UPPER MISSISSIPPI RIVER RESTORATION
FEASIBILITY REPORT
WITH INTEGRATED ENVIRONMENTAL ASSESSMENT

BEAVER ISLAND
HABITAT REHABILITATION AND ENHANCEMENT PROJECT

POOL 14, UPPER MISSISSIPPI RIVER MILES 513.0-517.0
CLINTON COUNTY, IOWA

APPENDIX H

HYDRAULICS AND HYDROLOGY

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TABLES

FIGURES

PHOTOGRAPH

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APPENDIX H

HYDRAULICS AND HYDROLOGY

I. INTRODUCTION AND LOCATION

The *Beaver Island Habitat Rehabilitation and Enhancement Project* (Project) is located between River Miles (RM) 513.0 and 517.0 within Pool 14 of the Upper Mississippi River, near the communities of Clinton and Camanche, Iowa, and Albany, Illinois. It is situated on the Iowa (western) side of the Mississippi River, along the inside of a large bend in the river. Beaver Slough flows along the right-descending bank (RDB) of the island and the Mississippi River flows along the left-descending bank (LDB).

Beaver Island is located in the upper third of Pool 14, approximately 22 miles upstream of Lock and Dam 14 and 7 miles downstream of Lock and Dam 13. Lock and Dam 14 is located near LeClaire, Iowa, and was placed into operation in June 1939. Lock and Dam 13, located in Fulton, Illinois, was placed into operation in May 1939. Pool 14 extends from RM 493.3 to RM 522.4 and includes portions of Clinton and Scott Counties in Iowa, and Rock Island and Whiteside Counties in Illinois. The Wapsipinicon River is the largest tributary to Pool 14 and is located on the Iowa side, approximately 8 miles downstream of the Project. Mill Creek, one of several minor tributaries to Pool 14, enters the Mississippi River along the lower end of Beaver Slough, adjacent to the Project. All elevations used in this appendix are expressed using the North American Vertical Datum of 1988 (NAVD88) unless otherwise stated. Table H-1 shows the conversion from NAVD88 to MSL 1912 encompassing the island reach.

Table H-1: Elevation Conversion from NAVD88 to MSL 1912 in Feet

River Mile	NAVD88 to MSL 1912 Conversion (ft)	River Mile	NAVD88 to MSL 1912 Conversion (ft)
511.8	+0.80	515.1	+0.86
512	+0.80	515.5	+0.87
512.7	+0.82	516	+0.88
513	+0.82	516.6	+0.89
513.3	+0.83	516.75	+0.89
513.5	+0.83	517	+0.89
514	+0.84	517.7	+0.91
514.4	+0.85	517.95	+0.91
515	+0.86	518.0	+0.91

II. CLIMATE

Monthly climate data for the Clinton #1 U.S. Cooperative Network Station (gage #131635) is summarized in Tables H-2 and H-3. The data for precipitation, snowfall and temperature below is from the most recent 30-year period, 1985-2014.

Table H-2: Average and Extremes of Monthly Precipitation and Snowfall (COOP gage #131635)

	Precipitation					Snow		
	Average	Maximum		Minimum		Average	Maximum	
Month	(in)	(in)	Year	(in)	Year	(in)	(in)	Year
Jan	1.47	2.84	1999	0.64	1986	9.4	20.3	1995
Feb	1.61	3.33	2001	0.17	1987	7.4	27.0	2008
Mar	2.24	5.27	1991	0.58	2014	3.1	13.3	1999
Apr	3.05	7.55	2013	0.75	2005	0.5	5.9	1997
May	3.94	12.35	1996	0.74	1992	0.0	0.0	
Jun	4.60	14.63	1990	0.89	1988	0.0	0.0	
Jul	3.60	8.75	1992	0.15	1991	0.0	0.0	
Aug	4.41	13.78	1987	1.10	2013	0.0	0.0	
Sep	2.95	6.35	1992	0.61	2009	0.0	0.0	
Oct	2.44	6.48	1985	0.29	2005	0.1	2.5	1997
Nov	2.12	5.42	1985	0.26	2007	1.6	10.3	1997
Dec	1.85	3.50	1992	0.48	1995	8.9	25.6	2000
Annual	**34.25**					**31.28**		

Fluctuation of temperatures in east-central Iowa can be extreme, evidenced by a minimum monthly temperature of -29°F in February and a maximum monthly temperature of 103°F in July. Precipitation is moderate with an average annual value of 34.25 inches. The average annual snowfall is 31.28 in.

Table H-3: Average and Extremes of Monthly Temperature (COOP gage #131635)

Month	Average (°F)	Maximum (°F)	Minimum (°F)
Jan	22.36	67	-27
Feb	26.27	70	-29
Mar	39.27	87	-15
Apr	51.84	91	16
May	62.51	94	24
Jun	71.25	100	39
Jul	74.89	103	49
Aug	72.64	101	39
Sep	65.05	98	29
Oct	52.91	91	15
Nov	39.50	79	2
Dec	26.52	70	-22
Annual	**50.52**		

III. TOPOGRAPHY

The Upper Mississippi River Restoration (UMRR) collaborated with the State of Iowa for collection of Pool 14 LiDAR. This data was flown on November 13, 2007 during a river elevation of 571.07 feet at Lock and Dam 14 (0.18 foot below flat pool) and 572.44 feet at the Camanche gage (RM 511.8) (55 percent duration). Land survey collected in 2014 was used to ground-truth the LiDAR and revealed the LiDAR to be on average 1.8 feet higher in elevation than the conventional survey. As a result, the LiDAR data on Beaver Island and in the vegetated areas within the model reach was adjusted down by 1.8 feet.

The Beaver Island Project area is 1,678 acres. Elevations throughout the Project area range from 555.2 feet to 612.8 feet. However, 82 percent of the Project area ranges in elevation from 571 to 580 feet. The highest elevations within the Project area exist along the middle reach of the right-descending island bank where dredged material historically had been placed in addition to a ridge feature near the upper end of the island that appears to represent a former island boundary.

Beaver Island is comprised of a network of channels and long and narrow backwater lakes. These backwater features include Upper Lake, Lower Lake, Sand Burr Lake, Blue Bell Lake, Stewart Lake, Crappie Slough and many others (Figure H-1). Some of these channels convey water throughout the year and others are ephemeral. Albany Island is a small island located near the lower LDB of Beaver Island. During 50 percent chance exceedance flood conditions, approximately 98 percent of Beaver Island is inundated.

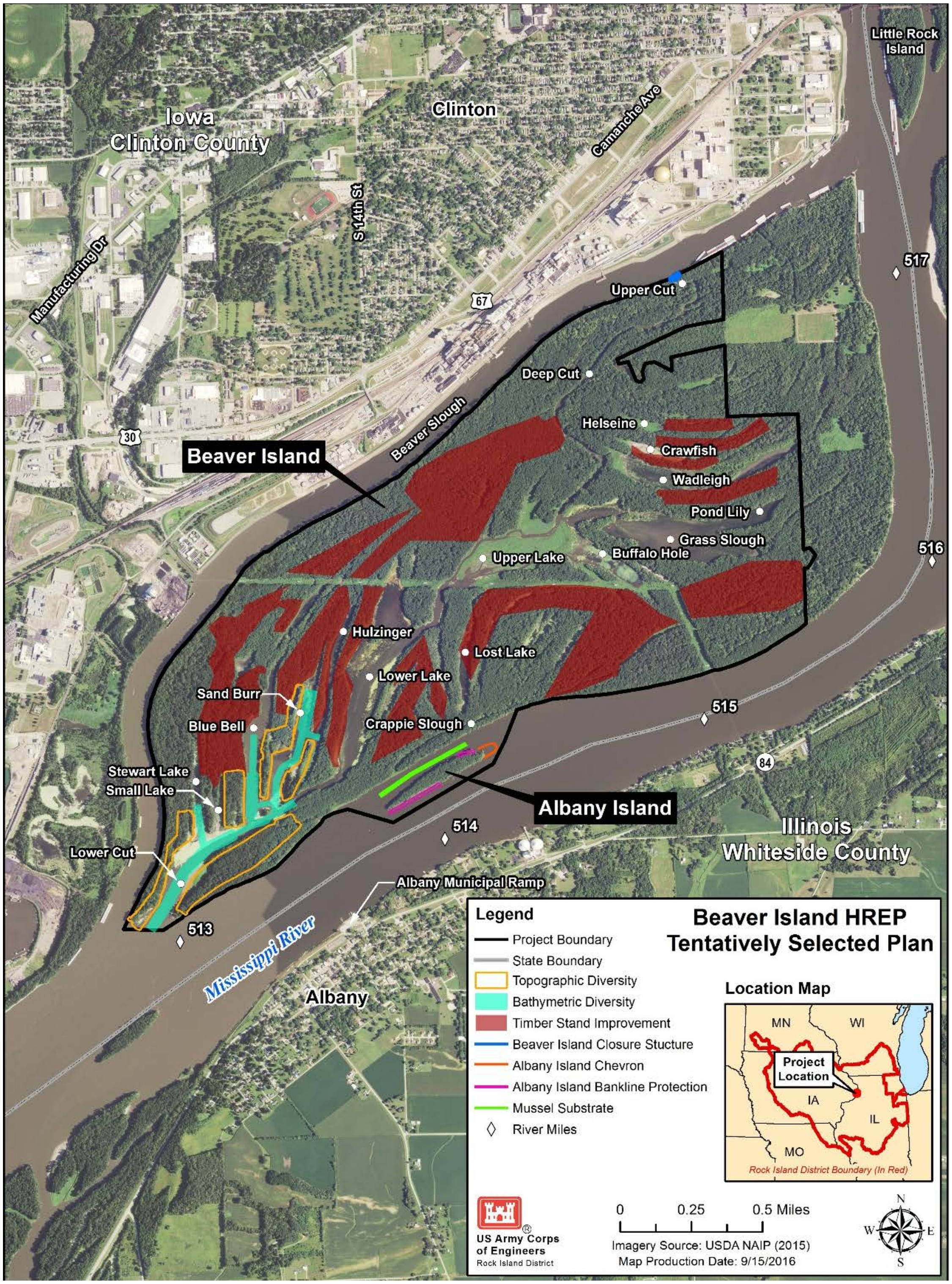

Figure H-1: Project Feature Map

IV. MISSISSIPPI RIVER – POOL 14

A. Historic and Current Mississippi River Hydrology. The Rock Island District records continuous stages at Lock and Dam 14 and at Lock and Dam 13. The USGS manages a stream gage on Beaver Slough (USGS gage 05420460) and the Rock Island District and the USGS make joint use of the stream gage at Camanche, Iowa (USGS gage 05420500, Mississippi River at Clinton, Iowa). A summary of the nearby gages and their characteristics is presented in Table H-4. The Clinton/Camanche gage (RM 511.8) is closest to the Project, and provides the longest period of record. The USGS maintains discharge records for a period of record beginning in 1873 to present for the Clinton/Camanche gage, whereas the Rock Island District maintains stage records for a period from 1939 (following construction of the locks and dams) to present. The Rock Island District has maintained records of discharge at the lock and dam gages since 1986.

Lock and Dam 14 provides navigable channel depths by maintaining a minimum water surface elevation of 571.24 feet (flat pool). Pool 14 is regulated using a dam control point. The annual hydrograph is impacted by the dam, whereby low river stages are made higher during low discharge periods, ultimately resulting in less river stage fluctuation. However, as you move further upstream in the pool, the effects of the dam are diminished and greater fluctuation in river stage occurs as illustrated in Figure H-2. As shown in this figure, the Clinton/Camanche gage, located approximately 1 mile downstream of the Project, in the upper portion of the pool, experiences significant fluctuation.

The Pool 14 drainage area is 88,400 square miles and includes portions of Illinois, Iowa, Minnesota, South Dakota and Wisconsin. The average annual discharge measured at the USGS Clinton gage is approximately 56,400 cfs (period of record 1984-2013). The long-term average annual stage hydrograph (at Clinton/Camanche) is characterized by a spring rise resulting from early rains and snowmelt (Figure H-2). The stage remains high through late spring to early summer as rain and snow or rain only events can produce floods. Stages typically decline sharply in July marking the beginning of a low-flow period that extends into mid-September before fall rains result in a modest rise that extends into the early winter months when flows drop off as tributary flows begin to decline due to freezing conditions.

Table H-4: Summary of Available Stream Gages

Gage Name	River Mile	Drainage Area (sq. miles)	Gage Zero Elevation (ft MSL 1912)	Gage Zero Elevation (ft NAVD88)	Period of Record	Flat Pool/Tail(ft MSL 1912) (ft NAVD88)
Mississippi River at Lock & Dam 13, Fulton, Illinois (Tailwater)	522.4	85,500	568.70	567.71	1939-present	572.00 571.01
USGS gage 05420460 Beaver Slough at 3rd St. at Clinton, Iowa	516.6	85,600	562.68 [1]	562.33	1992-present	n/a
Mississippi River at Camanche, Iowa/ (USGS gage 05420500 Mississippi River at Clinton, Iowa)	511.8	85,600	563.21 (562.68 [1])	562.41 (562.41)	1939-present (1873-present)	n/a
Mississippi River at Lock & Dam 14, LeClaire, Iowa (Pool)	493.3	88,400	557.08	556.34	1939-present	571.98 571.24

[1] References NGVD 1929 Vertical Datum

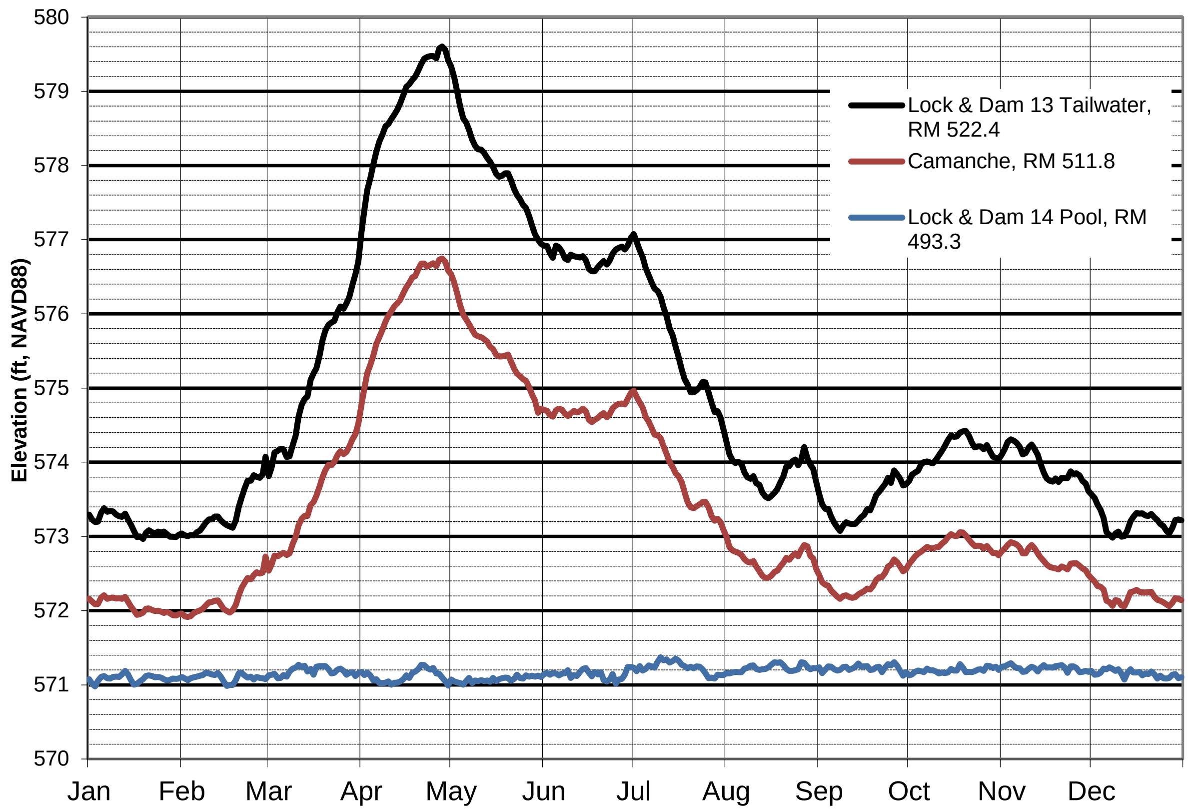

Figure H-2: Average Annual Elevation Hydrographs for the Upper, Middle, and Lower Portions of Pool 14 (1984-2013)

B. Flood Conditions. The 2004 Upper Mississippi River System Flow Frequency Study (2004 UMRS Flow Frequency Study) includes several cross sections through the Beaver Island reach (Reference 1). Table H-5 shows results from the 2004 UMRS Flow Frequency Study that pertain to Beaver Island; however, the elevations are in MSL 1912. The 50 percent exceedance probability discharge at RM 514 is 131,000 cfs, with a resulting water surface elevation of 578.7 feet NAVD88 (579.5 feet MSL 1912).

