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Analyzing the St. Marys Rapids for Suitable Fish Habitat

An Engineering with Nature® Demonstration Project

Timothy J. Calappi, Katherine A. Labuhn, Patrick S. Fowler, Burton C. Suedel, Justin L. Wilkens, Gaurav Savant, Marianne Bachand, and Guillaume Guénard

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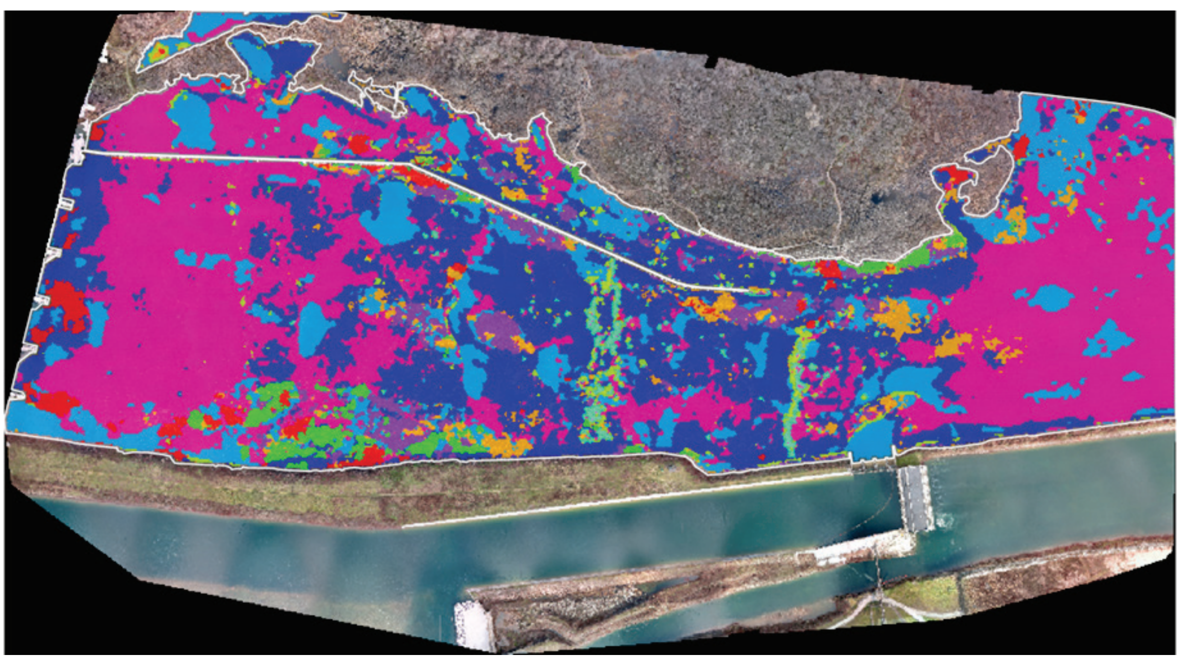

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Final Report

Prepared for Engineering With Nature® (EWN)

Under Project Number 476522

Abstract

The St. Marys rapids at the outlet of Lake Superior is a vital habitat for a wide range of aquatic species. The regulation of the outflows from Lake Superior by Compensating Works (i.e., a series of control structures) can lead to rapid changes in hydraulic characteristics, potentially creating adverse conditions for downstream biota. To accomplish more naturally varying flows, the U.S. Army Corps of Engineers (USACE) Detroit District (LRE) is constructing four remotely operated gates on the United States (U.S.) side of the Compensating Works. The gates will be capable of being opened slowly (over many hours) until a desired discharge is achieved. A two-dimensional (2-D) model was developed to evaluate multiple scenarios and analyze the total area available for fish spawning based on depth and velocity associated with a particular gate setting. The model also addressed the recommendation for water level rates of change associated with gate changes, suggesting that water level rates of change be held to less than 10 centimeters (cm)/hour to avoid stranding juvenile fish. This is consistent with Engineering With Nature® (EWN) principles of maximizing habitat value of the rapids while maintaining water regulation objectives.

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Preface

This report is a part of a larger study, “St. Marys Rapids Habitat Improvement: An Engineering with Nature® Demonstration Project” conducted for the International Lake Superior Board of Control, who is responsible for regulating the outflow of Lake Superior and managing the Compensating Works (Comp Works) on the St. Marys River. This project was funded by the International Joint Commission, the International Watersheds Initiative (field work associated with model calibration), the U.S. Army Corps of Engineers (USACE) Detroit District (LRE) (base model development and model calibration), and the USACE Engineering Research and Development Center (ERDC), Engineering With Nature® (EWN) initiative. The project number was 576522. Dr. Todd Bridges was the Program Manager of the Dredging Operations and Environmental Research (DOER) Program, and EWN lead.

This report was written under the direct supervision of Mr. Warren P. Lorentz, Chief, Environmental Processes and Engineering Division, ERDC Environmental Laboratory (EL); Dr. Bill Nelson, Chief, Environmental Risk Assessment Branch, EL; Dr. Jack E. Davis, Deputy Director, EL; and Dr. Ilker R. Adiguzel, Director, EL.

The orthomosaic analysis imagery was collected by the USACE Jacksonville District and analyzed by Environment and Climate Change Canada, who also performed the substrate analysis. Environment and Climate Change Canada is concurrently finishing a pilot study of ecological modeling in the St. Marys rapids, making use of the provided imagery and hydrodynamic outputs from this study. Sections 2.6 and 3.5 of this report are authored by Dr. Marianne Bachand, Mr. Sylvain Martin, Dr. Guillaume Guenard, Mr. Olivier Champoux and Dr. Jean Morin. The authors of this report are grateful for their significant contributions to this work.

The modeling effort benefitted from the extensive field measurements made by the following USACE LRE personnel: Mr. Matt McClerren, Mr. Josh Friend and Mr. Justin Gresell along with contributions from the U.S. Geological Survey (USGS) and Water Survey Canada, Mr. JaVaughn Perkins handled the survey harmonization and initial mesh development, Mr. Jacob Bruxer, Ms. Cindy Jarema and Mr. Charles Sidick provided assistance with the Lake Superior outflow regulation details, and Mr. Evan Patton provided graphics support.

At the time of publication of this report, Ms. Kathy M. Griffin was Headquarters USACE Acting Navigation Business Line Manager, and Mr. Charles E. Wiggins, ERDC Coastal and Hydraulics Laboratory (CHL), was the ERDC Technical Director for Navigation.

COL Teresa A. Schlosser was Commander of ERDC, and Dr. David W. Pittman was the Director of ERDC.

