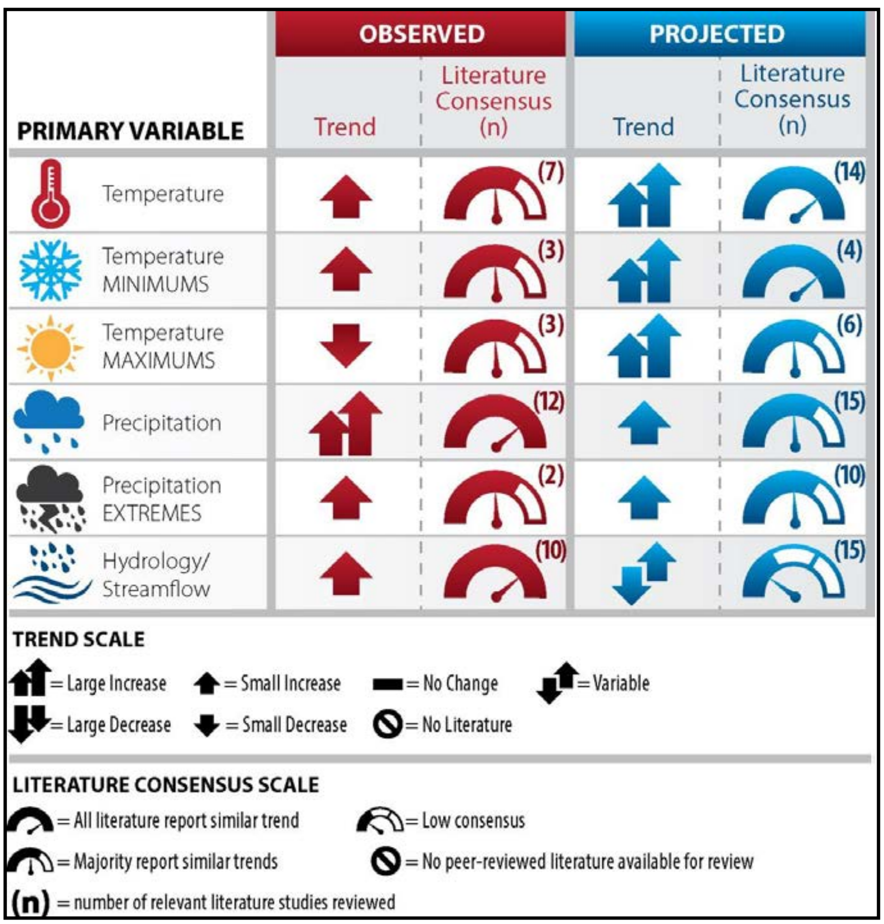

Figure 35. Summary matrix of observed and projected regional climate trends and literature consensus (from USACE 2015b)

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 °C (3.6 to 10.8 °F) 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.

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 to consider only 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 Chester Gage near Chester, IL (7020500) is shown in Figure 36. 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 change in peak flows over the last 72-year period of record (1942-2014).