Table H-5: 2004 Upper Mississippi River System Flow Frequency Study (Elevations in MSL 1912)

	Exceedance Probability															
River	0.5		0.2		0.1		0.04		0.02		0.01		0.005		0.002	
Mile	feet	cfs	feet	cfs	feet	cfs	feet	cfs	feet	cfs	feet	cfs	feet	cfs	feet	cfs
510.1	578.3	131,000	580.6	174,000	582.5	202,000	584.5	235,000	586.1	260,000	587.5	283,000	588.6	306,000	589.8	337,000
511	578.5	131,000	580.9	174,000	582.8	202,000	584.8	235,000	586.4	259,000	587.8	283,000	588.9	306,000	590.1	337,000
511.6	578.7	131,000	581.1	174,000	583.1	202,000	585.1	235,000	586.6	259,000	588.0	283,000	589.1	306,000	590.3	337,000
512	578.9	131,000	581.4	174,000	583.3	202,000	585.4	235,000	586.9	259,000	588.3	283,000	589.4	306,000	590.6	337,000
512.7	579.1	131,000	581.6	174,000	583.6	202,000	585.6	235,000	587.2	259,000	588.6	283,000	589.7	306,000	590.9	337,000
513	579.2	131,000	581.8	174,000	583.8	202,000	585.9	235,000	587.4	259,000	588.9	283,000	590.0	306,000	591.2	337,000
514	579.5	131,000	582.2	174,000	584.1	202,000	586.3	235,000	587.8	259,000	589.3	283,000	590.4	306,000	591.5	337,000
514.4	579.7	131,000	582.4	174,000	584.3	202,000	586.5	235,000	588.0	259,000	589.5	283,000	590.6	306,000	591.7	337,000
515	579.9	131,000	582.6	174,000	584.6	202,000	586.7	235,000	588.3	259,000	589.8	283,000	590.9	306,000	592.0	337,000
515.5	580.1	131,000	582.9	174,000	584.9	202,000	587.0	235,000	588.6	259,000	590.0	283,000	591.1	306,000	592.3	337,000
516	580.4	131,000	583.1	174,000	585.1	202,000	587.2	235,000	588.8	259,000	590.2	283,000	591.3	306,000	592.5	337,000
516.6	580.5	131,000	583.3	174,000	585.3	202,000	587.4	235,000	589.0	259,000	590.4	283,000	591.5	306,000	592.7	337,000
517	580.6	131,000	583.4	174,000	585.4	202,000	587.6	235,000	589.1	259,000	590.6	283,000	591.7	306,000	592.8	337,000
517.7	580.8	131,000	583.6	174,000	585.6	202,000	587.8	235,000	589.4	259,000	590.8	283,000	591.9	306,000	593.0	337,000
517.95	580.8	131,000	583.6	174,000	585.6	202,000	587.9	235,000	589.5	259,000	590.9	283,000	592.0	306,000	593.2	337,000
518	580.9	131,000	583.7	174,000	585.7	202,000	587.9	235,000	589.5	259,000	590.9	283,000	592.0	306,000	593.1	337,000
518.05	580.8	131,000	583.7	174,000	585.7	202,000	587.9	235,000	589.5	259,000	591.0	283,000	592.1	306,000	593.2	337,000
518.1	580.9	131,000	583.7	174,000	585.8	202,000	588.0	235,000	589.6	259,000	591.0	283,000	592.1	306,000	593.2	337,000
518.15	581.0	131,000	583.8	174,000	585.9	202,000	588.1	235,000	589.7	259,000	591.2	283,000	592.3	306,000	593.4	337,000
518.4	581.1	131,000	584.0	174,000	586.0	202,000	588.3	235,000	589.9	259,000	591.4	283,000	592.5	306,000	593.6	337,000
519.1	581.3	131,000	584.2	174,000	586.3	202,000	588.6	235,000	590.2	259,000	591.7	283,000	592.8	306,000	593.9	337,000
519.6	581.4	131,000	584.3	174,000	586.4	202,000	588.7	235,000	590.4	259,000	591.9	283,000	593.0	306,000	594.1	337,000
519.75	581.4	131,000	584.4	174,000	586.5	202,000	588.8	235,000	590.4	259,000	591.9	283,000	593.0	306,000	594.2	337,000
519.9	581.5	131,000	584.4	174,000	586.5	202,000	588.8	235,000	590.5	259,000	592.0	283,000	593.1	306,000	594.2	337,000
519.95	581.5	131,000	584.5	174,000	586.6	202,000	588.9	235,000	590.6	259,000	592.1	283,000	593.2	306,000	594.3	337,000
520	581.6	131,000	584.5	174,000	586.6	202,000	589.0	235,000	590.6	259,000	592.2	283,000	593.3	306,000	594.4	337,000
520.4	581.7	131,000	584.7	174,000	586.8	202,000	589.2	235,000	590.8	259,000	592.4	283,000	593.5	306,000	594.7	337,000
520.6	581.8	131,000	584.8	174,000	586.9	202,000	589.3	235,000	591.0	259,000	592.6	283,000	593.7	306,000	594.9	337,000
521	581.9	131,000	585.0	174,000	587.1	202,000	589.5	235,000	591.2	259,000	592.8	283,000	593.9	306,000	595.1	337,000
521.2	581.9	131,000	585.0	174,000	587.2	202,000	589.6	235,000	591.3	259,000	592.9	283,000	594.0	306,000	595.2	337,000
521.7	582.0	131,000	585.1	174,000	587.3	202,000	589.8	235,000	591.5	259,000	593.1	283,000	594.3	306,000	595.5	337,000
522.2	582.1	131,000	585.2	174,000	587.4	202,000	589.9	235,000	591.6	259,000	593.2	283,000	594.4	306,000	595.6	337,000
522.3	582.1	131,000	585.3	174,000	587.5	202,000	589.9	235,000	591.7	259,000	593.3	283,000	594.5	306,000	595.7	337,000
522.4	582.1	131,000	585.3	174,000	587.5	202,000	590.0	235,000	591.7	259,000	593.3	283,000	594.5	306,000	595.7	337,000
522.5	582.2	131,000	585.3	174,000	587.5	202,000	590.0	235,000	591.7	259,000	593.3	283,000	594.5	306,000	595.8	337,000
522.6	583.0	131,000	585.7	174,000	587.9	202,000	590.4	235,000	592.1	259,000	593.7	283,000	594.9	306,000	596.2	337,000
522.7	583.1	131,000	585.9	174,000	588.0	201,000	590.5	235,000	592.2	259,000	593.8	283,000	595.0	306,000	596.2	337,000
522.8	583.1	131,000	585.9	174,000	588.1	201,000	590.5	235,000	592.2	259,000	593.8	283,000	595.0	306,000	596.2	337,000

Table H-6 lists the 12 highest water events at the Camanche gage; the highest flood on record occurred in late April 1965 and resulted in a water surface elevation of 587.06 feet (24.65 feet of stage).

Table H-6: Record High Stages at Camanche Gage for the 1940-2013 Period of Record

Stage	Elevation (ft NAVD88)	Date
20.64	583.05	10/07/1986
20.65	583.06	03/25/1973
20.78	583.19	05/07/1975
21.00	583.41	04/26/1951
21.16	583.57	06/15/2008
21.24	583.65	04/27/1952
21.52	583.93	04/26/1969
21.58	583.99	04/19/1997
21.93	584.34	04/21/2011
22.98	585.39	07/08/1993
23.62	586.03	04/24/2001
24.65	587.06	04/28/1965

C. Stage Hydrographs and Elevation Duration. The Camanche gage is located just 1.1 miles downstream of the lower boundary of Beaver Island. Figure H-3 shows the long-term post-impoundment average annual hydrograph for the Camanche gage. Figure H-4 shows the annual elevation duration curve at the Camanche gage and indicates a median river elevation of 573.4 feet (period of record 1984-2013). Comparison of annual elevation-duration curves for the current 30-year period of record and the previous 30-year period of record indicate an increase of ~0.5 feet in stage duration.

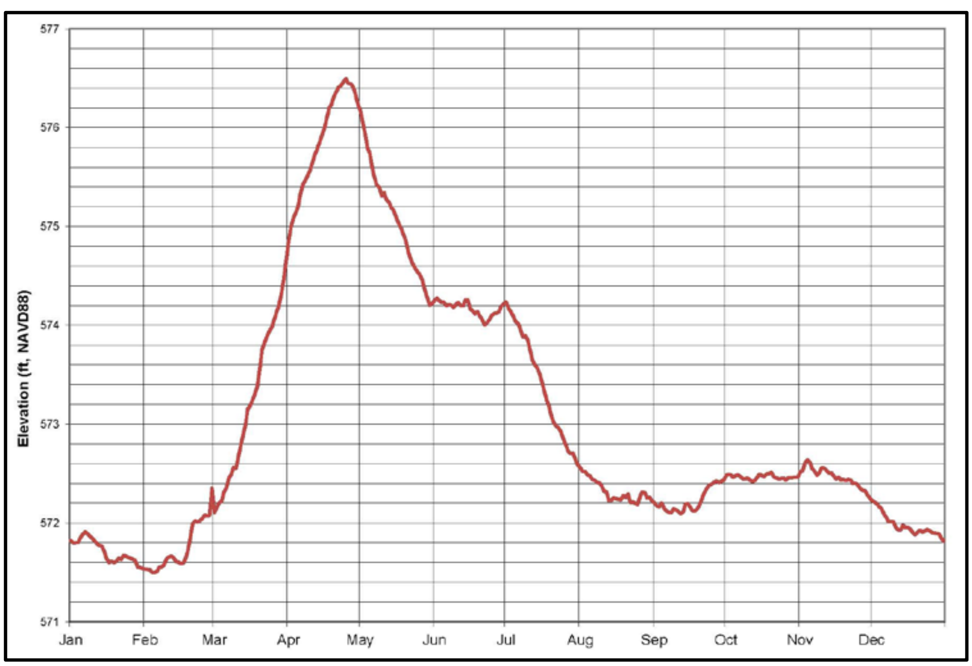

Figure H-3: Long-Term Average Annual Elevation Hydrograph at the Camanche Gage (1940-2013)

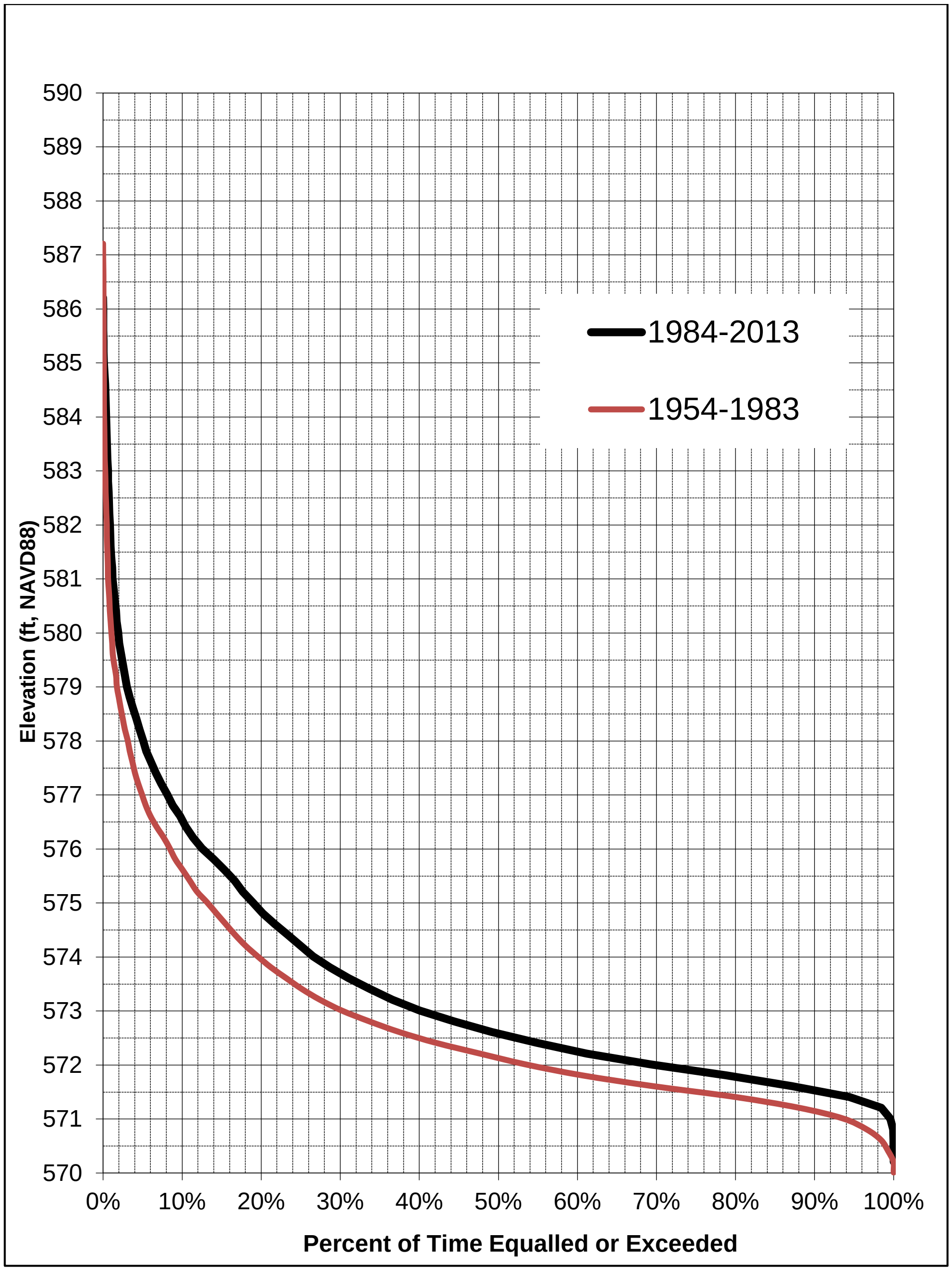

Figure H-4. Comparison of Annual Elevation-Duration Curves for Current and Previous 30-year Periods of Record (Camanche Gage)

The period from 1984-2013 was selected to characterize existing conditions and as the basis for design. The most recent 30-year period was selected because it is considered short enough to represent a stationary dataset (i.e. statistical properties of the data are not changing over time) and long enough to provide a large enough sample size to adequately represent the population. Two seasonal duration curves were computed based on the periods critical to habitat targeted for restoration at

Beaver Island. Low water conditions, which threaten dissolved oxygen concentrations and fish habitat, occur during the winter (November through February) and summer (July through August) months. The period between November and February represents the more critical conditions for fish. During the overwintering months, a water surface elevation of 572.0 feet is exceeded 60 percent of the time at the Camanche gage (70 percent of the time during the entire year). This elevation was chosen to represent typical low water and the reference water surface elevation to distinguish floodplain (above water) from aquatic (below water) habitat.

V. SEDIMENT DEPOSITION

Temporal and spatial variability is inherent in the numerous processes that drive sediment deposition; thereby sediment deposition rates are also dynamic. Some of the watershed features that impact backwater sediment deposition rates include geology and soils, land use and other rainfall runoff characteristics of the contributing watershed, in addition to spatial and temporal variability in natural impoundments such as beaver dams. To date, backwater sediment deposition studies within the UMR have focused on Pools 4-10 and Pool 13 (References 2, 3, 4, 5, 6, and 7). Results from these studies vary from as much as 4.0 cm/yr (Pools 4-10) and as little as 0.2 cm/yr (Pool 7). The Cumulative Effects Study indicates backwater sediment deposition rates derived from the sediment budget that vary from 0.05 cm/yr for Pools 12-19 to 0.31 cm/yr for Pools 20-26 (Reference 8).

Seven backwater sites within Pool 14 were monitored for sediment deposition from 1984 through 2000 by former IADNR biologist, Bill Aspelmeir (Reference 7). Two of these sites were located in Beaver Island—one at the lower end of Upper Lake (Station 5), and the other in the middle of Bottom Bay/Lower Cut (Station 6). Annual measurements at each site were collected along transects from 1984-1989 and again in 1994 and 2000. Table H-7 summarizes the observed sediment deposition rates at each station as estimated based on successive measurements, as well as a single sediment deposition rate based on the entire period of recorded measurements. Rates range from -0.8 in/yr (erosion) to 1.9 in/yr of deposition; however, the overall trend is toward deposition. Based on the study period, the average sediment deposition rate at Stations 5 and 6 are 0.8 in/yr (2.0 cm/yr) and 0.5 in/yr (1.3 cm/yr), respectively.

As a result of the variability in reported values and the inherent variability in sediment deposition rates, an average annual sediment deposition rate of 1 cm/yr was assumed for the Beaver Island HREP.

Over the last 15 years there have been two main channel sites near the Project that have been dredged for channel maintenance (Figure H-5). One is on the upstream end of Beaver Slough, just downstream of the entrance to Beaver Slough near RM 517.5. The other is in the main channel near RM 516.5. Historical dredging locations near the Project are concentrated at the entrance to Beaver Slough, near RM 517.5 both in the main channel and in Beaver Slough. Several locations throughout Beaver Slough and within the main channel between RM 515.75 and 517.25 and between RM 513 and 515 have also been dredged during the past 70 years (Figure H-5).