Acronyms and Abbreviations

2-D	Two-Dimensional
AOI	Area of Interest
CHS	Canadian Hydrographic Service
CHL	Coastal and Hydraulics Laboratory
cm	Centimeters
CMS	Cubic Meters per Second
Comp Works	Compensating Works
DOER	Dredging Operations and Environmental Research
EL	Environmental Laboratory
ENC	Electronic Navigation Chart
ERDC	Engineer Research and Development Center
EWN	Engineering with Nature®
GDAL	Geospatial Data Abstraction Library
GIS	Geographic Information System
LRE	USACE Detroit District
m	Meters
NOAA	National Oceanic and Atmospheric Administration
RD&T	Research, Development, and Technology
RTK-GPS	Real Time Kinetic-Global Positioning Satellite
U.S.	United States
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey

Unit Conversion Factors

Multiply	By	To Obtain
Acres	4,046.873	square meters
acre-feet	1,233.5	cubic meters
cubic feet	0.02831685	cubic meters
cubic inches	1.6387064 E-05	cubic meters
cubic meters per second	35.31466	cubic feet per second
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
Feet	0.3048	Meters
Hectares	1.0 E+04	square meters
Inches	0.0254	Meters
miles (nautical)	1,852	Meters
miles (U.S. statute)	1,609.347	Meters
miles per hour	0.44704	meters per second

1 Introduction

1.1 Background

The St. Marys River drains Lake Superior into Lake Huron near Sault Sainte Marie, Michigan, which is separated from its twin city Sault Sainte Marie, Ontario by the river. This connecting channel naturally makes the river an important ecological corridor, helping to fulfill many processes including most notably, the movement of animals and maintenance of fish populations. The river also plays an important role as a waterway for commerce, hydropower, water supply, and recreational fishing. Originally, due to the rapid drop in elevation in an area known as the St. Marys rapids (rapids), navigation between Lakes Superior and Huron was not possible (Figure 1).

Figure 1. Great Lakes region with project area circled.

Beginning in the 1850s, a number of structures were built at the headwaters of the rapids to allow navigation between the lakes. Development and improvements continued through 1921 when the

St. Marys River complex, owned and operated by the U.S. Army Corps of Engineers (USACE), was completed. This complex consists of Compensating Works (Comp Works), four navigation locks, and two hydropower plants. The control structures, together with their associated dikes, form a dam to control the outflow of Lake Superior.

The Comp Works consist of 16 steel sluice gates suspended between towers and piers. Counterweights and roller trains are used to manually move the sluice gate position up or down by a three person crew. Gates 1–8 are located in Canadian waters and are owned, operated, and maintained by the Brookfield Renewable Energy Group, Sault Sainte Marie, Ontario, who also operates a hydropower plant. Gates 9–16 are located in United States (U.S.) waters and are owned by the USACE. The operation and maintenance is performed by the Cloverland Electric Cooperative, Sault Sainte Marie, Michigan, through a contract with the USACE. Cloverland Electric and the USACE each operate a hydropower plant (Figure 2; H and F, respectively).

Figure 2. Hydropower and other control structures on the St. Marys River connecting Lake Superior (bottom of photo) and Lake Huron (top, in the distance).

The International Lake Superior Board of Control is responsible for monthly regulation of Lake Superior outflows. The International Lake Superior Board of Control operates under a set of conditions and criteria outlined in the Orders of Approval issued by the International Joint

Commission. The original Orders of Approval, issued in 1914, established the objectives for, and limits to, the regulation of Lake Superior's outflow. Several amendments to the Orders have been issued, most recently in 2014, following recommendations from the International Upper Great Lakes Study, completed in 2012 (http://www.ijc.org/en_/ilsbc/Plan2012).

As required by the Lake Superior Regulation Plan, the International Lake Superior Board of Control must maintain a minimum flow through the main portion of the St. Marys rapids equivalent to one-half gate open at the Comp Works. The main portion of the rapids is immediately downstream of the Comp Works. The minimum flow is achieved by partially opening four gates, this helps to distribute the water more evenly across the rapids. The one-half gate setting has been used almost exclusively during the recent period of low water levels in Lake Superior (occurring between 1997 and 2013). By May 2014, the water level on Lake Superior had risen enough that the regulation plan frequently required multiple gate openings. The International Lake Superior Board of Control began to employ multiple, partially open gates in lieu of fully open gate settings, which have been used historically, to pass an equivalent required flow. Partially open gate settings instead of fully open gate settings are expected to provide a number of ecological benefits as a result of the discharge being more evenly distributed across the entire area of the St. Marys rapids. This action should minimize changes in wetted perimeter during gate changes and reduce the water level rate of change and velocities, which should minimize events such as fish entrapment. This new approach, developed in consultation with natural resource managers, will require additional study and field data collection to realize the operational and ecological benefits.

The St. Marys rapids is an important habitat for a variety of aquatic species. However, by 1915, a 50% reduction in the area of the main rapids (now approximately 28 hectares) occurred. Construction of the St. Marys River Complex structures to improve navigation and hydropower resulted with most water flow being directed to the hydropower plants (Bray 1996). After the Comp Works were completed in 1921, the mean annual discharge through the rapids decreased substantially (<50% of total discharge normally with <10% occasionally) and the frequency of low and high discharge rates increased (Bray 1996). Habitat availability in the rapids, for fish species in particular, is attributed to flow rates. Differences in flow rate effects on spawning habitat during high flows, and entrapment during low flows, are primary concerns in the rapids (Bain et al. 2010). The construction of dams has resulted in an altered fluctuation state, therefore, it is important to understand past and current conditions in the rapids to guide a return to former, and more naturally varying conditions that may be more suitable for important sport and commercial fisheries. Commercial and sport fishing industries contribute over $5 billion annually to the Great Lakes economy (Great Lakes Environmental Research Lab 2016), therefore, maintaining healthy fish populations is vital to the regional economy. Optimizing gate operations to return discharge rates to more natural fluctuations is an inexpensive way to increase suitable habitat for fishes.

The International Joint Commission and the Lake Superior Board of Control have recently made efforts to address concerns about the frequency of low and high discharges, with additional research planned to better understand the dynamics within the rapids. In 2014, a Supplementary Order included a new condition requiring the rates at which the gates of the Comp Works are opened and closed, be such as to minimize the risk of fish being flushed or entrapped in the rapids. Recent research suggests that water depth changes less than 10 centimeters per hour (cm/hour) are needed to reduce fish entrapment (Bain et al. 2010). However, the ecological relevance of this rate has not been verified in the rapids and there are limited hydraulic data available to translate what this rate of change means in terms of an operational limit on gate movements. In an effort to accomplish more naturally varying flows, the USACE Detroit District (LRE) has started construction to remotely operate four gates on the U.S. side of the Comp Works. These gates will be remotely operated, and capable of being opened slowly over the course of many hours until a desired discharge is achieved to meet regulatory, environmental, and recreational needs.