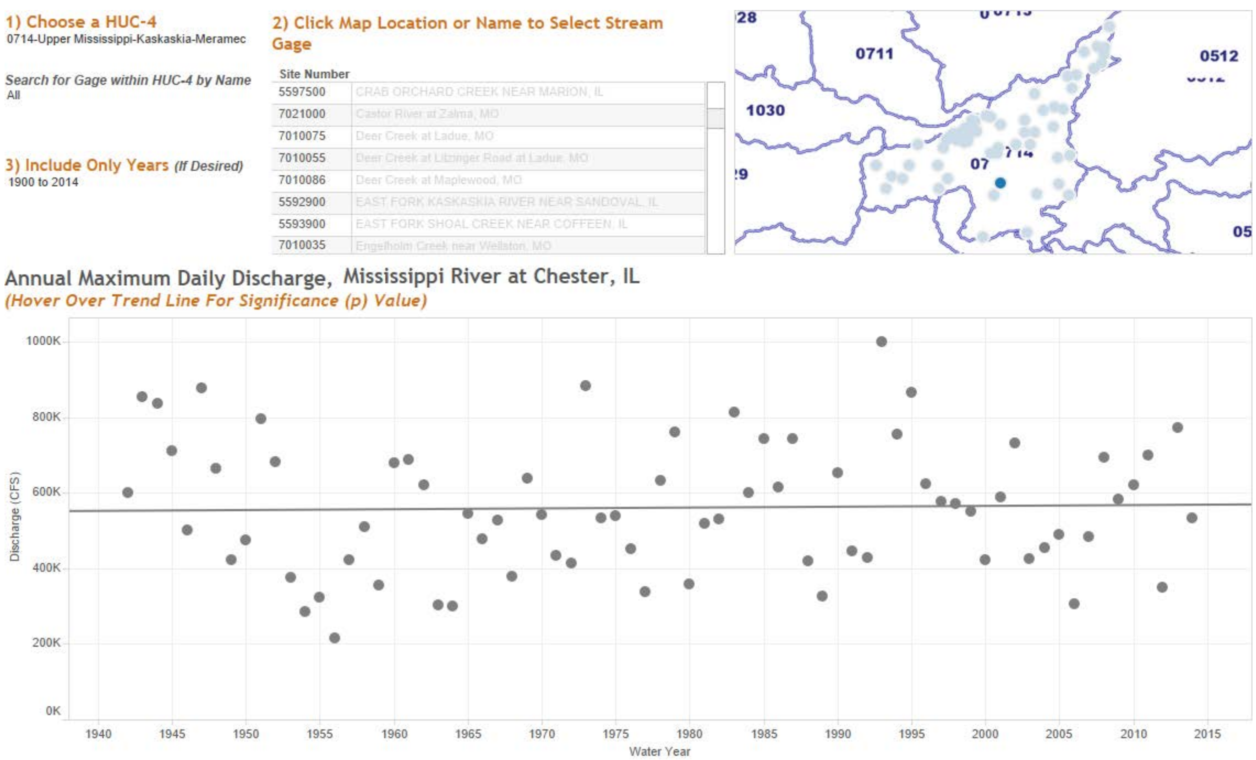

Figure 36. Annual Peak Instantaneous Streamflow, Mississippi River at Chester, Trendline Equation: Q = -219.332 * (Water Year) + 126640, p = 0.819679.

The Nonstationarity Detection Tool was also used to examine the hydrologic time series at the Chester gage near Chester, IL (7020500). The Bayesian sensitivity had to be increased to 0.9 because it was observing nonstationaries nearly every year. No other nonstationarities were detected in the record Figure 37, 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 48 years (1967 – 2015) was used since the Missouri River reservoirs came online in 1967. The results of the nonstationarity detection analysis indicate that overall, there has been no statistically significant change in annual peak flows, as measured.