Table H-7: Summary of Aspelmeir Sediment Deposition Rates at Stations 5 and 6 within Beaver Island

	1984-1985 in/yr (cm/yr)	1985-1986 in/yr (cm/yr)	1986-1987 in/yr (cm/yr)	1987-1988 in/yr (cm/yr)	1988-1989 in/yr (cm/yr)	1989-1994 in/yr (cm/yr)	1994-2000 in/yr (cm/yr)	Avg 1984-2000 in/yr (cm/yr)
Station 5	1.5 (3.8)	0.6 (1.5)	-0.4 (-1.0)	2.7 (6.9)	-0.8 (-2.0)	0.4 (1.0)	1.2 (3.0)	0.8 (2.0)
Station 6	-0.5 (-1.3)	-0.6 (-1.5)	-0.5 (-1.3)	1.7 (4.3)	1.9 (4.8)	0.9 (2.3)	0.2 (0.5)	0.5 (1.3)

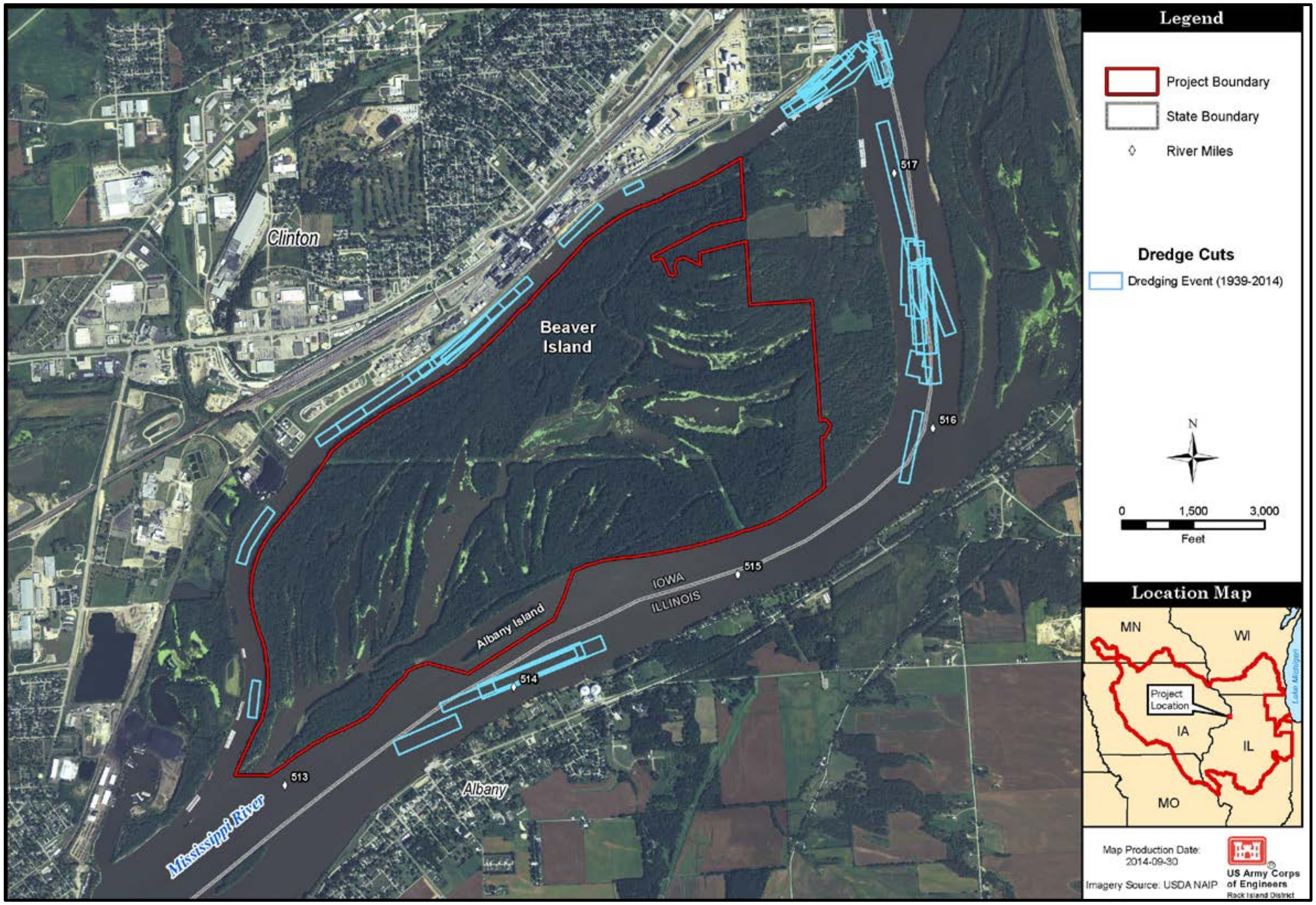

Figure H-5: Historical Dredge Cuts near Beaver Island

Suspended sediment concentration data was collected at the USGS Clinton gage for water years (WY) 1995-1997 (Figure H-6). Table H-8 shows the mean daily concentration and sediment discharge. Based on daily mean suspended sediment values for this 3-year period the average annual computed load would be nearly 3.8 million tons/yr. Suspended sediment loading is a function of rainfall duration and intensity as well as field conditions and vegetation at the time of the rainfall event; therefore, the relationship between discharge and suspended sediment load is not easily defined. The 2013 WY Water-Data Report provides 14 suspended sediment concentration sample results that were collected approximately monthly throughout the WY as summarized in Table H-9 (Reference 9). Using the average of these 14 observations to compute an annual suspended sediment load, the result is 6.4 million tons/yr. Particle size analysis of the suspended sediments suggests that most all of the sediments in suspension are silt-sized or smaller (no less than 95 percent). Photograph H-1 is a downstream view showing the mouth of Upper Cut in the center, illustrating significant suspended sediment concentrations entering through Upper Cut into the Beaver Island Complex on June 9, 2015 during a helicopter tour. This occurred during a river stage of ~576.04 at the Camanche gage, which is ~12 percent exceedance duration stage.

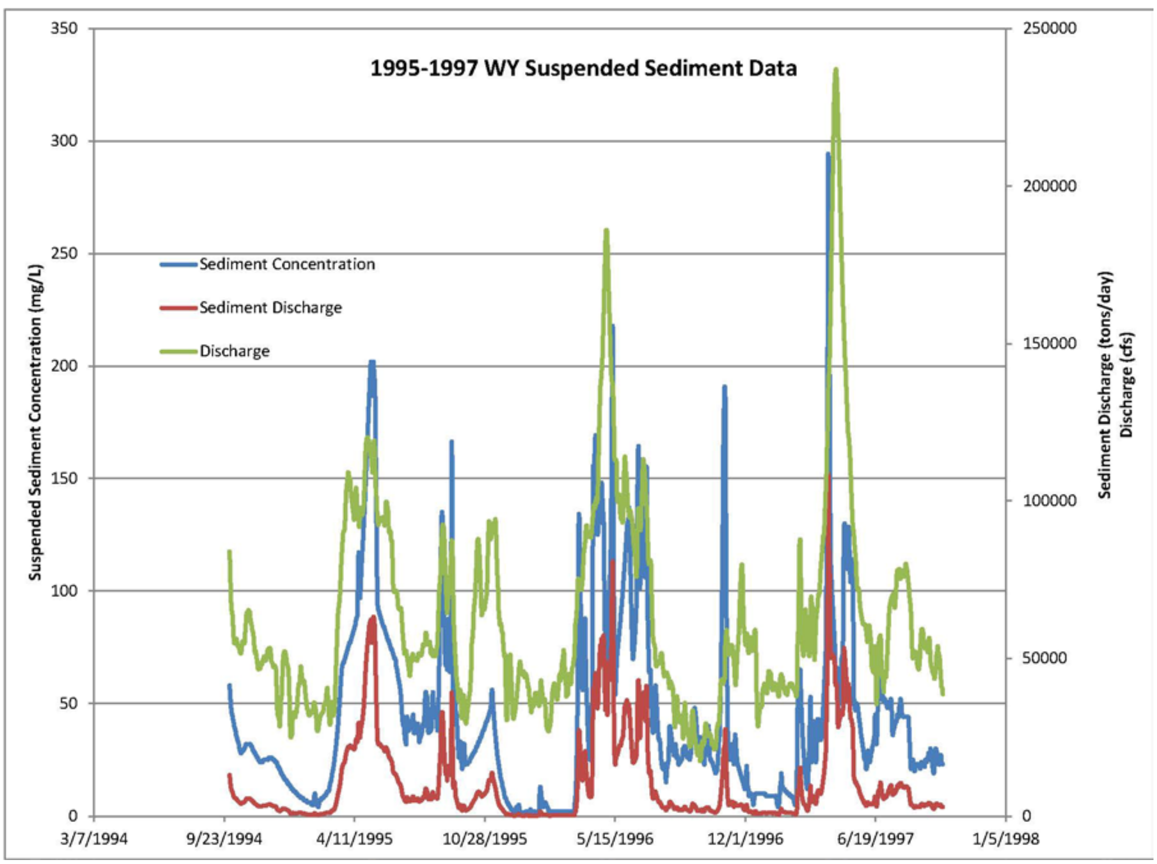

Figure H-6. WY 1995-1997 Suspended Sediment Concentration and Discharge Data at Clinton, Iowa

Table H-8: WY 1995-1997 Suspended Sediment Concentration Data at Clinton, Iowa

WYs 1995-1997	Suspended Sediment Concentration (mg/L)	Suspended Sediment Discharge (tons/day)
Mean	45	10,352
Median	32	4,360

Table H-9: WY 2013 Suspended Sediment Concentration Data at Clinton, Iowa

Date	Percent Smaller Than 0.0625 mm	Suspended Sediment Concentration (mg/L)	Suspended Sediment Discharge (tons/day)
10/3/2012	99	27	984
12/3/2012	98	18	1,030
2/27/2013	99	18	1,020
3/7/2013	96	4	349
3/25/2013	99	53	5,020
4/2/2013	99	39	6,170
4/17/2013	96	201	75,400
5/1/2013	97	103	37,000
5/13/2013	97	74	31,800
6/5/2013	99	70	25,900
6/20/2013	98	54	14,400
7/2/2013	99	71	34,000
7/16/2013	98	52	13,100
8/13/2013	95	14	1,210

Photograph H-1: Upper Cut Introducing Sediment into the Beaver Island Complex

VI. HYDRAULIC MODELING

In 2009, a two dimensional (2-D) mesh for the Beaver Island area was constructed for use with the hydraulic model Adaptive Hydraulics (AdH) in anticipation of the upcoming Project (Reference 10). The upstream boundary of the model is RM 520.33 and the downstream boundary of the model is RM 511.74. The model mesh was a simplification and several backwater storage areas, marinas and side channels were not included in the mesh. Areas that were excluded from the mesh include Sunfish and Cattail Sloughs, Mill Creek and Meredosia Slough. The extents of the mesh do not fully include the 2-year discharge extents in some limited areas, however the value added to the analysis did not warrant the time necessary to expand the mesh.

A 2-D steady-state hydrodynamic model was chosen in order to capture all the flow leaving the main channel relevant to the Project. For example, flow down Beaver Slough and into the Beaver Island complex, as well as flow down Albany Slough were all considered relevant based on the Project features identified for feasibility evaluation. Modeling these components is most effectively done using a 2-D model.

In 2014, when the Project was kicked-off, an updated elevation model for the Project area and model reach was developed based on the most current bathymetry, wing dam surveys, adjusted LiDAR and land survey. Additionally the mesh was updated in order to provide greater resolution around the Albany Island area.

Model Calibration. Acoustic Doppler Current Profiler (ADCP) measurements were collected under two different discharges. In June of 2009 ADCP transects were collected under an average total discharge of 44,571 cfs which is approximately the 51 percent exceedance duration discharge. On April 9, 2010 ADCP transects were collected under an average total discharge of 129,379 cfs (Table H-10). This is very near the 50 percent annual exceedance probability discharge (131,000 cfs) and the 5 percent exceedance duration (130,000 cfs). Figures H-7 and H-8 show the location of the ADCP transects for the 2009 and 2010 collections, respectively.

Table H-10. Summary of 2010 ADCP (129.4k cfs) Observed vs. Computed Discharge

	Description	Observed Q (cfs)	Computed Q (cfs)	Residual Q (cfs) (Computed - Observed)	% Error (ABS(Residual/ Observed))
0_00	*outside of model extent*	~~129658.578~~	~~0~~	~~-129658.578~~	~~100%~~
0_01	*outside of model extent*	~~129100.006~~	~~0~~	~~-129100.006~~	~~100%~~
0_02	Side Channel RM 518.5	31684.57	29035.846	-2648.724	8%
0_03	Side Channel RM 518.5	32043.235	29101.763	-2941.472	9%
0_04	Main Channel RM 518.5	94579.53	99715.123	5135.593	5%
0_05	Main Channel RM 518.5	96770.806	100319.251	3548.445	4%
0_06	Main Channel US of Beaver Slough RM 517.4	123210.444	129407.756	6197.312	5%
0_07	Main Channel US of Beaver Slough RM 517.4	120255.54	129483.166	9227.626	8%
0_08	US Beaver Slough RM 517.2	31628.433	28189.223	-3439.21	11%
0_09	US Beaver Slough RM 517.2	30927.17	28120.773	-2806.397	9%
0_10	Main Channel DS Beaver Slough RM 517	93196.953	100762.501	7565.548	8%
0_11	Main Channel DS Beaver Slough RM 517	92365.418	100907.579	8542.161	9%
0_12	Cattail Slough RM 516.1 *outside of extent*	~~3130.478~~	~~3.846~~	~~-3126.632~~	~~100%~~
0_13	Cattail Slough RM 516.1 *outside of extent*	~~2797.942~~	~~-0.342~~	~~-2798.284~~	~~100%~~
0_14	Main Channel RM 515.2	94769.599	100759.08	5989.481	6%
0_15	Main Channel RM 515.2	95279.823	100752.254	5472.431	6%
0_16	Main Channel RM 513.5	93106.128	96060.568	2954.44	3%
0_17	Main Channel RM 513.5	94365.154	96157.415	1792.261	2%
0_19	Beaver Island Outlet	4755.256	5609.669	854.413	18%
0_20	Beaver Island Outlet	4856.007	6423.46	1567.453	32%
0_21	DS Beaver Slough	30184.651	25340.585	-4844.066	16%
0_22	DS Beaver Slough	29869.964	25368.095	-4501.869	15%
0_23	*outside of model extent*	~~104715.55~~	~~23.717~~	~~-104691.833~~	~~100%~~
0_24	*outside of model extent*	~~103064.667~~	~~0~~	~~-103064.667~~	~~100%~~
0_25	*outside of model extent*	~~15964.261~~	~~0~~	~~-15964.261~~	~~100%~~
0_26	*outside of model extent*	~~15542.257~~	~~0~~	~~-15542.257~~	~~100%~~