The automation of the Comp Works gates to maximize habitat value of the rapids while maintaining other regulation plan objectives is consistent with Engineering With Nature® (EWN), a USACE initiative defined as “the intentional alignment of natural and engineering processes to efficiently and sustainably deliver economic, environmental, and social benefits through collaborative processes.” The following four EWN elements are addressed through the implementation of the current project: 1) the use of science and engineering to produce operational efficiencies supporting sustainable delivery of project benefits, 2) the use of natural processes to maximum benefit, thereby reducing demands on limited resources, minimizing the environmental footprint of projects, and enhancing the quality of project benefits, 3) increasing the value provided by projects to include social, environmental, economic benefits, and 4) using collaborative processes to organize, engage, and focus interests, stakeholders and partners.

1.2 Objectives

The primary objective of this study is to develop recommendations for gate operations to minimize the potential adverse effects on aquatic biota immediately downstream of the Comp Works. This was accomplished by following the recommendations of Bain et al. (2010), who suggested water level changes in the rapids should not exceed 10 cm/hour so as to not pose a threat to fish in the river. The St. Marys rapids habitat was also quantified with respect to water velocity and depth. Upon collection of validation data, an orthomosaic, created from aerial images acquired by a drone, was analyzed to better understand the locations of useable habitat for various gate openings. Collection of the validation data occurred when the gate openings were conducive to field work. Finally, this model provided the hydrodynamic foundation for an ecohydraulics model built by Environment and Climate Change Canada. This model integrated the outputs of physically-based biological models including hydrodynamics with the goal of quantifying suitable habitat for multiple fish species that would be suitable under a variety of water management plans.

1.3 Approach

This study relies on outputs from a hydrodynamic model of the St. Marys rapids. A hydrodynamic model is required to quickly and efficiently evaluate a broad range of gate openings at various water level conditions. Lake Superior has a historic range of water levels spanning approximately 1 meter (m) between its historic low and historic high water level. Seasonal variation on the lake is approximately 0.3 meters (m).

Because limited hydrodynamic data existed on the rapids, field data were needed for model calibration. The LRE, in consultation with the Lake Superior Board of Control, began deploying instruments in the St. Marys rapids to measure water levels and total head on the Comp Works to establish discharge curves based on orifice flow assumptions. A series of pressure sensors were deployed within the St. Marys rapids at hydraulically significant locations to measure water levels for model calibration, and discharges at various gate settings, so that recommendations on gate operations could be made to meet both hydrodynamic and environmental objectives.

Habitat suitability and larvae survivability were modeled using an integrated environmental response model. The model integrated physical characteristics of the system (e.g., bathymetry, bottom slope, water temperature, and substrate) with water velocities and water depths from a hydrodynamic model. Integrating these variables helped predict locations where successful spawning and survivability occurs. Combining previously disparate sources of data will help inform water management strategies in the St. Marys rapids.

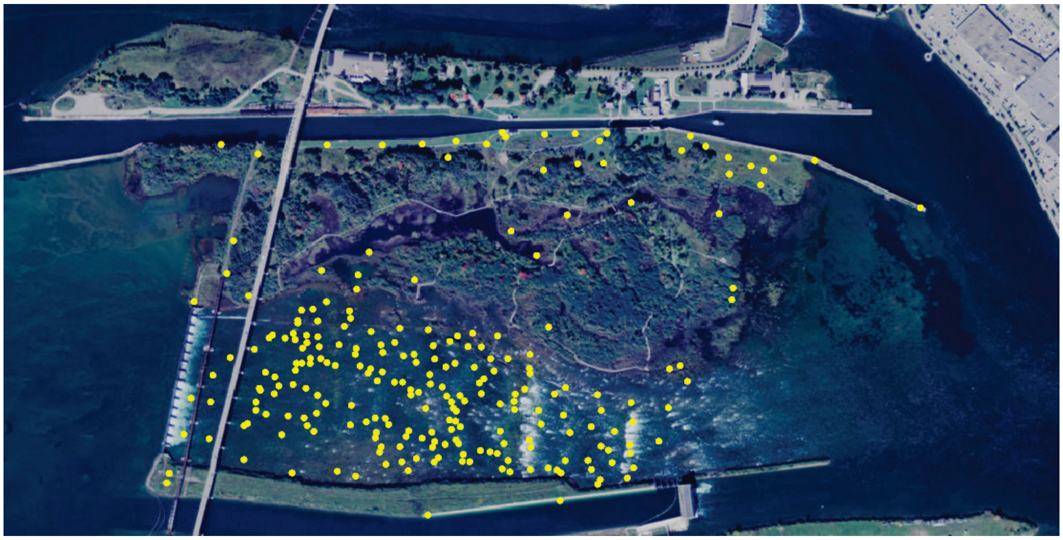
2 Field Data Collection

The St. Marys rapids are a challenging environment for field data collection. The site is remote and human access is restricted on the United States side due to multiple physical constraints and hazards. The USACE has access to the site, but mobilizing equipment to the rapids from either side (U.S. or Canada) requires significant coordination and effort, and until recently, public and stakeholder interest in increasing the multiple benefits provided by the rapids was minimal.

Early on, geometric data were the primary interest. Photographic evidence exists that survey data were collected in 1939 (Figure 3), however, these data were not located to include in this report. The next known survey was conducted in 1985 when the fisheries dike was constructed (Figure 4). There is no other historical evidence of water level or velocity data throughout the rapids.

Figure 3. Photo of a survey team in the St. Marys rapids circa 1939.

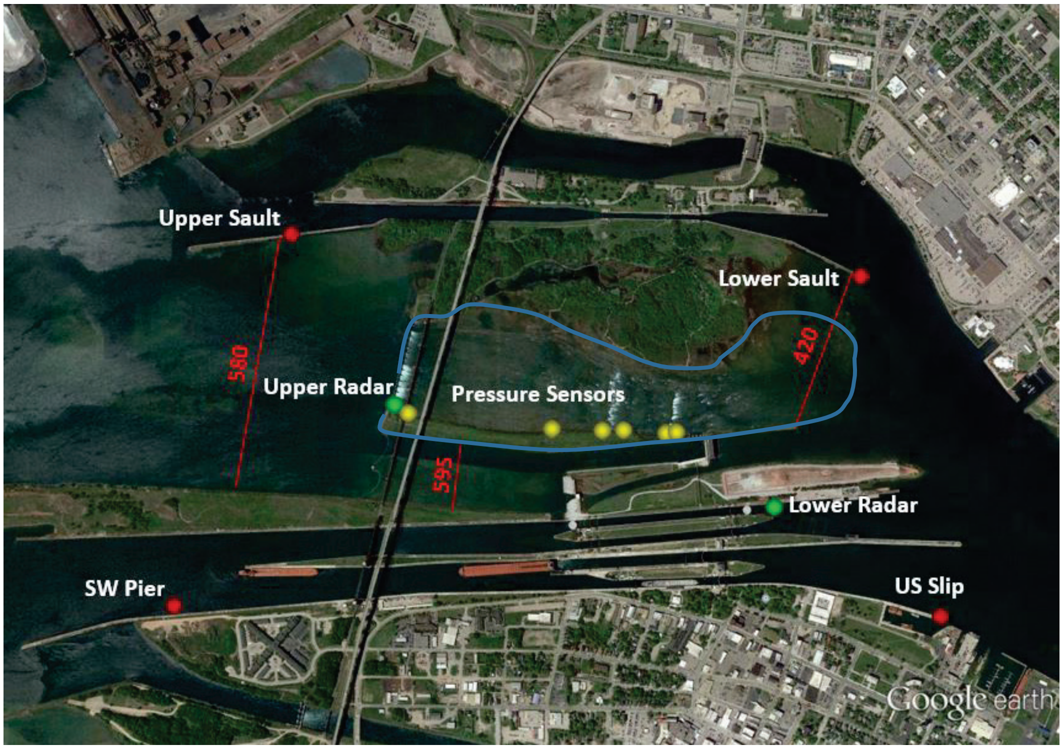
Figure 4. Solid yellow circles represent survey locations collected during construction of Fishery Dike in 1985 (as completed see Figure 2 C).