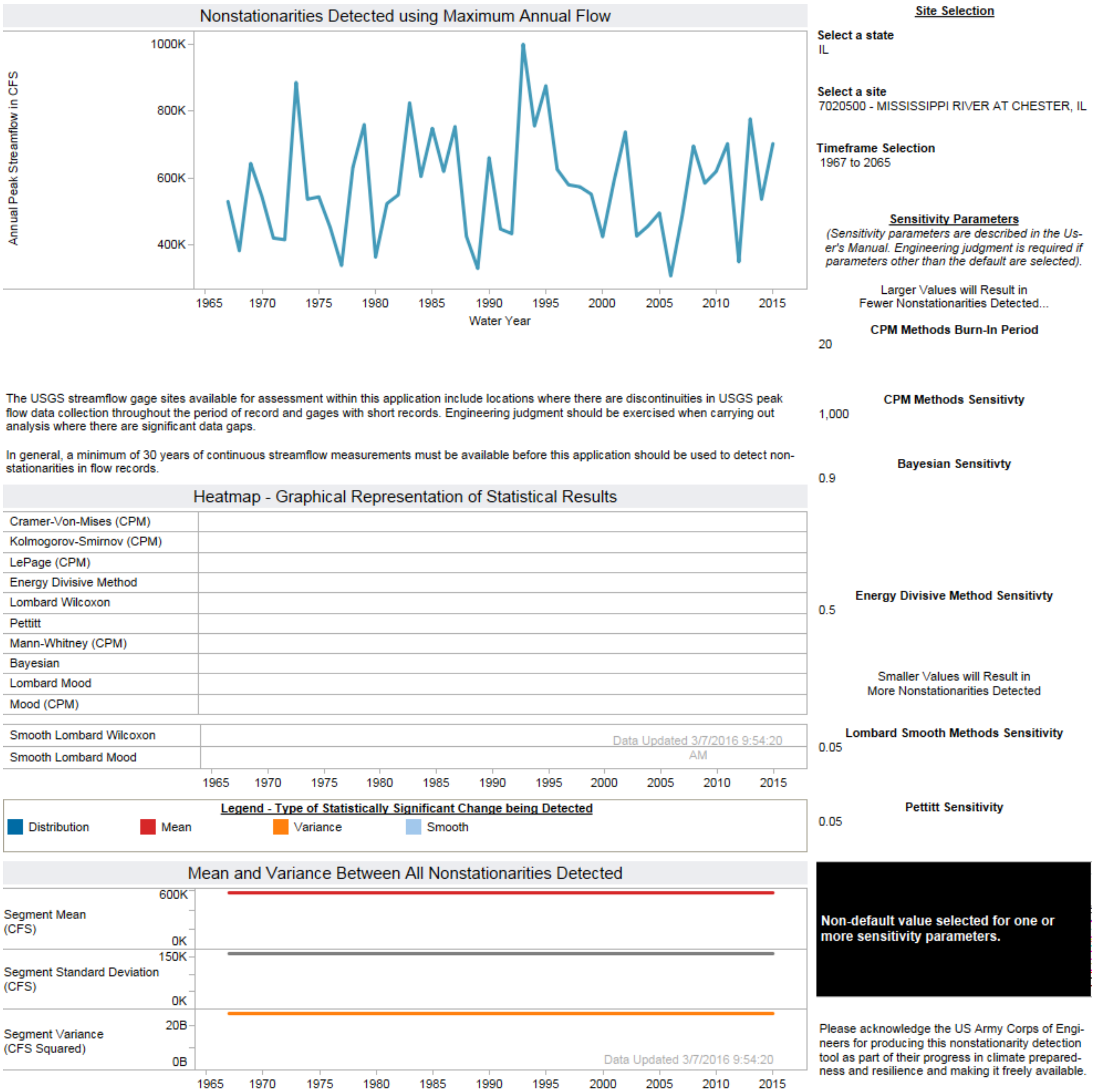

Figure 37. Nonstationarity Analysis of Maximum Annual Flow, Mississippi River near Chester, IL.

6.2. Phase 2 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 38), the overall projected trend in annual peak instantaneous streamflow increases over time (Figure 39). This increase is statistically-significant (p-value <0.0001). This finding suggests that there may be potential for higher peak streamflows in the future.