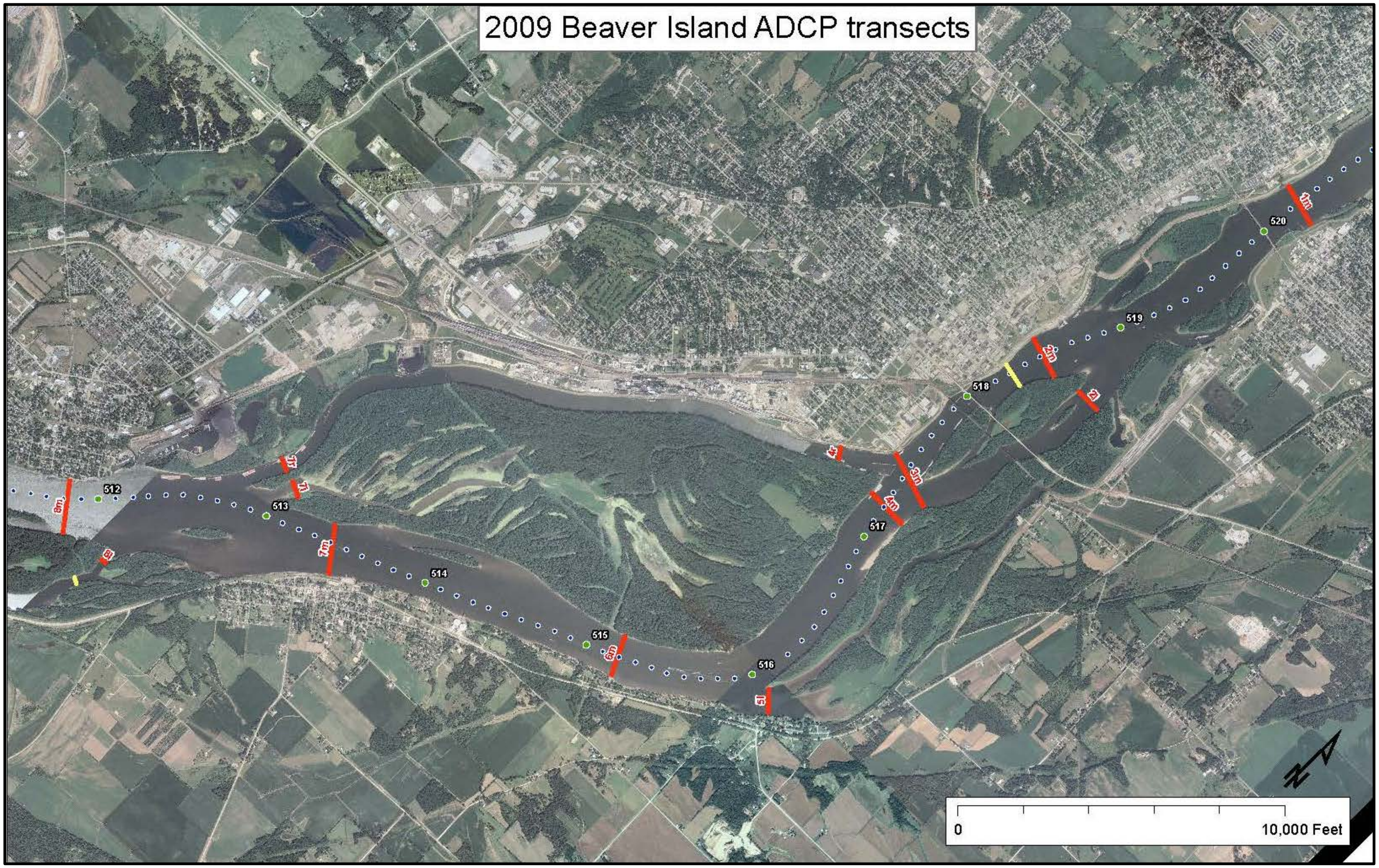

Figure H-7: 2009 ADCP Transects at Beaver Island

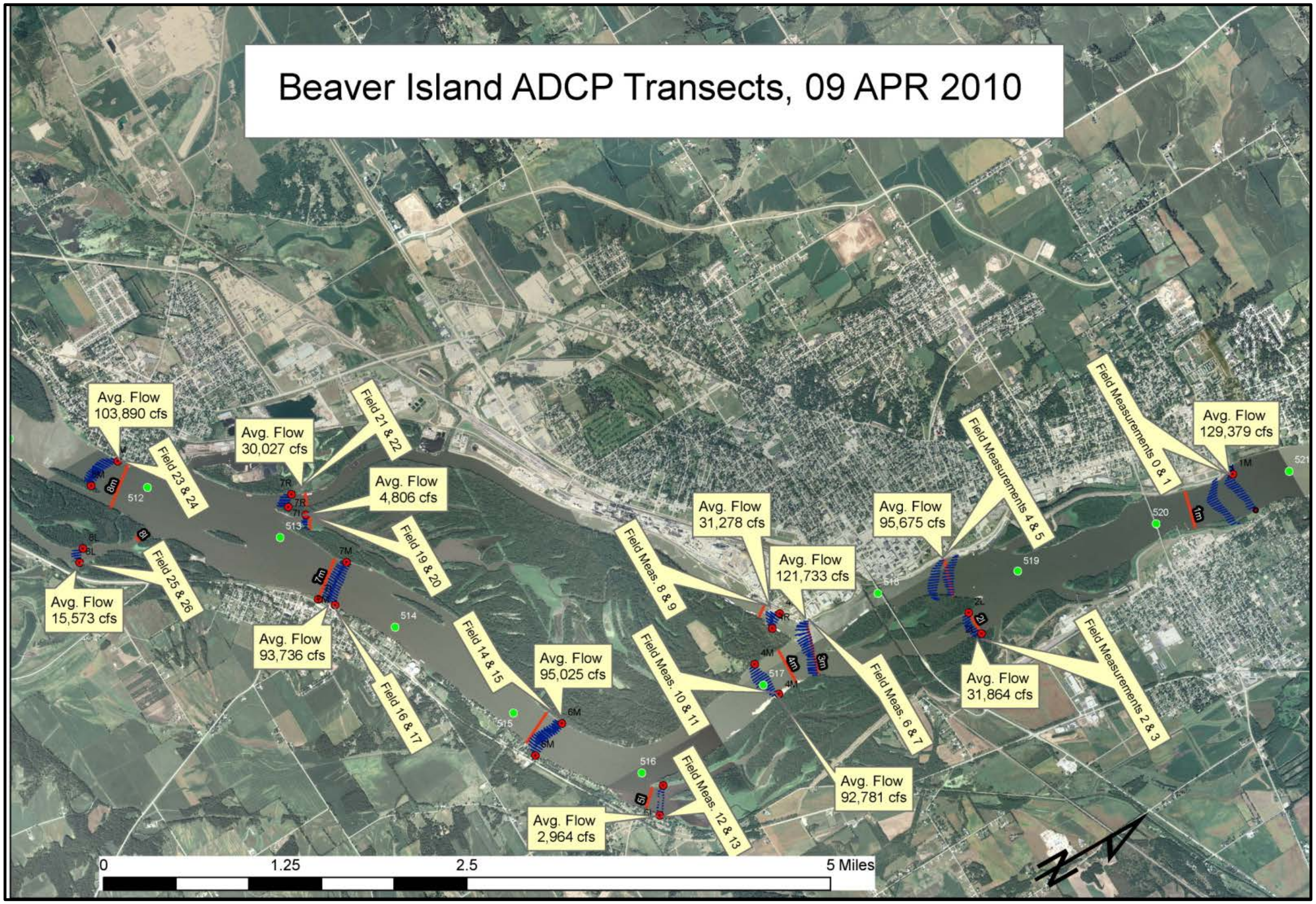

Figure H-8: 2010 ADCP Transects at Beaver Island

Calibration of the AdH model began with a comparison of observed vs. simulated fall between Lock and Dam 13 (RM 522.4) and the Camanche gage (RM 511.8). The downstream model boundary extends to RM 511.74, just downstream of the Camanche gage. The upstream model boundary only extends to RM 520.33, so in order to estimate a "simulated" water surface elevation the slope computed between RM 511.8 and the upstream model boundary was linearly extrapolated upstream to RM 522.4 (Lock and Dam 13). The observed fall record was comprised of water surface elevations under the modeled discharge for the most recent 30-year period of record. Values from December through February were removed in order to ensure ice-impacted stages were not included. Figure H-9 shows the results of this comparison.

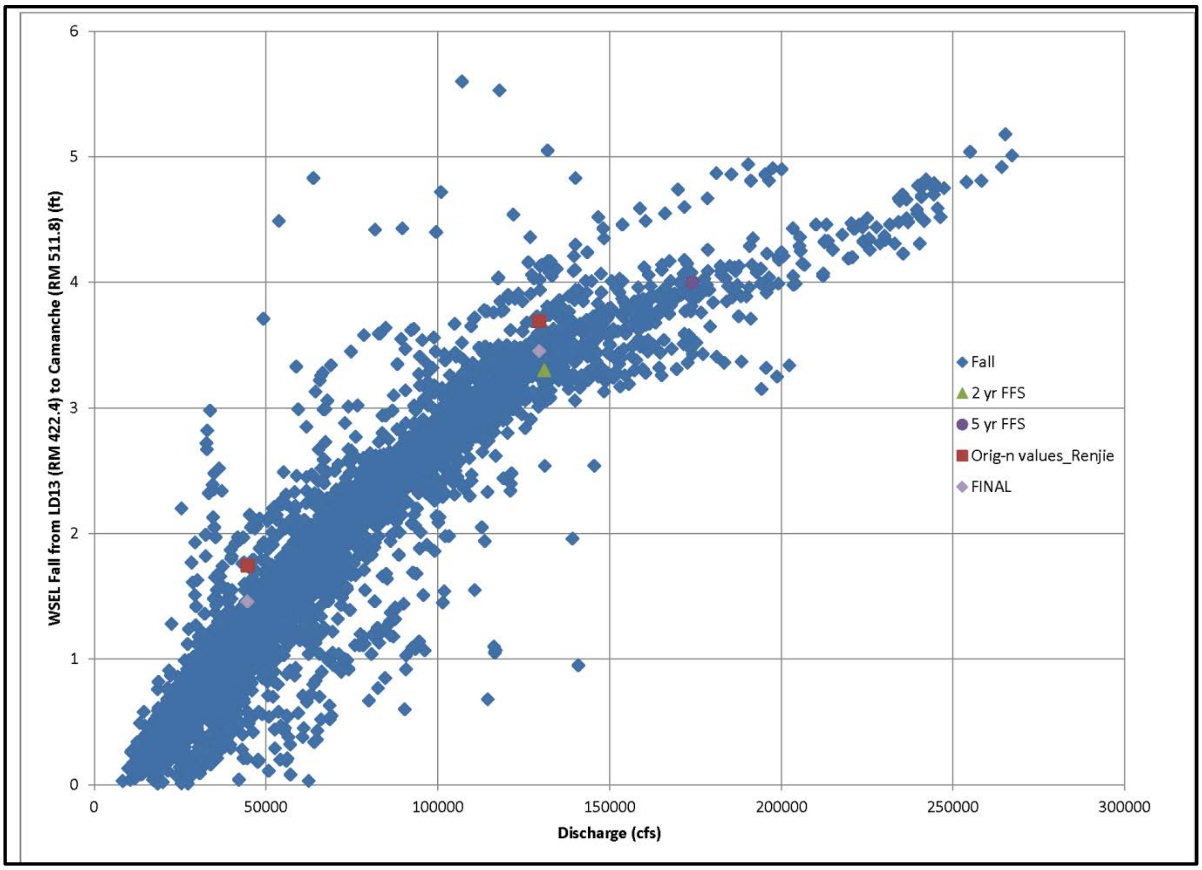

Figure H-9: Beaver Island Model Simulated vs. Observed Fall from Lock and Dam 13 to Camanche, Iowa

Water surface elevation information collected at the Albany boat ramp (RM 513.5) during land survey of the island was also used to evaluate the simulated water surface elevation at this location. This gave a better sense of how well the model simulates the slope between the model boundaries. Discharge at Lock and Dam 13 during the 3 days of the land survey was similar to the 44.6K cfs simulation (43.1K, 45K and 50.3K cfs). Water surface elevations measured at the boat ramp during those 3 days were compared to the simulated water surface elevation near the boat ramp under the 44.6K cfs simulation. These results suggest the model is simulating a slightly higher water surface elevation, ranging from 0.1 to 0.5 foot higher (Table H-11).

Table H-11: Summary of Surveyed Water Surface Elevations

Date	Lock & Dam 13 Discharge (cfs)	Surveyed WSEL (MSL1912)	Computed WSEL (MSL1912)	Observed-Computed (ft)
11/12/2014	43,121	573.38		-0.34
12/16/2014	45,008	573.2		-0.52
12/22/2014	50,310	573.63		-0.09
Simulated	44,571		573.72	

Model adjustments that were made to improve the simulated slope included decreasing Manning's roughness (n) values and changing downstream boundary conditions. A plot of model downstream boundary conditions (at RM 511.74) as a function of total discharge, compared to 30 years of observed water surface elevations at Camanche (RM 511.8) as a function of discharge at Lock and Dam 13 is shown in Figure H-10. Values from December through February were removed to ensure ice-impacted stages were not included in the observed record.

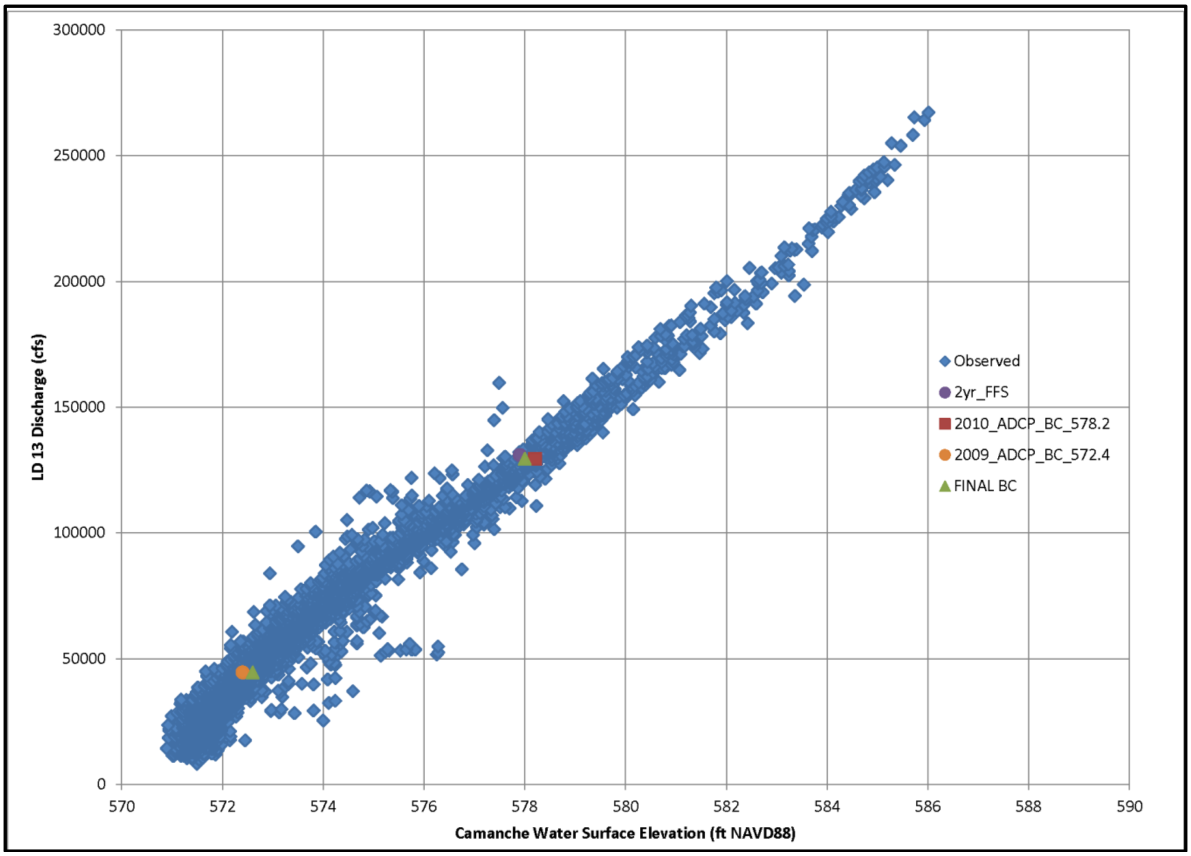

Figure H-10. Boundary Conditions Compared to Observed Elevation at Camanche (RM 511.8) as a Function of Lock and Dam 13 Flow

The second calibration procedure involved comparing observed and computed discharge values. As shown in Table H-12, the low flow model had more difficulty sending enough flow down Beaver Slough than did the higher flow simulation.

Table H-12. Summary of 2009 ADCP (44.5k cfs) Observed vs. Computed Discharge

		Description	Observed Q (cfs)	Computed Q (cfs)	Residual Q (cfs) Computed - Observed	% Error (ABS(Residual/ Observed))
	000_0	Upstream Main Channel RM 520.2	45348.867	44234.145	-1114.722	2%
1M	000_1	Upstream Main Channel RM 520.2	43793.658	44275.48	481.822	1%
	000_2	Side Channel RM 518.6	7201.482	6350.256	-851.226	12%
2L	000_3	Side Channel RM 518.6	7479.247	6305.223	-1174.024	16%
	000_4	Main Channel RM 518.3	36497.122	37975.972	1478.85	4%
2M	000_5	Main Channel RM 518.3	36163.619	37440.129	1276.51	4%
3M	000_6	Main Channel US Beaver Slough RM 517.5	44364.384	44017.958	-346.426	1%
	000_7	US Beaver Slough RM 516.9	10966.371	8294.525	-2671.846	24%
4R	000_8	US Beaver Slough RM 516.9	10491.776	8263.317	-2228.459	21%
	000_9	Main Channel DS Beaver Slough RM 517.1	33377.082	35386.076	2008.994	6%
4M	000_10	Main Channel DS Beaver Slough RM 517.1	32651.001	35013.744	2362.743	7%
	000_11	Cattail Slough RM 516.1	-371.52	5.972	377.492	102%
5L	000_12	Cattail Slough RM 516.1	151.019	12.176	-138.843	92%
	000_13	Main Channel RM 515.1	32785.205	35771.087	2985.882	9%
6M	000_14	Main Channel RM 515.1	32689.917	35790.232	3100.315	9%
	000_15	Main Channel RM 513.4	32955.578	35835.161	2879.583	9%
7M	000_16	Main Channel RM 513.4	33402.456	36049.541	2647.085	8%
	000_17	Lower Cut-Beaver Interior RM 513.1	187.7	-7.665	-195.365	104%
7I	000_18	Lower Cut-Beaver Interior RM 513.1	280.53	-1.971	-282.501	101%
	000_19	DS Beaver Slough RM 513.1	10338.26	8225.014	-2113.246	20%
7R	000_20	DS Beaver Slough RM 513.1	10753.128	8172.218	-2580.91	24%
	000_21	Downstream Main Channel RM 511.8	41053.66	44037.456	2983.796	7%
8M	000_23	Downstream Main Channel RM 511.8	40400.586	44121.671	3721.085	9%
	000_25	Downstream Side Channel RM 512 *outside of extent*	~~3741.602~~	~~0~~	~~-3741.602~~	~~100%~~
8L	000_26	Downstream Side Channel RM 512 *outside of extent*	~~3470.944~~	~~0~~	~~-3470.944~~	~~100%~~

Accurately simulating the flow split is typically most sensitive to model geometry. As seen from Figure H-11, although there is dense multi-beam hydrosurvey data to support the chevron at the head of Beaver Island, the coarse nature of the main channel and Beaver Slough hydrosurvey data may be underestimating the Beaver Slough channel capacity. It was also observed that the 2009 mesh extents in several locations throughout the model reach do not capture the full wetted channel, even under the 44.5k cfs discharge in some locations (Figure H-12).