Because limited hydraulic or geometry data for the rapids exist, the project team performed field work in 2015 to collect these data. The goal of the field work was to collect sufficient data to validate a hydrodynamic model capable of replicating depths and velocities in the St. Marys rapids under various hydropower demand, navigation allotments, and Comp Works gate settings.

Access to the south side of the rapids is only possible through the USACE Sault Lock facility. The rapids are accessed down a steep embankment with a vegetated, loose rock, and clay surface. Based on the location, the gauging techniques used on the rest of the St. Marys system are not applicable in the rapids, therefore, pressure sensors were installed to measure water levels and surveyed in position (see Section 2.1). The locations established for the data collection stations in the rapids, including National Oceanographic and Atmospheric Administration (NOAA) and Canadian Hydrographic Service (CHS) gauging, are shown in Figure 5.

Figure 5. St. Marys rapids (outlined in blue) with pressure sensor locations (yellow dots, sensor 1 is most upstream), radar gauge locations (green dots), NOAA or CHS gauging locations (red dots) and discharge measurement locations (red lines).



2.1 Pressure sensors

Pressure sensors capable of monitoring water level changes were used at six locations throughout the rapids (Figure 5). The loggers were placed at locations of hydraulic interest and efforts were made to reduce the effects of velocity head where possible. Loggers are labeled as 1–6, where number 1 is the most upstream, and number 6 is the most downstream location. Logger 1 was placed in a location of relatively slack water, logger 2 is located at the upstream side of a break in slope, loggers 3 and 5 are on the upstream side of a step in the bed, and loggers 4 and 6 are on the downstream side of the steps. A 7th level logger was mounted above ground to record barometric pressure changes for correcting the water levels of the sensors placed underwater.

Each logger was attached to a 2 cm rebar that was hand-driven into the bed of the rapids until refusal. The top of the rebar was then surveyed using real time kinematic global-positioning satellite (RTK-GPS). The distance from the top of the rebar to the face of the pressure sensor was recorded to determine the elevation of the level logger. All level loggers were programmed to collect data at 6-minutes (m) intervals and were synced with the NOAA water level gauges both up- and downstream of the rapids. Data were collected from 1 May through 5 November 2015 for six gate changes, from a three gate setting in May, to six equivalent gates open in July, and back to a three gate equivalent in October.

The half-gate settings in April and November were not recorded. If the pressure sensors were to remain serviceable throughout the field season, they could not be placed too far from the north dike. This necessitated their placement on dry land at the half-gate setting. Had placement been chosen for the sensors to be wet at the half-gate setting, they would not have been serviceable at higher gate settings.

2.2 Radar water level sensors

Radar water level sensors (Radar Series H-3611, WaterLog, Yellow Springs, OH, U.S.) equipped with a SatLink2® data logger (Sutron, Sterling, VA. U.S.) were installed at the upstream and downstream reaches of the rapids (Figure 6). These sensors provide a more traditional approach to water level management on this system and vertical control was easier to establish and verify. The H-3611 radar used NOAA specifications for water level logging at 6-min intervals. The data were then transmitted to the LRE for further use.

Figure 6. Upstream radar gauge placed on a Comp Works Gate 14.

Radar sensors were installed prior to the July 2015 gate changes. The sensors were left in place through the winter 2015/2016. The validity of the data through the winter months required user input because the sensor may only have given the height of an ice affected surface. These sensors were serviced in the spring of 2016 and checked for vertical control. No adjustment to vertical was required in the spring of 2016. The sensors were left in place through the summer and fall of 2016 and were removed prior to winter 2016/2017. The sensor on the Comp Works was removed to accommodate automation of four of the Comp Works gates.

The upstream radar water level sensor was mounted on the downstream side of the Comp Works and measured the stage just downstream of the closed Gate 14 (Figure 6). The International Lake Superior Board of Control permitted the USACE to close the gate immediately upstream of the radar sensor. The sensor measured still water between two piers, eliminating the effect of velocity head. The instrument was mounted at the center point between two piers approximately 16 m apart. Therefore, the radar cone was not intersecting any part of the structure. Based on the beam angle of the instrument and the height above the water, the radar had a diameter of about 3 m.

The downstream radar sensor was mounted to a coffer dam approximately 270 m from the rapids (Figure 7). The location was chosen because of the lentic water conditions and the total energy was assumed to approximately represent the downstream end of the rapids. This pair of sensors, along with the pressure sensors, are the only known measurements of the water surface elevation through the rapids. The radar gauges were operated from July 2015 through October 2016.

Figure 7. Downstream radar gauge placed on a coffer dam.

2.3 Discharge measurements

Water discharge through the Comp Works has been measured for many decades. Historically, if the International Lake Superior Board of Control recommended opening six gates, the gates would be opened until the bottom of the gate cleared the water surface. Flow (Q) was estimated using Equation 1 (Edmands 1931).

$$Q = cLH^{3/2} \tag{1}$$

Where,

c = a weir coefficient,
L = the length of the weir, and
H = the head on the weir.

Under the current operation plan, if the International Lake Superior Board of Control recommends opening six gates, the gates are partially opened to release an equivalent flow as compared to the full gate settings. In 2014, the water levels on Lake Superior rose significantly (http://www.lre.usace.army.mil/Portals/69/docs/GreatLakesInfo/docs/WaterLevels/LTA-GLWL-Graph_2016.pdf). In response, the Lake Superior Regulation plan required multiple gates be opened in May, which was the first time since 1997 that the plan regularly required multiple gate openings throughout the forecast period. Ice was still on the upstream side of the gates and concerns for damaging the gate seals if the gates were fully opened led to the partial gate strategy. By partially opening the gates, ice remained at the surface of the water and did not pass through the gates, preventing damage to the gate seals. However, the rating equations had previously been developed based on fully opened gates and weir type discharge equations since the bottom of the gate cleared the water surface. Under these new operating conditions, gated flow equations and measurements of partial gate opened are required to develop orifice flow relationships. Currently, standard orifice flow equations are used to estimate flow through partially opened gates to determine the required height of the gate opening. The orifice flow equation is defined by Equation 2.

$$Q = C * 15.91 * GS * \ (2 * 9.81 * H)^{0.5} \qquad (2)$$

Where,

C = coefficient of 0.62,
GS = gate setting (height of gate opening in m),
H = total gate height (two different settings, the sill for gates 5 through 8 is at a lower elevation than the other gates).