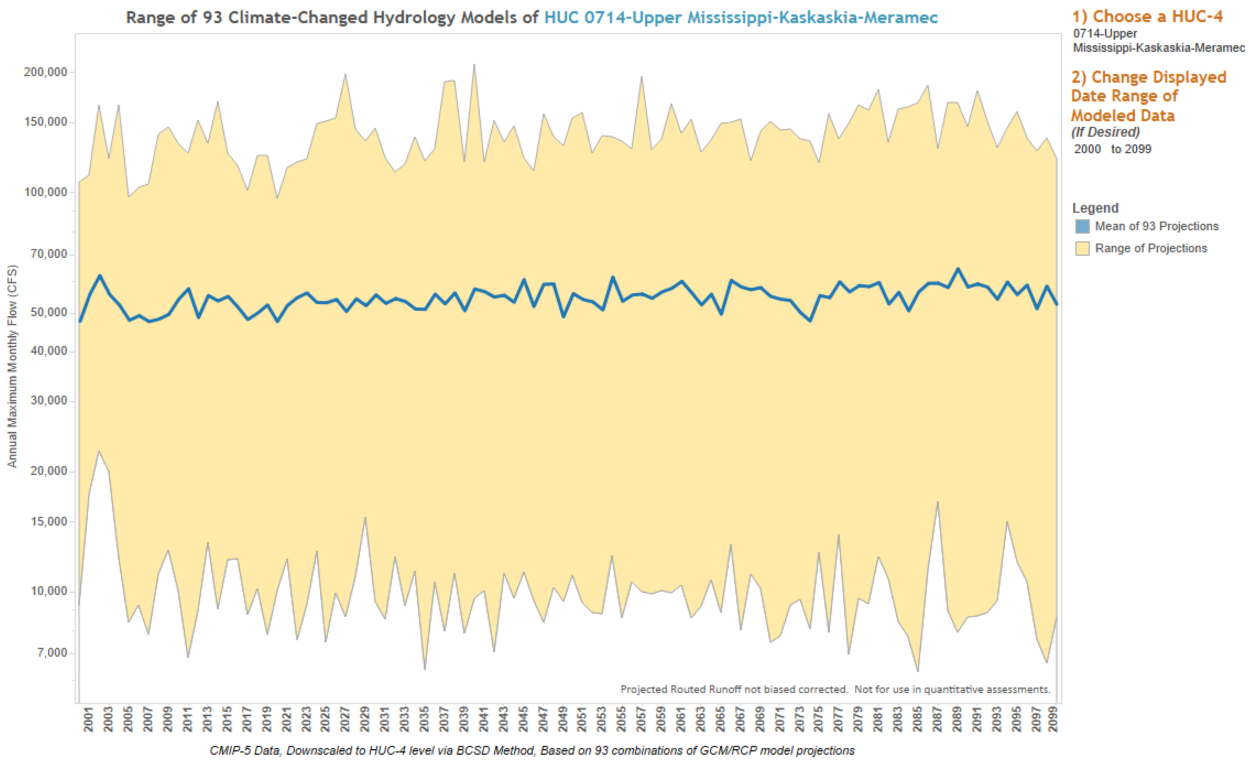

Figure 38. Range in the Projected Annual Maximum Monthly Flows, HUC 0714 Upper Mississippi-Kaskaskia-Meramec