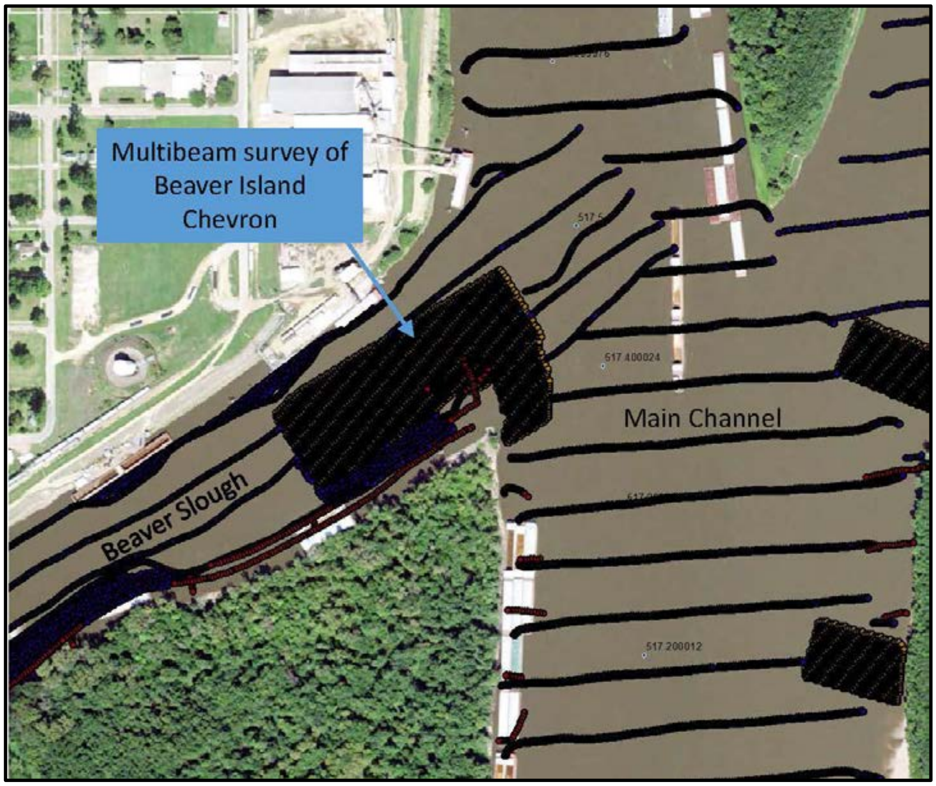

Figure H-11: Extent of Hydrosurvey Data near the Chevron at the Upstream End of Beaver Island

The locations of the features for analysis are just upstream of Albany Island near RM 514 (Figure H-12) and at the mouth of the Beaver interior channel (near lower cut). A chevron upstream of Albany Island was evaluated for relative impacts to existing condition velocities in the adjacent slough, as was a rock structure on the LDB of Lower Cut to prevent sediment deposition within the proposed excavated channel. The chevron is intended to reduce velocities upstream of Albany Island to prevent further island erosion, but not significantly increase shear stress and water surface slope within Albany Slough where there is an existing mussel bed. The chevron was evaluated under three flow conditions (Q5, Q50 and Q95). The purpose of the rock structure at lower cut is to prevent and/or limit sediment deposition within the excavated channel. It is assumed this is of greater concern under low flows where suspended sediment backs up into the interior. The decision was made that the value added to the Project feature analyses by improving the model calibration does not warrant the required resources and time. Improving the calibration for the flow down Beaver Slough and through the Beaver Island interior would improve the simulation of flow at the confluence of Beaver Slough, lower cut and the main channel. Nevertheless, a comparative analysis of with and without structure provides an indication of the effectiveness of the proposed structure and impacts to the velocity vectors. Additional calibration is unlikely to impact the Albany Island chevron as we have no ADCP transects near the Island. Again, a comparative analysis will sufficiently identify the presence/absence of shear stress and water surface slope impacts.

Figure H-12: Extent of the Beaver Island AdH Model Mesh

VII. PROJECT FEATURES EVALUATED

A. Chevron. A chevron placed at the head of Albany Island was designed and evaluated for the purpose of preventing further erosion at the upstream end of Albany Island that would potentially result in the loss of existing mussel habitat. The chevron design used information from consultation with the St. Louis District (MVS), which has significant expertise in designing and constructing chevron-type structures; referencing the UMRR Design Handbook, which included design information on the LaGrange Island chevron from the Gardner Division HREP, Pool 21; and design information and field observations of the Oquawka (Pool 18) Environmental Assessment (EA) (Reference 11). Four hundred and fifty-pound stone is assumed to be used for construction. The chevron was designed with a 6-foot top width and 2H:1V side slopes. The top of the chevron is located approximately 250 feet upstream of the head of Albany Island and the overall width of the structure is about 200 feet, which is similar to the overall island width. The chevron ties into the river-side of Albany Island and is open on the Albany Slough side to allow for fish-access and flow egress. A design elevation of 578.5 feet, just below the 50 percent exceedance probability elevation was initially selected in order to maximize the overtopping head conditions to create a scour hole downstream of the chevron. This initial design was based largely upon the Oquawka chevron design elevation (~5 percent exceedance duration elevation). The existing channel bottom near the chevron footprint is at about 569.5 feet.

The Albany Island chevron design described above was added to the AdH mesh and evaluated for impacts to the existing mussel bed within Albany Slough based on the hydrophysical criteria specified in the Pool 8 Classification and Regression Tree (CART) model for dive data (Reference 12). The method for evaluating mussel impacts as described in the following, as well as the mussel bed location, were identified by the Project Delivery Team (PDT) biologist. Figure H-13 approximates the existing mussel bed in pink with the existing wing dam locations in gold).

The analysis approach used was to both verify that the hydrophysical parameters within the mussel bed vicinity meet the CART model presence criteria under ‘existing conditions’ and determine whether or not the CART model presence criteria is still met under ‘with-chevron conditions’. Two-dimensional steady-state hydrodynamic model results (using AdH) for depth and velocity under discharge conditions of ~Q5, ~Q50 and ~Q95 were used to compute shear stress. Discharge duration was determined based upon a 30-year period of record (1984-2013) from the Clinton gage.

Figure H-13. Mussel Bed Location Used for Analysis

Based on field observations, the bed material within the existing mussel community was assumed to be a silt loam, with an assumed D50 of 0.055mm (coarse silt size). Shear stress was computed using the same equation as Zigler et al. (Reference 12), as described in Statzner et al., 1988 (Reference 13).

[Tau= Density*Velocity^2/((5.75LOG10(12*Depth/Ks))^2)]
Tau= shear stress (Pascals)= ((Dynes/cm^2)/10)
Density= 1000 kg/m^3
Velocity (m/s)
Depth (m)
Ks= substrate roughness (m) = 4.5*D50= 0.000248 m

Table H-13 is a summary of the computed shear stress results in the existing mussel bed area.

Table H-13: Shear Stress Results Summary Comparing Existing and Plan Conditions

	Shear Stress (Dynes/cm^2)					
	Q5 Exist	**Q5 Plan**	**Q50 Exist**	**Q50 Plan**	**Q95 Exist**	**Q95 Plan**
Maximum	6.08	5.44	2.59	2.21	0.68	0.57
Minimum	2.67	2.49	0.03	0.04	0.01	0.01
Mean	4.64	4.11	1.16	0.99	0.23	0.19
Median	4.53	4.02	1.14	0.98	0.20	0.17
S.D.	0.81	0.67	0.60	0.49	0.17	0.13

Table H-14 shows a summary of the 5m bed slope results in the existing mussel bed area, computed using the procedure specified in Zigler et al. (Reference 12).

Table H-14: Summary of 5-Meter Bed Slope Results

	Maximum	**Minimum**	**Mean**	**S.D.**
Slope (degrees)	3.928035	0.020964	0.919887	0.758162

Relative Substrate Stability (RSS) was computed as described in Zigler et al. (Reference 12) and detailed in Morales et al. (Reference 14). The critical shear for erosion for an alluvial silt loam was assumed to be 0.045 lb/sq ft (21.5 Dynes/cm^2) for all three discharge conditions (Reference 15). Table H-15 is a summary of the resulting RSS values.

Table H-15: Relative Substrate Stability Results Summary Comparing Existing and Plan Conditions

	RSS = Tau / Tau Critical					
	Q5 Exist	**Q5 Plan**	**Q50 Exist**	**Q50 Plan**	**Q95 Exist**	**Q95 Plan**
Maximum	0.28	0.25	0.12	0.10	0.03	0.03
Minimum	0.12	0.12	0.00	0.00	0.00	0.00
Mean	0.22	0.19	0.05	0.05	0.01	0.01
Median	0.21	0.19	0.05	0.05	0.01	0.01
S.D.	0.04	0.03	0.03	0.02	0.01	0.01

The hydrophysical parameters summarized above were applied to the Pool 8 CART Model (Reference 12). Both ‘existing conditions’ and ‘with-chevron conditions’ follow the same path along the regression tree, as illustrated in Figure H-14. This indicates that the chevron is not expected to change the hydrophysical parameters significantly or impact the presence of mussels, as defined by the Pool 8 dive CART model.

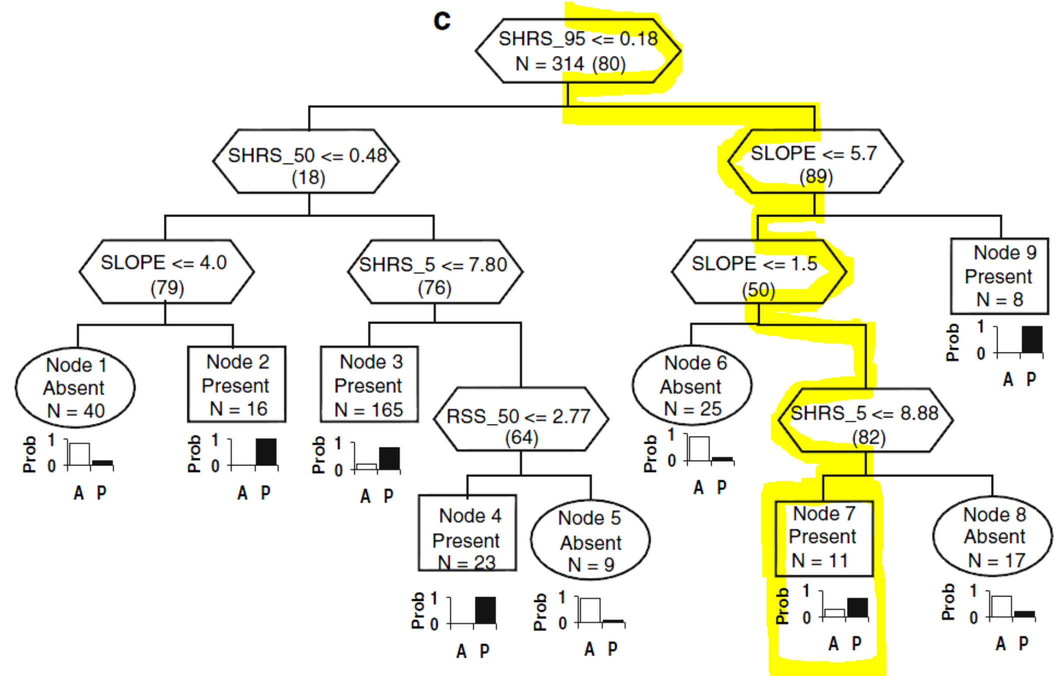

Fig. 2 Classification tree models of mussel presence and absence based on brail (**a**), sled (**b**), and dive (**c**) data in Navigation Pool 8, Upper Mississippi River. Models are read from the top down beginning at the root node, which contains all data. At each subsequent decision node, data that satisfy the splitting rule move to the left branch and all other data move to the right branch. For splitting rules using continuous predictor variables, numbers in parentheses are the quantile of the rule value over all data for that gear. Observations in terminal nodes are classed as present (P, solid bar) or absent (A, clear bar) based on the probabilities shown in the graph below each node. Abbreviations for variables are given in Table 3

Figure H-14: Pool 8 CART Model of Mussel Presence and Absence Based on Dive Data (Reference 12)

Additional review of the Albany Island chevron design, including review by MVS staff and a site visit to evaluate performance of the Oquawka Chevrons, resulted in further design changes following completion of the impact analysis on the 578.5-foot elevation. A summary of the design criteria used at each of the projects referenced to aid in the Albany Island chevron design is included in Table H-17. During the site visit to the Oquawka chevrons, the design that was most similar to the initial Albany Island chevron design, the differences in purpose became more evident. The Oquawka Islands chevrons were intended as river training structures to prevent flow from jumping the main channel and changing course down the side channel, whereas the intent of Albany Island chevron is to prevent further erosion on the head of the island and induce scour and subsequent deposition behind the chevron. The Albany Island feature is perhaps more accurately defined as a bullnose dike rather than a chevron and is more like the LaGrange Island blunt nose chevron design at Gardner Division and other various bullnose dikes completed by MVS than the Oquawka chevrons.

These structures are all designed for flow to overtop the structure much more of the time than the Oquawka chevrons are overtopped and have successfully shown to create scour holes and subsequent material deposition. As a result, the final Albany Island chevron design elevation was revised to 574.15’ in order to increase the exceedance duration to ~30 percent, much more like MVS design criteria. However, as discussed in Section VIII, in order to provide additional resilience for increased stage durations associated with climate change, the final design elevation was increased slightly higher (575’, ~25 percent exceedance duration). This design is a significantly smaller footprint than the design modeled for the mussel impact analysis; therefore, the impacts are considered to be even less and the revised design is not considered to result in impacts to the existing mussel bed. CHANLPRO was used to size required stone for this final feasibility design based upon the structure slope, flow depth and velocity (Reference 16). A specific weight of 162 lb/cf and a design factor of safety of 1.4 resulted in a D100 of 36lbs. However, given ice force considerations, limitations of depth-averaged velocity results and standard gradation availability, the Geotechnical Engineer ultimately recommended a top size of 450 lbs.

An additional feature associated with the chevron is approximately 300 feet of bankline protection on the Albany Slough side of the island, along the chevron opening. The bankline protection will prevent erosion along the Albany Island bankline that is due to chevron-overtopping flows that become concentrated as they egress through the chevron opening. The riprap is to be covered with river stone or other aggregate conducive to mussel habitat. CHANLPRO was used to size required stone for the riprap bankline protection design based upon the side slope, flow depth and velocity (Reference 16). A specific weight of 162 lb/cf and a design factor of safety of 1.4 resulted in a D100 of 36 lbs. However, given ice force considerations and standard gradation availability, the Geotechnical Engineer ultimately recommended a top size of 250 lbs.

If monitoring results indicate an inability to reach success criteria for 2 consecutive years, modifications to the chevron will be implemented to increase protection of Albany Island, decrease water velocities within Albany Slough, or a combination of the two. Preliminary information suggests an increase in the chevron to 576 feet would be warranted.

Table H-17. Summary of Existing Chevron Design Criteria

	Location (RM)	Design Elevation (MSL 1912) (ft)	Design Duration (% time exceeded)	Flat Pool (MSL 1912)	2-yr Elevation (MSL 1912) (ft)	Distance Upstream of Existing Island (ft)
Oquawka Islands-Pool 18	415.5	531.5	~5	528	531.6	~200-900
Gardner Division HREP-Pool 21	337	473	~49	470	480.1	350
MVS Chevron/ Bull Nose Dike-General Guidance	Various	Above Hinge Pt: Mean Pool+2	~30	Various	Various	100-700
Final (Initial) Beaver Island HREP-Pool 14 Design	514.4	575[1] (578.5) [1]	~25 (~5)	571.2[1]	580.55[1]	250

[1] Elevations in NAVD88

B. Lower Cut Deflection. The Sponsor raised concerns over recirculation of flow back into the Beaver Island interior channel, which could result in sediment deposition in the Lower Cut excavated channel. An evaluation of existing conditions was initially undertaken. Under median discharge existing conditions, very little flow comes down the interior channel while flow from the main channel expands into the Beaver Slough interior, mixing with the slack water and resulting in an eddy that propagates upstream within the interior channel. In order to more closely evaluate the likelihood of deposition under these flow conditions, shear stresses were computed. Based on work done by Engineering Research and Development Center (ERDC) for the Peoria Lake Enhancement HREP (Reference 17), it was assumed that shear stresses less than 0.96 Pa would result in the deposition of coarse silts. Under existing conditions (without the excavated channel in place), the resulting shear stresses within the lower portion (~200 feet) of the channel are high enough that this area does not clearly indicate deposition of coarse silt (under median flow conditions). Figure H-15 shows shear stress values of 0.96 Pa and higher under existing conditions in the location of the proposed excavated channel under median discharge conditions.