Measurements of partial gate settings occurred from May to November 2015 to help verify coefficients associated with the partial gate equation. Discharge through the Comp Works were measured using Teledyne RDI® acoustic Doppler current profiler equipped on a manned vessel and unmanned vessel at three different transects. The choice of equipment was determined by the number of gates open at the time of the measurement. If three or fewer gates were open, the downstream section 420 (Figure 5) was measured using a manned boat with a side mounted Rio Grande 1,200 kHz acoustic Doppler current profiler. If more than three gates were opened, the upstream sections 580 and 595 were measured simultaneously (Figure 5); section 580 was measured similarly to section 420, and section 595 was measured using a remotely operated Ocean Science Z-Boat with a RDI RiverRay 600 kHz Phased Array. The upstream measurement is converted into a Comp Works discharge by subtracting the section 595 discharge from the section 580 discharge (Figure 5).

From May 2015 through November 2015, 11 discharge measurements were made at the Comp Works under various gate configurations. To minimize the number of gate changes and the potential for adverse impacts of large fluctuations in hydraulic conditions in the rapids, measurement schedules were coordinated with the Lake Superior Board of Control so that they corresponded with gate changes required as part of normal monthly regulatory operations. The required gate changes were also done in stages over the course of a few days, with discharge measurements made before and after each gate change to allow for measurements of multiple gate configurations during a single field visit. Measurements were completed following the guidance in U.S. Geological Survey (USGS) TM3A22 (Mueller et al. 2013).

2.4 Hydrographic survey

Hydrographic survey data were collected from USACE, NOAA and Canadian Hydrographic Survey sources. Data ranged from the 1970s to 2014 for the federal navigation channel and other portions of the river surveyed for various project needs. The combination of these data represented the best available knowledge about the geometry of the St. Marys River at the time of model development.

2.5 Light detection and ranging (LIDAR) data collection

High resolution bathymetry was used to generate detailed habitat maps. To capture high resolution data in the rapids and throughout the nearshore of the entire model domain, topographic-bathymetric LIDAR was used for this project. High resolution geometry helped clearly define sensitive habitat along the entire reach of the river on both the U.S. and Canadian sides. Figure 8 shows an example of bathymetric bottom, water surface elevation, and vegetation.

Topobathymetric LiDAR was collected 250 m landward of the shoreline and up to 150 m waterward of the shoreline or to laser extinction between October and November 2015 (Figure 9). All the data were collected before the first snowfall, and the portion over the St. Marys rapids was collected at the minimum one-half gate setting in the rapids.

Figure 8. Typical cross section showing column surface (blue), channel bottom (white) and vegetation (green) high resolution bathymetry results obtained during the LIDAR survey.

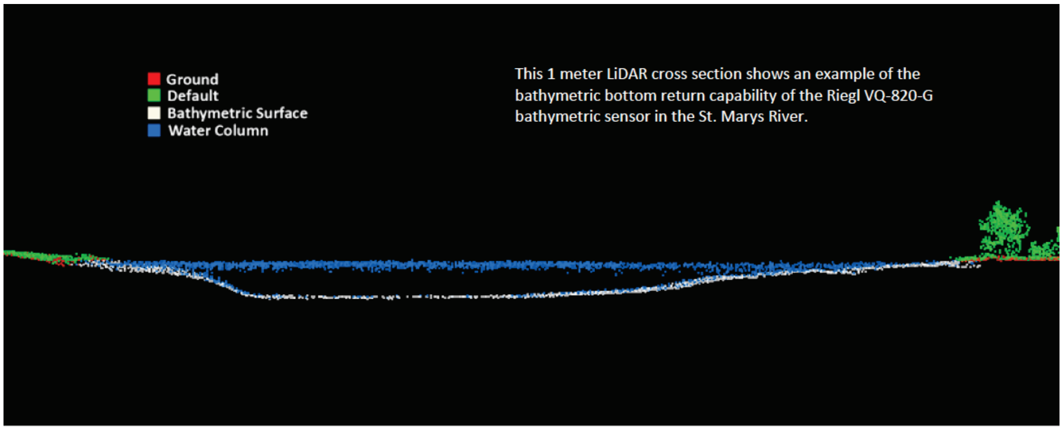
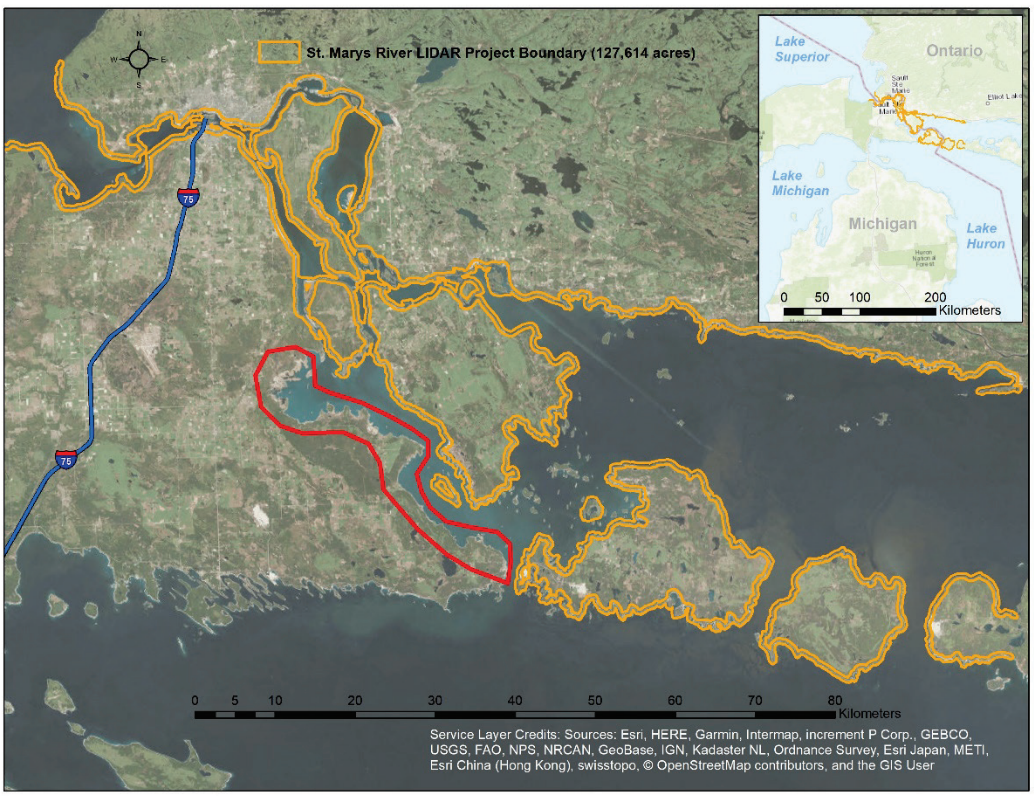


Figure 9. Yellow line shows the extent of topobathymetric LiDAR data delineating the project boundary. Red line shows approximate extent of the 2012 Joint Airborne Lidar Bathymetry Technical Center of Expertise (JABLTX) data collection.