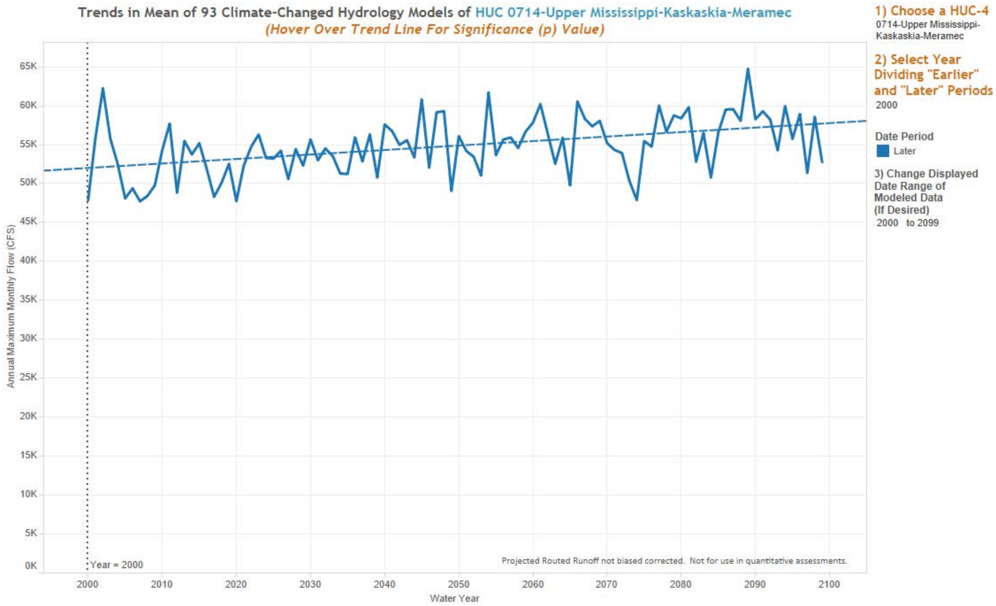

Figure 39. Mean Projected Annual Maximum Monthly Streamflow, HUC 0714 Upper Mississippi-Kaskaskia-Meramec. Trendline Equation: Q = 57.5719 * (Water Year) – 63194.8, $p < 0.0001$

6.3. 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 Crains Island because it is an ecosystem restoration project, not a flood control project. Average daily flows were analyzed using 15 year time increments from 1951 – 2016. Figure 40 shows average daily flows increased during the 1961 -1976 period. From 1976 – 2016 averages have remained consistent, but they have shifted later into the year.

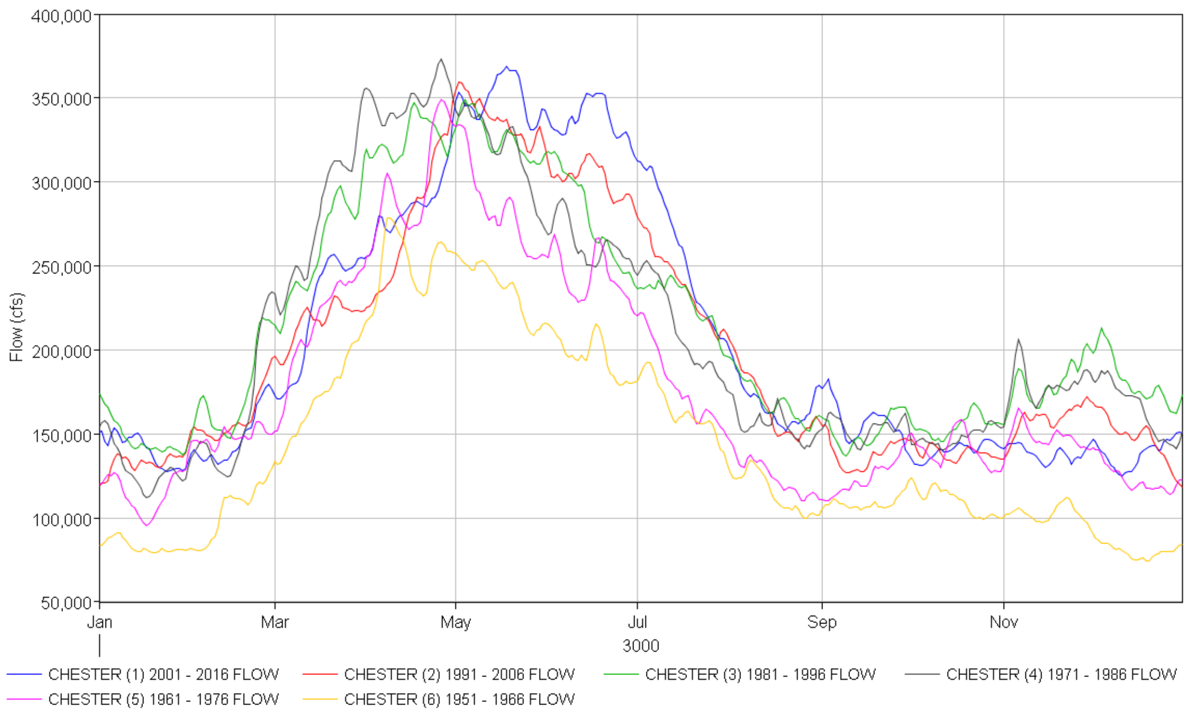

Figure 40. Daily Average Flow for the Mississippi River at Chester, IL (RM109.9) in 15 year increments from 1951 to 2016. Increments include: 1961 to 1976, 1971 to 1986, 1981 to 1996, 1991 to 2006, and 2001 to 2016.

References

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