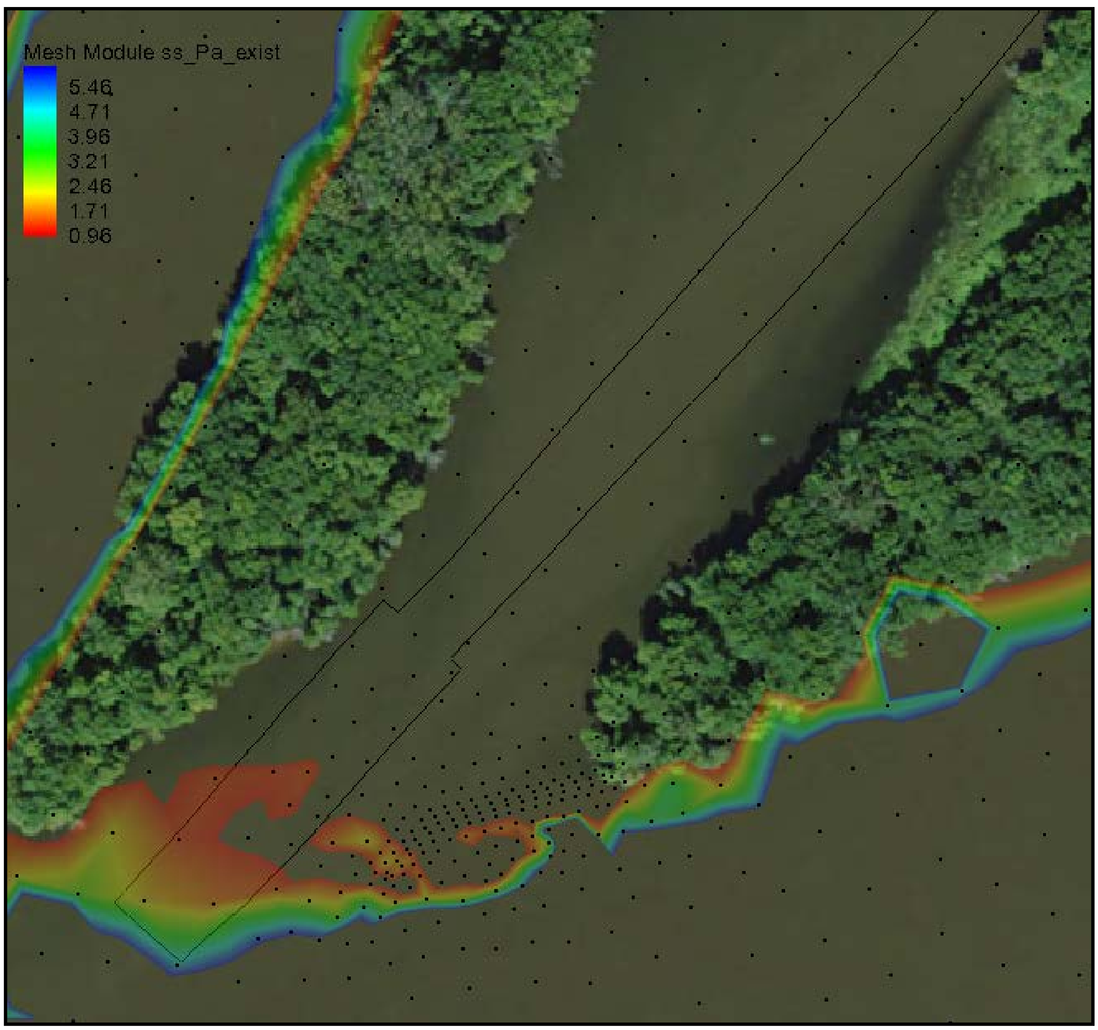

Figure H-15. Existing Conditions Shear Stress (Pa) Under Median Discharge Conditions

The gross representation of the proposed Lower Cut excavation was included in the mesh and simulated to quantify the anticipated drop in shear stress and increased likelihood for deposition. Figure H-16 shows shear stress values of 0.96 Pa and higher with the channel in place. It can be seen that throughout most of the proposed Lower Cut channel footprint shear stresses are below 0.96 Pa, indicating that the channel will reduce shear stresses and increase the likelihood for deposition of coarse silts in this area.

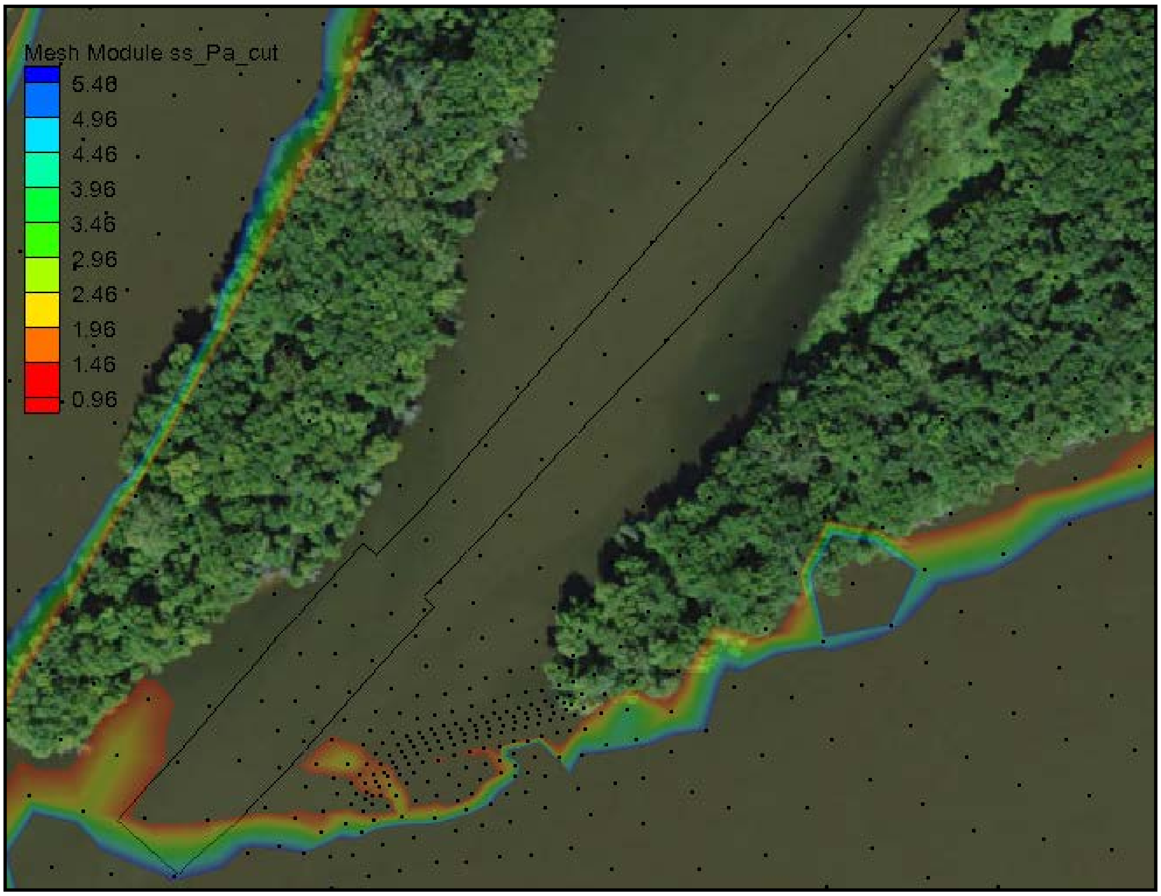

Figure H-16. Shear Stresses (Pa) with Approximated Channel Under Median Discharge Conditions

An emergent deflection structure was located (location was restricted due to navigation constraints) to evaluate the effectiveness in reducing sediment deposition within the proposed Lower Cut channel. The location of the deflection structure was highly constrained due to the proximity of the navigation channel and a fleeting area just off the left descending bank of Beaver Island. The structure was modeled with an elevation of 573 feet so that it would be emergent under median discharge conditions. The gross channel approximation, the modeled deflection structure alignment and the resulting shear stresses (0.96 Pa and higher) are shown in Figure H-17. Under this scenario, the area with shear stress values less than 0.96 Pa (where deposition of coarse silt is likely to occur) remains within the proposed channel area. This suggests that the proposed deflection structure does not reduce the likelihood for deposition of coarse silts under median discharge conditions.

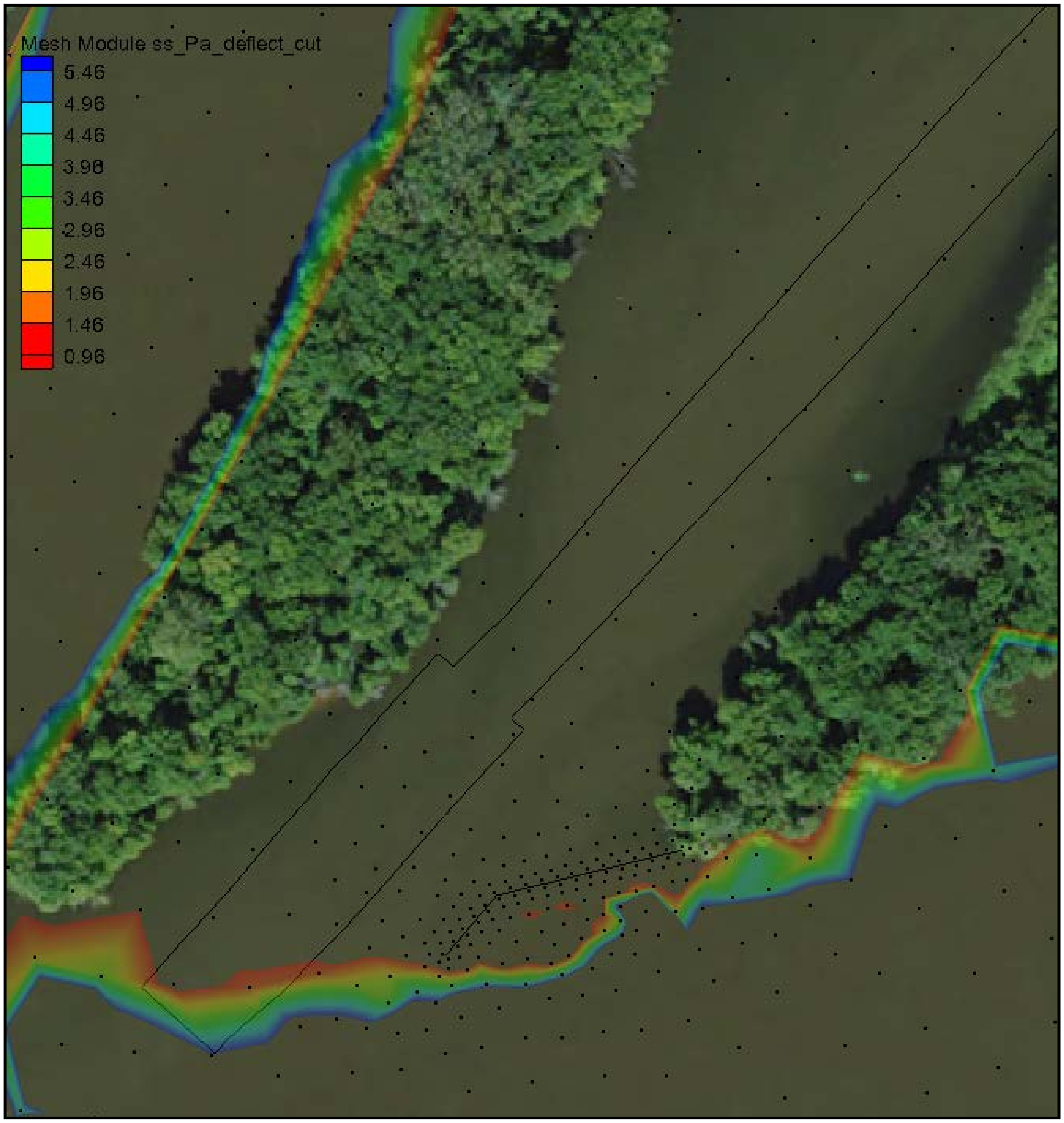

Figure H-17: Shear Stresses (Pa) With Deflection Structure and Approximated Channel Under Median Discharge Conditions

However, since sediment transport is a very dynamic process and this is a steady-state model simulation, it is important to evaluate a higher flow condition to determine how the proposed channel and potential deflection structure might impact potential for scour/sediment removal in the location of the proposed channel. Based upon an ERDC technical note (Reference 16), the maximum allowable shear stress (prior to entrainment) for an alluvial silt is ~2.15 Pa. In order to evaluate the potential for scour within the location of the proposed Lower Cut channel, each of the above scenarios were evaluated for shear stress under 50 percent chance exceedance flood conditions. Under 50 percent chance exceedance discharge conditions, there is significantly more flow coming down the Beaver Island interior channel which increases shear stress. Figure H-18 shows shear stresses greater than 2.15 Pa within the proposed channel location under existing conditions. These results indicate shear stress under existing conditions (50 percent chance exceedance floods) above what is required to transport coarse silts.

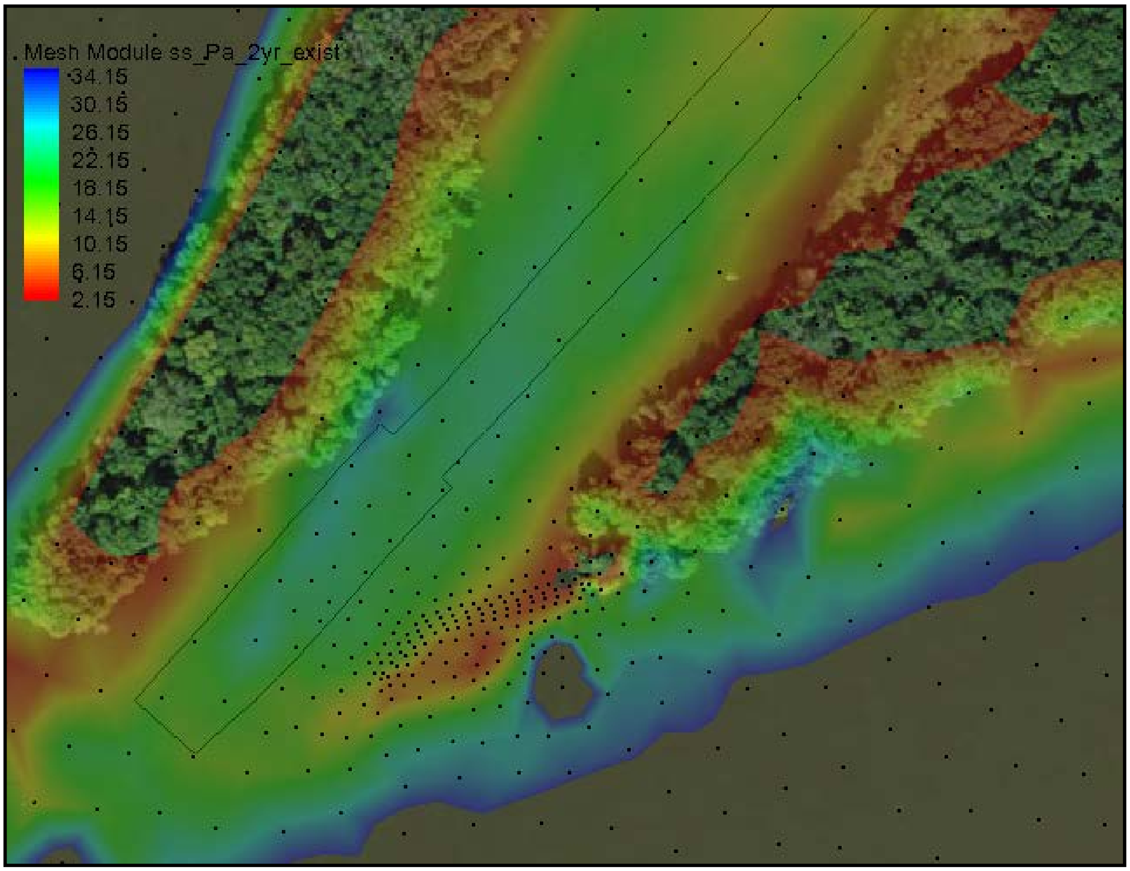

Figure H-18: Existing Conditions Shear Stresses (Pa) under 50% Chance Exceedance Discharge Conditions

Figure H-19 shows shear stresses above 2.15 Pa with the proposed channel in place. Although the channel reduces shear stress, they remain high enough to indicate likely scour of coarse silts under 50 percent chance exceedance conditions.