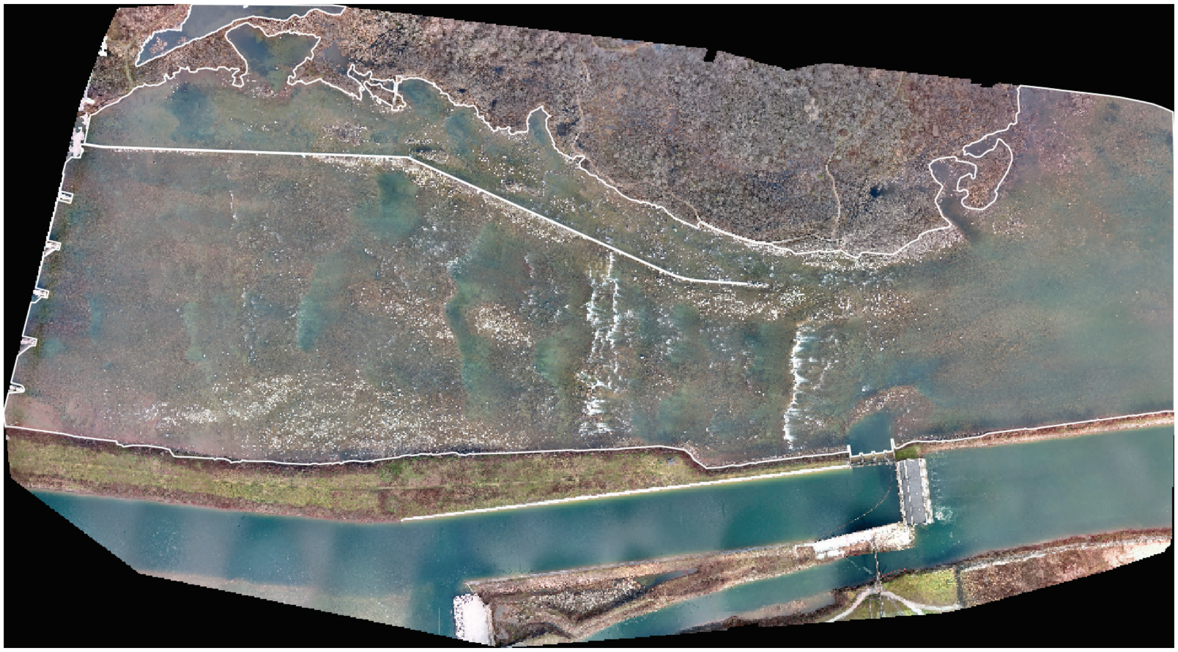
The accuracy of the data can be analyzed in two different ways, first in terms of absolute accuracy (the consistency of the data with external data sources), and relative accuracy (the consistency of the dataset with itself). Absolute accuracy was assessed using Fundamental Vertical Accuracy, which compares known ground control points established in areas where

LiDAR was collected to the triangulated surface generated by the LiDAR points. The St. Marys River LiDAR had 164 ground control points which were used to achieve an accuracy of 0.045 m. Additionally, 334 bathymetry (submerged or along the water's edge) check points were also collected to achieve an average vertical accuracy of -0.013 m. The relative vertical accuracy was computed by comparing the ground surface model of each individual flight line with its neighbors in overlapping regions. The average line-to-line relative vertical accuracy for the St. Marys River survey was 0.029 m.

2.6 Unmanned aerial system (UAS) imagery

To better understand the substrate type present in the rapids, an unmanned aerial system (UAS) deployed by the USACE Jacksonville District (SAJ) was used to acquire high resolution imagery (Figure 10). An autonomous, line-of-site-flight was conducted using the eBee platform (senseFly, Switzerland, sensefly.com), which was a fixed-wing ultra-light UAS equipped with a digital camera (Canon S110). This lithium-polymer battery powered drone acquired geospatially tagged images from seven programmed flight paths over the rapids. Each programmed flight was conducted at an above ground altitude of 120 m with 90% longitudinal and lateral overlap and 4.4 cm ground resolution. Ten ground control points were placed on the North Dike on the south shore of the rapids, six were used for three-dimensional control points for processing, and four were used as horizontal and vertical validation points. The mean horizontal error was approximately 4 cm while the mean vertical error was approximately 8 cm. The purpose of collecting the orthomosaic imagery was to classify the substrate as bedrock, fractured bedrock, boulders, cobble, or sand/silt. To take advantage of the high resolution modeling, an automated approach to image analysis was performed.

Figure 10. Compound image obtained from multiple aerial pictures taken from an UAS flying over a trans-border stretch of the St. Marys River, located north of Edison Sault Hydroelectric Plant (Michigan, USA; +45.5062,-84.3493). Dimensions (x × y): 1197 m × 659 m.



The imagery was acquired on 29 and 30 November 2016 after the minimum flow in the rapids was achieved, thereby exposing more bottom habitat as well as reducing the remaining water depth to improve visibility of underlying habitat. The combination of low water levels and high water clarity in the rapids was ideal for remote sensing to penetrate the water column.

Environment and Climate Change Canada analyzed the imagery based on red, green, and blue pixel values. This method uses aerial terrain images to obtain surrogates of substrate composition and fish habitats. The method proceeds by segmenting the raster into square tiles of a fixed dimension and applying type-II Discrete Cosine Transforms (Figure 11). Coefficients from these transformations were combined to obtain rotation-invariant descriptors of texture at different mean feature size. Functions of the latter texture descriptors, with respect to the mean size of the features that create them, were then used to estimate representative surface roughness (Figure 12).

Figure 11. Left- Image of rough substrate (metric boulders). Right - Power spectrum of pixel intensity (black line). Right - Chromatic variability (yellow line) calculated using a window with N=112 (resolution: 0.04455 m, window width: 4.990 m).