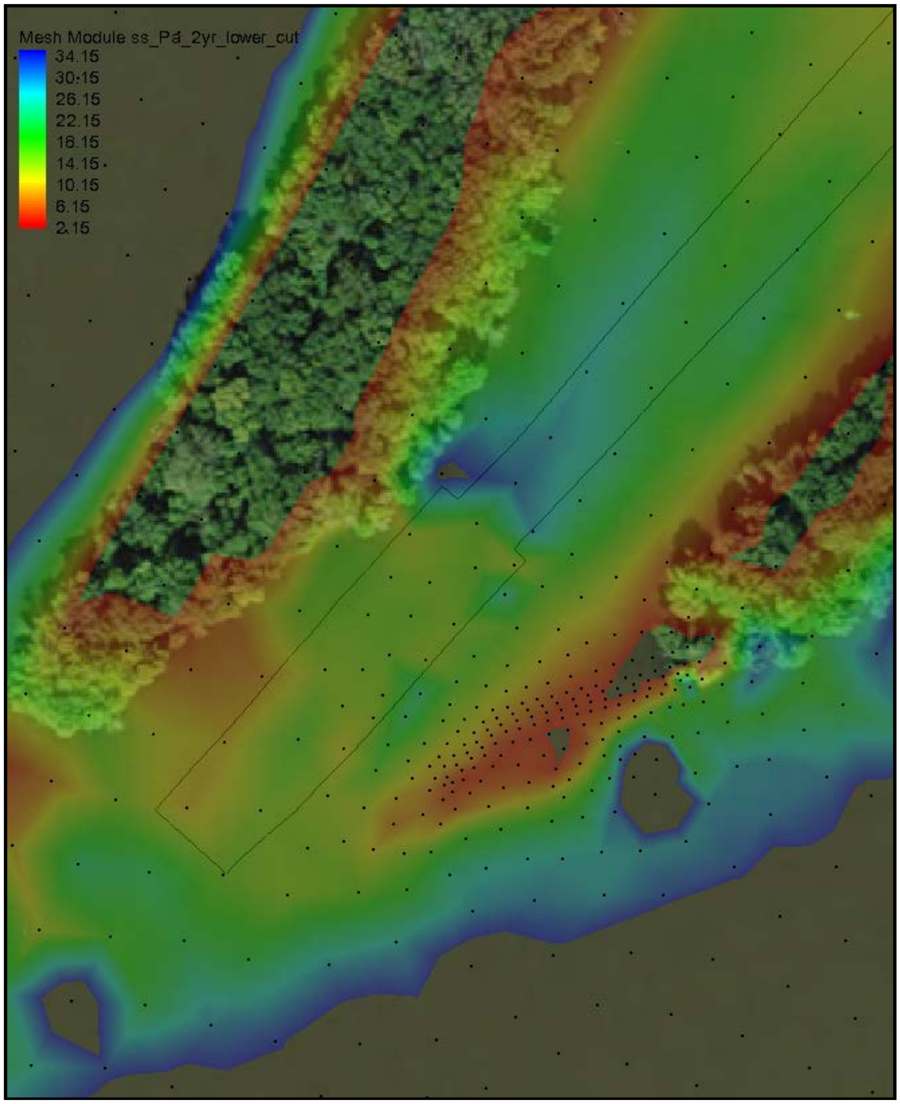

Figure H-19: Approximated Lower Cut Channel Shear Stresses (Pa)
Under 50% Chance Exceedance Discharge Conditions

Figure H-20 shows shear stresses with the channel and deflection structure in place. Figure H-21 shows the difference in shear stress between the with-deflection structure condition and the without-deflection structure condition (with-deflection minus without-deflection) and more clearly illustrates that the with-deflection structure slightly increases shear stresses within the proposed channel location (by less than 2 Pa).

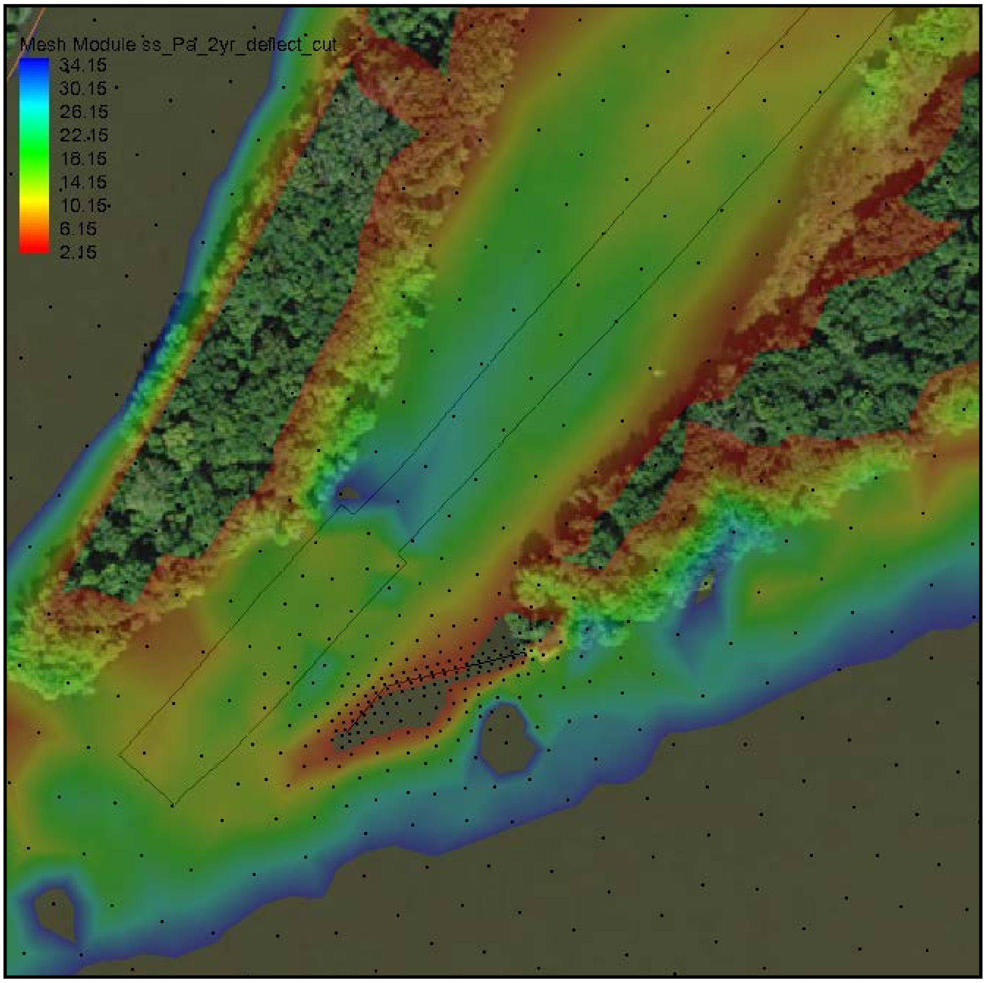

Figure H-20: Deflection Structure with Approximated Lower Cut Channel Shear Stresses (Pa) Under 50% Chance Exceedance Discharge Conditions

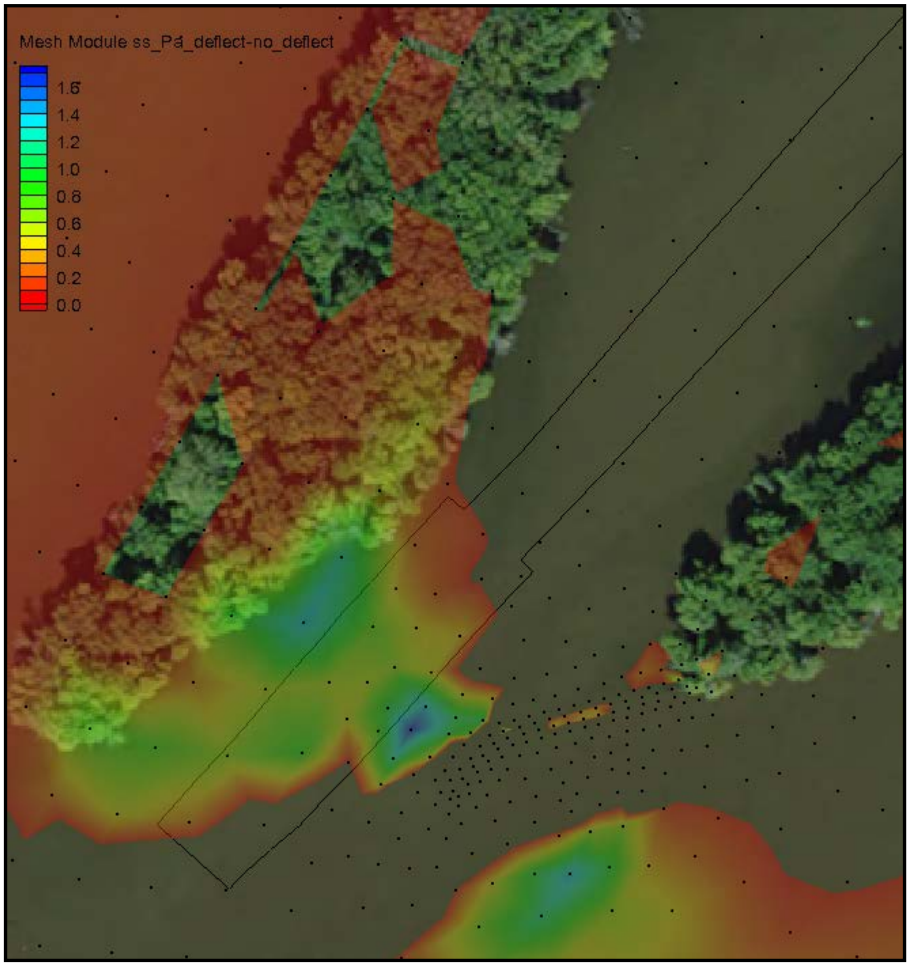

Figure H-21: Difference in Shear Stress due to Deflection Structure (With-Minus Without-Deflection Structure) Under 50% Chance Exceedance Conditions

In conclusion, the analysis has shown that the constrained alignment of the deflection structure does not reduce the likelihood of sediment deposition under median discharge. The hope with the proposed deflection structure was that it would force the zone of eddying out away from the channel toward the main channel, but this was not achievable. Under 50 percent chance exceedance discharge conditions, the deflection structure produces a slight increase in shear stresses (<2 Pa) within the proposed channel area. The magnitude of this shear stress increase is not enough to result in the erosion of more fine-grained (colloidal) sediments. These results do not indicate a benefit in terms of increasing the longevity of the proposed Lower Cut channel and are therefore not recommended.

C. Albany Island Erosion. On the downstream navigation-channel side of Albany Island, the Sponsor reported significant bankline erosion. They indicated the extent of this erosion is about half the length of the island. The PDT does not have good survey coverage for this area; therefore, the AdH model does not capture the bankline geometry with a lot of accuracy. Six simulated velocity transects from the RDB of Albany Slough, across Albany Island and across the main channel, were evaluated under approximate bankfull conditions both for existing conditions and with-Project conditions. Velocity results near the observed erosion do not illustrate attacking flows or velocity-induced erosion under either existing or with-Project conditions. Wind-driven waves are also not likely to be the cause. Vessel position density data do not support erosion due to navigational mooring or wave-action. It is likely that sustained high water results in soil saturation and subsequent felled trees are impacting the bankline stability. In order to prevent further erosion, the PDT has identified approximately 1,000 feet of bankline protection to be placed along the navigation side of Albany Island. CHANLPRO was used to size required stone for the bankline protection design based upon the side slope, flow depth and velocity (Reference 16). A specific weight of 162 lb/cf and a design factor of safety of 1.4 resulted in a D100 of 36lbs. However, given ice force considerations and standard gradation availability, the Geotechnical Engineer ultimately recommended a top size of 250lbs.

D. Upper Cut Rock Closure. Initially this feature was identified as an overwintering fish structure. Velocities exceeding 1 cm/s during the overwintering period produce unsuitable conditions for fish; therefore, a rock closure at the head of Upper Cut was designed with the purpose of preventing flow during the overwintering period. The 95 percent non-exceedance duration elevation during the overwintering months was selected as the design elevation for an emergent rock structure to prevent flow. The resulting elevation at RM 516.75 was 575.1 feet. As sediment delivery through Upper Cut was identified as a significant risk to the life of the channel excavation features, the rock closure's intent was modified to prevent flow down the channel year-round. As such, the design elevation was increased to match surrounding top of bank at about 579.5 feet. Under the initial overwintering design criteria, the rock closure elevation was revised to provide greater resiliency under climate change. This is further discussed in Section VIII. CHANLPRO was used to size required stone for the bankline protection design based upon the side slope, flow depth and velocity (Reference 16). A specific weight of 162 lb/cf and a design factor of safety of 1.4 resulted in a D100 of 36lbs. However, given ice force considerations and standard gradation availability, the Geotechnical Engineer ultimately recommended a top size of 250lbs.

E. Floodplain Forest Diversity Features. Floodplain forest diversity is dependent on river conditions during the growing season. The growing season for Pool 14 was defined as beginning April 15th and running through October 15th. Increasing elevations for tree plantings will improve floodplain forest diversity and mortality. The Hydrologic Engineering Center-Ecosystem Function Model (HEC-EFM) was used to establish an upper limit and lower limit for tree planting, based on inundation duration tolerance of specific tree-species (Reference 18). This similar approach was used for Huron Island, another recent HREP located in Pool 18. Inundation duration tolerances were established by the PDT forester for different tree species. The three inundation duration classifications that were established included: maximum tolerance (45-day inundation duration); moderately tolerant (35-day inundation duration); and minimally tolerant (25-day inundation duration). The upper limit for the tree planting elevation was based upon the 25 percent exceedance probability for the minimally tolerant growing season inundation criteria (25-day inundation duration), which is 577.9 feet at RM 514. The lower limit for the tree planting elevation was determined based upon the 25 percent exceedance probability for the moderately tolerant growing season inundation criteria (35-day inundation duration), which is 576.7 feet at RM 514. As discussed in Section VIII, these elevations were further revised to provide greater resiliency based on the incorporation of climate change.

F. Screened Features

1. Isolated Herptile Habitat. The creation of isolated herptile habitat was evaluated specifically for the construction of berms to limit the frequency of inundation. The elevation of the herptile berms was determined based upon the 10 percent annual exceedance probability elevation determined using HEC-EFM. The resulting elevation was 585.1 feet at RM 514. However, these features were eventually removed from further consideration based on a site visit to the Project area by the sponsor in April 2015 that identified many existing ephemeral wetlands, which presently provide suitable herptile habitat.

2. Beaver Slough Cut. The PDT proposed cutting a channel from Beaver Slough to an interior overwintering backwater or back out to Beaver Slough. The intent of the connection is to provide centrarchid overwintering habitat and allow scouring flows through the channel to maintain the channel and prevent sediment deposition. An adjustable closure structure such as a gate would be required to shut off flow during the overwintering period and allow for flow during the spring high flows. The preferred feature was the cut from Beaver Slough back out to Beaver Slough (Figure H-22); therefore, a hydraulic analysis was completed to evaluate the performance. The following assumptions were made as part of the analysis:

- A gate at the inlet of the cut would be closed during winter to allow for centrarchid overwintering and would be opened during the spring to flush sediments that deposit during low water and flood conditions;
- The material that would be deposited is assumed to be alluvial silt, non-colloidal [with a permissible velocity of 3.5 feet per second (ft/s) (Reference 16)]; therefore velocities of 4 ft/s would be required to “flush these sediments”;
- Channel bottom 30 feet
- Side slopes 4H:1V
- Dredging depth is 6 feet below flat pool (11 feet deep)
- Maximum in-channel velocities would occur under bankfull conditions, approximated as the 50 percent chance exceedance discharge.

Figure H-22. Proposed Beaver Slough Cut

The fall of the river (under 50 percent to 20 percent chance exceedance flows) along the 2,400-foot length of the proposed cut (RM 531.6 to RM 531.1) is closer to 0.2 foot; however, 0.4 foot was used for slope calculation to be generous. The average channel velocity was calculated under bankfull conditions for this channel using Mannings equation = 1.8 ft/s and the resulting Q =736 cfs. Based on this discharge, the cross-sectional area required to achieve the 4 ft/s velocity to flush sediments was determined as 184 ft^2. This reduced cross-sectional area would be achieved by placing wing-dam pairs spaced approximately two wing-dam lengths (as measured from centerline to centerline). The height of the wing dams will match the top of bank (11 feet tall), the rock size will be 400-lb stone, 2H:1V side slopes, and the top width will be 3 feet. The wing dams will extend 7.75 feet along the channel bottom into the center of the channel. The overall footprint (US & DS) of the wing dams will be 47 feet, therefore the spacing between wing dams along the length of the channel is about 100 feet to prevent sediment deposition downstream of the wing dam sets. This results in approximately 24 wing dam sets.