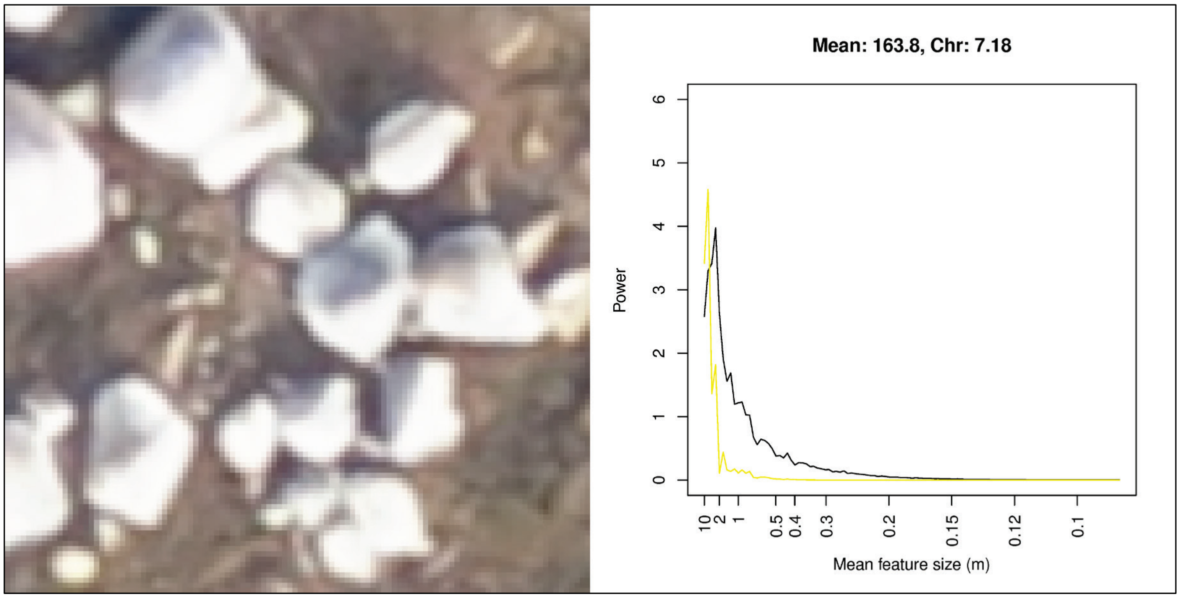
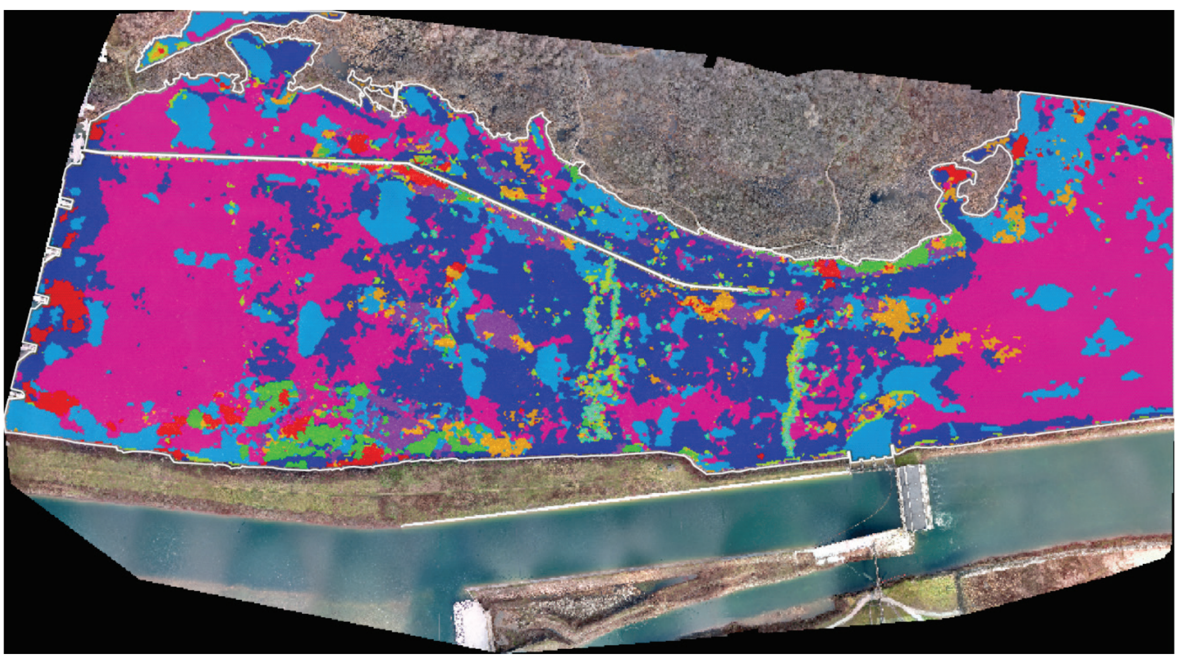


Figure 12. Map of the k-means clustering obtained from the texture descriptors developed in this study. Least squares were calculated on the basis the Mahalanobis distance. The nine groups are shown with different colors. Zones with the same color are similar in surface roughness.