It was then estimated that the necessary excavation costs for the channel would amount to ~$1.6 Million (97,000 CY) and the 24 rock structures would cost ~$6.8 Million. The habitat benefits for overwintering fish (>4-foot depth) would total only ~1.8 acres. In conclusion, there is just not enough of a hydraulic gradient to produce sediment-flushing velocities, and the cost for creating these conditions does not justify the small benefit. This measure was then screened from further analysis.

3. Upper Cut Channel Excavation. Another measure proposed by the PDT was a channel along the full length of Upper Cut (about 7,000 feet long). The maximum channel velocity within Upper Cut is assumed to be during bankfull conditions or somewhere around the 50 percent exceedance probability discharge. Similar rationale to that which was applied to the Beaver Slough Cut was also applied to the Upper Cut Dredging. The upstream head on Beaver Slough at the inlet and the downstream head at the Beaver Slough/Mississippi River confluence limit the slope of the water surface The fall of the river (under 2-5yr Q) along the 7,000-foot length of the proposed cut (RM 516.2 to RM 515) is 0.98 foot. This produced a slope very similar to that calculated for the Beaver Slough Cut.

Without repeating the analysis done for the Beaver Slough Cut in full for the Upper Cut channel, the conclusion was reached that because the velocities are limited by the slope of the river, the enormous cost necessary to produce sediment-flushing velocities would not justify the minimal benefit for the Upper Cut channel. Therefore, this measure too was screened from further analysis.

VIII. CLIMATE CHANGE RESILIENCY

In compliance with ECB-2014-10, *Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs, and Projects*, Phases I and II of the qualitative analysis were completed (Reference 19). Phase I asks if the Project goals or design are relevant to climate change. If climate change is relevant to Project goals or design, then Phase II asks the direction of the potential climate change in the variables that may affect the hydrology of the Project. As an exercise in demonstrating compliance with the Phase I and Phase II analysis requirements, a risk matrix was developed identifying each of the Project objectives and determining whether climate change is relevant to the Project goals or design and to further evaluate the risk to each objective posed by a changing future climate. The risk matrix was developed using the following steps:

1) identify design criteria for each objective;
2) develop metric for design criteria;
3) identify important hydrologic variables influencing associated metrics for each objective;
4) identify the driving climate variables;
5) determine if the important hydrologic variable is climate sensitive;
6) evaluate the future climate;
7) evaluate likelihood of impact to objective due to climate change;
8) evaluate consequences of impacts to objective;
9) identify unknowns regarding future climate; and
10) identify additional design considerations.

Table H-18 illustrates the risk matrix that was developed based upon the Project objectives with features of the Recommended Plan.

Table H-18. Climate Change Risk Matrix

<---PHASE I--->						<---PHASE II--->				
							Risk			
Objective	**1. Design Criteria**	**2. Metric**	**3. Important Hydrologic Variable**	**4. Driving Climate Variables**	**5. Is the Important Hydrologic Variable Climate Sensitive**	**6. Future Climate**	**7. Likelihood of Impact**	**8. Consequence of Change**	**9. Unknowns**	**10. Design Considerations**
1) Diversify floodplain forest habitat on Beaver Island, as measured in acres of elevated topography and number of hard mast tree species present in Project area	Limit inundation duration of roots (<35 days for moderately tolerant) during growing season (Apr 15-Oct 15)	EFM 25% exceedance probability (EP) stage.	Stage	Seasonal Precipitation; Temperature (snow melt)	Yes	Increases in EFM 25% EP elevation observed in historical record (0.9 ft). Assuming similar rate into future, EFM 25% EP elevation will increase 1.5 ft in 50 yrs. Iowa Climate Report indicates increasing average annual precipitation and increased extreme heavy precipitation in summer.	High	If frequency of inundation (>35 days) increases, objective would not be met and increased mortality observed		Raise Project areas to increase resiliency (coping range) **CONSTRAINTS:** Wetland delineation, Floodplain
2) Increase year-round aquatic habitat diversity, as measured by acres and native fish use of spawning, rearing and overwintering habitat	Velocity < 0.5 cm/s during overwintering (Nov-Feb)	95% non-exceedance duration stage during overwintering (closure structure overtopping)	Flow	Seasonal Precipitation; Temperature (snow fall vs. rain)	Yes	Increase in 95% non-exceedance duration elevation observed in historical record (0.3 ft). Assuming similar rate into the future, 95% non-exceedance duration elevation will increase 0.5 ft in 50 yrs.	High	Objective would not be met (no creation of overwintering habitat)		Raise closure structure to increase resiliency (coping range) **CONSTRAINTS:** Wetland delineation, Floodplain
	Depth > 4ft	99% exceedance duration stage during overwintering	Stage	NA - Stage during low flow conditions controlled by Dam 14.	No (Dam 14 limits 99% exceedance duration elevation)	NA	Low	Objective would not be met (loss of overwintering habitat)	Impact of climate change on future sedimentation rates.	NA
	DO > 5 mg/L	> 5 mg/L during overwintering	Residence Time (volume, dredging depth, stage)	Temperature, Seasonal Precipitation	Yes	Iowa Climate Change Report indicates increasing winter temps since the 1970s are expected to continue, decreasing duration, extent and thickness of ice cover.	Low - near-freezing water temps will not change DO/Temp relationship	Low DO can impact fish survival.	Impacts of temperature on snowpack and ice clarity-photosynthesis-DO	No change
3) Increase structure and function of side channel habitat, as measured by native freshwater mussel use	Construct chevron so as to prevent further erosion of Albany Island, thereby preserving Albany Slough and associated mussel habitat	30% annual exceedance duration	Stage	Seasonal Precipitation; Temperature (snow melt)	Yes	Increases in 30% annual exceedance duration stage (0.7 ft) observed in the historical record. Assuming similar rate into the future, 30% annual exceedance duration will increase 1.13 ft in 50 years. Iowa Climate Report indicates increasing average annual precipitation and increase in extreme heavy precipitation in summer.	High	Given the relatively conservative design adopted for the design metric (30% exceedance duration), relative to the broad range of metrics (30-50% exceedance duration) identified in previous successful chevron designs, in addition to the adaptive management measure which would allow for the increase in chevron elevation after 5-7 years, the overall risk to the objective is considered moderate to low.		Increase chevron design height to result in less frequent overtopping

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In the absence of hydrology projections for the Upper Mississippi River Basin, the assessment of future climate was limited to consideration of observed changes in hydrology and qualitative findings in published literature. Any conclusions reached based on historic observations were supported by published information on regional future climate projections relevant to the Project (References 20 and 21). The primary assumption made in this approach is that changes in hydrologic stage observed between the previous 30-yr record and the present 30-yr record reflect changes projected between the present 30-yr record and the future 30-yr record. The specific design criteria metrics analyzed in Table H-19 and included in the risk matrix (Table H-18) are those identified during Project objective development by the PDT: EFM 25 percent exceedance probability stage; 95 percent non-exceedance duration stage during overwintering; 99 percent non-exceedance duration stage during overwintering; >5mg/L DO during overwintering; and 30 percent annual exceedance duration. Design criteria were then computed based upon the present 3-decade stage record and estimates of what the "current" 30-yr stage record would look like at year 50, providing a range of design elevations intended to increase resilience (Table H-19). Table H-19 illustrates the differences observed between the historical record and the present record, identifies the rate of change and shows the projected design metric for 50 years from present. The results apply to the Camanche Gage location (RM 511.8) and are reported in the MSL 1912 vertical datum.

The approach identified by the PDT to minimize climate change risk to the Project in general was to select the 50-yr future design elevation for the Recommended Plan and evaluate the floodplain impacts resulting from this design elevation maximized for resiliency. If the maximum design elevation results in floodplain impacts, the elevation will be incrementally reduced until there are no floodplain impacts. As the Project planning phase continued, an additional objective was developed to maintain existing mussel habitat (chevron feature), and an existing rock closure feature was modified to provide year-round flow reduction for the purpose of reducing sediment deposition.

The chevron feature, as described in Section VII. A. is the exception to this. Unlike the other design metrics, where the risk to the Project objectives due to climate change is high, the chevron objective is faced with a moderate to low risk due to climate change. The overall risk was considered moderate to low due to the relatively wide range in design metric (annual exceedance duration) applied in previous chevron designs that have performed successfully; i.e. ~30 percent to 49 percent. As a result, the design elevation was moderately increased for the chevron in order to provide greater resiliency to climate change. The final chevron design was 575 feet (~25 percent annual exceedance duration).

The resulting design elevation at the Project features' location had to be interpolated upstream from the Camanche gage (RM 511.8) based upon the appropriate water surface profile (Table H-20).

Table H-19. Design Metric Results at Camanche Gage, RM 511.8, in Vertical Datum MSL 1912

Design Metric	1953-1983 POR Design (ft. MSL 1912)	1983-2013 POR Design (ft. MSL 1912) [1]	Change Over 3-decade Period (ft)	"Rate" (ft/yr)	50-yr Future Change (ft)	Revised Design for 50 Years Out (ft. MSL 1912) [1]
Upper Tree Planting Elevation: 25% exceedance probability for 25-day growing season inundation duration	576.9	578.0	1.1	0.035	1.8	579.8
Lower Tree Planting Elevation: 25% exceedance probability for 35-day growing season inundation duration	576.0	576.9	0.9	0.03	1.5	578.4
Overwintering Velocity: 95% non-exceedance duration over-wintering	574.7	575.0	0.3	0.01	0.5	575.5
Chevron Design Elevation: 30% exceedance duration	573.8	574.5	0.7	0.02	1.13	575.6

[1] These two columns represent the lower and upper limits of the design elevation range.

Table H-20: Design Metric Results Various Locations, Beaver Island HREP

	Design Criteria	El. w/o Climate Change (ft, NAVD88)	El. w/ Climate Change @ yr 50 (ft, NAVD88)	Design Elevation (ft, NAVD88)
Upper Topographic Diversity Limit, RM 514	EFM 25% Exceedance Probability for **Minimally** Tolerant Species (25 days during the growing season 4/15 to 10/15)	577.9 (578.7 MSL 1912)	579.8 (580.6 MSL 1912)	579.8 (580.6 MSL 1912)
Lower Topographic Diversity Limit, RM 514	EFM 25% Exceedance Probability for **Moderately** Tolerant Species (35 days during the growing season 4/15 to 10/15)	576.7 (577.6 MSL 1912)	578.3 (579.2 MSL1912)	578.3 (579.2 MSL1912)
Upper Cut Rock Closure, RM 516.75	Top of Bank for sediment deposition reduction (*Initially 95% non-exceedance duration over-wintering)	575.1 (576 MSL 1912)*	575.8 (576.7 MSL 1912)*	Top of Bank approx. 579.5 (580.4 MSL 1912)
Chevron Design Elevation, RM 514.4	30% annual exceedance duration	574.15 (575 MSL 1912)	575.47 (576.32 MSL 1912)	575 (575.85 MSL 1912)

IX. FLOODPLAIN ASSESSMENT OF RECOMMENDED PLAN

The location of the Beaver Island Project area imposes two sets of criteria with regard to impacts to the floodplain. First, the Clinton, Iowa, Levee System is located on the RDB of Beaver Slough. Located next to an existing Federal project, the Beaver Island Project is restricted to "no-rise" to the 1 percent chance exceedance probability water surface profile. The District has interpreted "no-rise" to mean less than 0.1 foot of rise. Second, the Beaver Island Project is located within the floodway which the Federal Emergency Management Agency requires "no-rise" to the 1 percent exceedance probability water surface profile. The State of Iowa interprets this as restricting impacts to the 1 percent exceedance probability water surface profile to 0.01 foot of rise per Iowa Administrative Code 567 (Reference 22).

In order to model the impacts of the Recommended Plan, HEC-RAS v4.1 was used to compute the water surface profiles resulting from 'existing-conditions' and 'with-Project'. The 2004 Floodway HEC-RAS steady flow model for the Mississippi River Navigation Pool 14 served as the starting point for this modeling effort. The 'existing-condition' model geometry was enhanced in order to better identify water surface impacts caused by the Beaver Island HREP's proposed features. The enhancement involved using geometry from the 'existing condition' TIN which is based on more recent bathymetry and LiDAR data than that used in the 2004 Floodway model, and increasing the number of cross-sections to accommodate the proposed Project features identified in the 'with-Project' model. The resulting cross-section layout used for both the 'existing condition' and 'with-Project' models is shown in Figure H-23.

The 1 percent chance exceedance discharge was simulated for both the 'existing condition' and the 'with-Project' condition. The results from the 'with-Project' simulation indicate that the Recommended Plan results in 'no-rise' (less than 0.01 foot) per Iowa Administrative Code 567 (Reference 22). Prior to submission of the permit package the Upper Cut Rock Closure revision should be updated in the model.

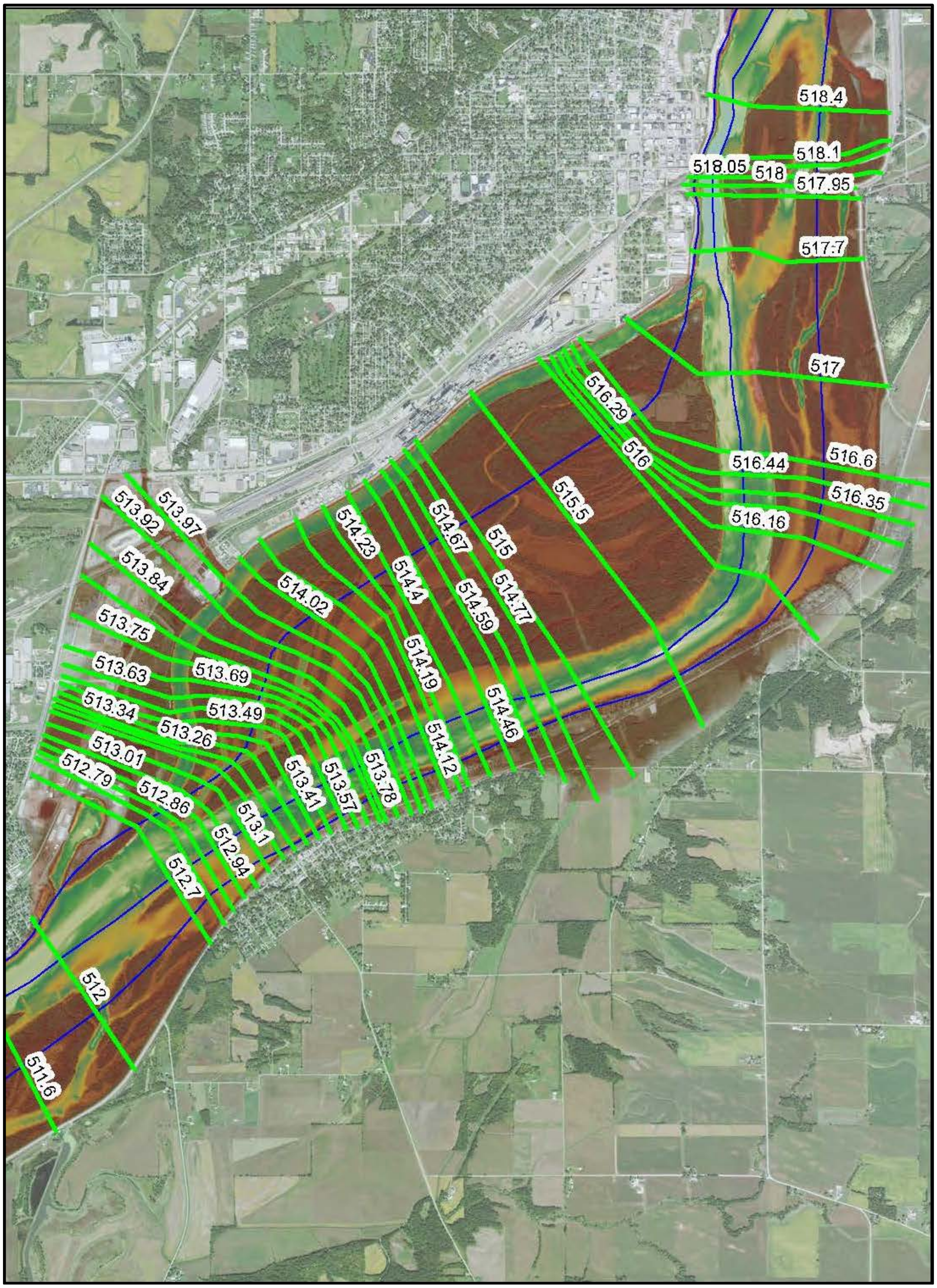

Figure H-23: Cross Section Layout for HEC-RAS Beaver Island Floodplain Impacts Assessment

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