3 Modeling

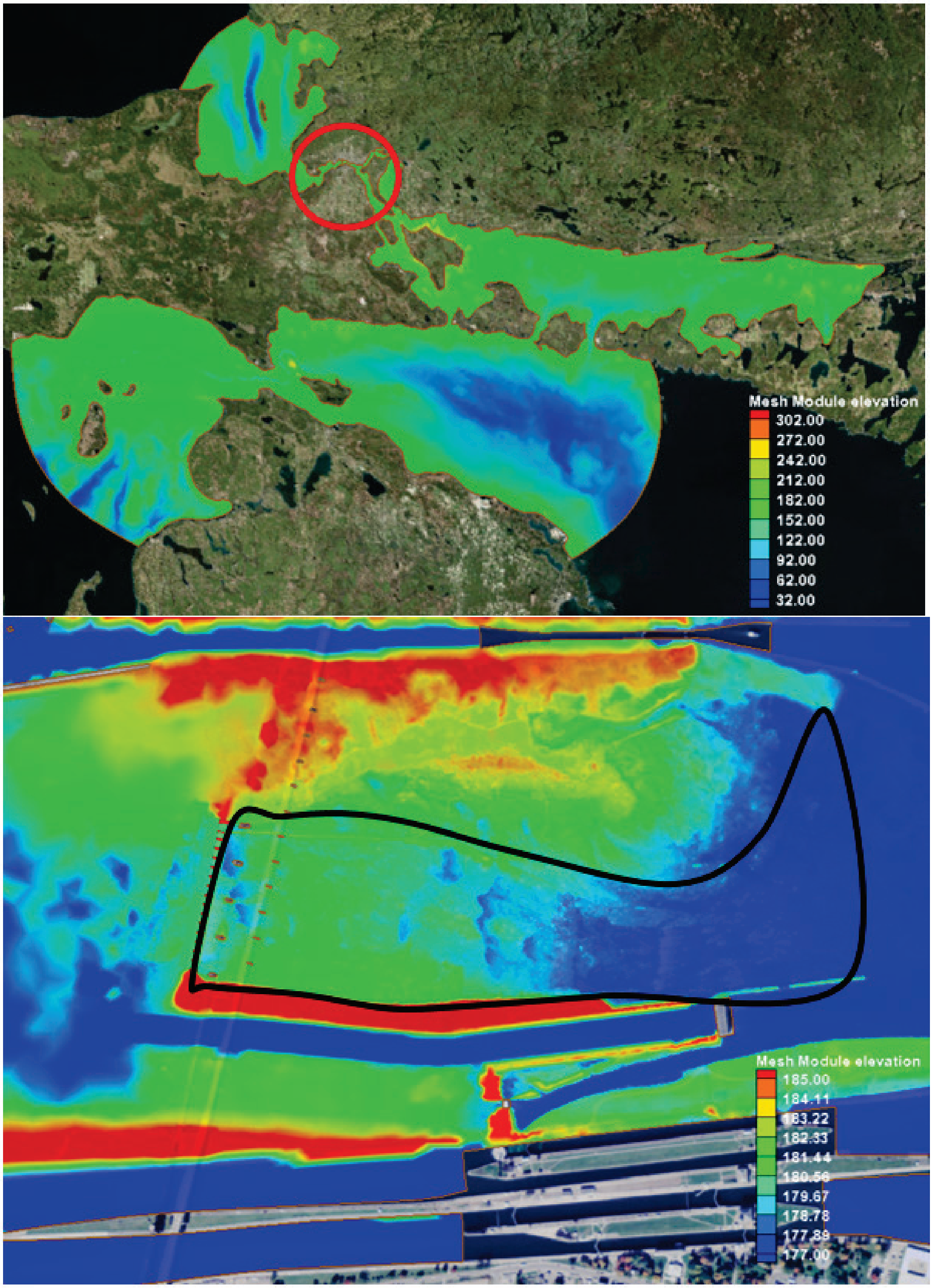
3.1 Introduction

A two dimensional (2-D) Adaptive Hydraulics model of the St. Marys system was built to investigate water management decisions, future projects on the river, and dam break analysis. Adaptive Hydraulics is a physics-based finite element numerical hydrodynamic code that simulates the 2-D shallow water equations. Adaptive Hydraulics was chosen as the computational engine due to resolution adaption and general flexibility of the modeling platform that allows a developed model to be used in a wide variety of circumstances. In addition to calculating the basic hydrodynamics of a modeled system such as circulation and water surface elevations, the code simulates the transport of additional properties such as vorticity, conservative dye tracers, salinity and temperature with density effects, and sediment.

The hydrodynamic model uses more than 300,000 elements that are allowed to wet and dry to define the model domain and implements water level boundary conditions on Lake Superior, Lake Michigan, and Lake Huron (Figure 13). Flow was fully specified at each of the control structures near the St. Marys rapids. Discharge through the Comp Works was defined for each of the 16 gates and determined by the equations described by Swamee (1992).

This report focuses on water level rates of change in the St. Marys rapids as a function of the number of Comp Works gates open, and classifies areas in the rapids as potential spawning habitat for various fish species.

Figure 13. The Adaptive Hydraulics model domain for the St. Marys River with colored bathymetry (top; project area circled) and the rapids outlined (bottom; black line).



3.2 Model calibration

3.2.1 Water level calibration

The model was calibrated for a period in July 2015. Gauges relevant for the work performed in the St. Marys rapids were, starting from upstream: 1) NOAA S.W. Pier (9076070), 2) Canadian Hydrographic Service above the locks (10980), 3) USACE temporary radar gauge on the downstream side of Comp Works, 4) six USACE temporary pressure sensors in the St. Marys rapids, 5) Canadian Hydrographic Service below the locks gauge (11010), 6) USACE Lower Radar, and 7) NOAA U.S. Slip (9076060). The first two gauges measure the head on the Comp Works and determine the flow through the gates (Figure 5). Figures 14–24 highlight the model calibration through the rapids. Calibration plots for the remainder of the gauges in the model domain are provided in Appendix A.

Pressure sensor 1 was in direct conflict with the upper radar gauge. The model could not be calibrated to both of these gauges. Adjusting friction and eddy viscosity parameters so the model matched the pressure sensor made the model less optimally with respect to the radar gauge. Therefore, the radar gauge was used as the calibration point because the gauge was more reliably installed and vertical control was established upon install and checked throughout the year. The pressure sensors only had vertical control established upon pressure sensor install so it is not known if the sensor shifted throughout the season.

Friction values ranged from 0.022 to 0.055 throughout the whole domain while in the rapids they ranged from 0.025 to 0.043. A dynamically calculated eddy viscosity scheme was employed in the model. The method, as described in the adaptive hydraulics manual, uses an isotropic term to describe turbulent mixing and an anisotropic term for streamwise dispersion (Berger et al. 2014).

Figure 14. Calibration plot for SW Pier NOAA (9076070).

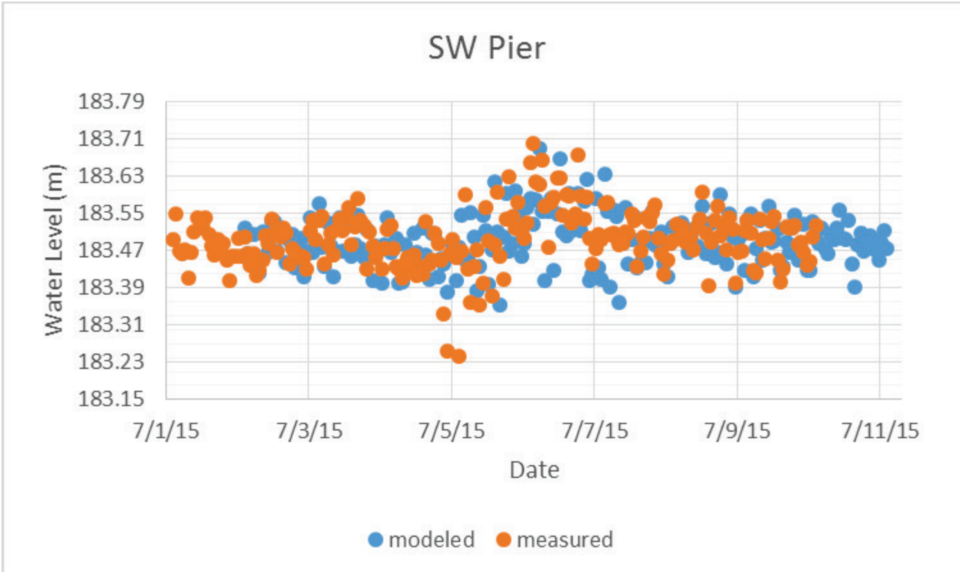


Figure 15. Calibration plot Above the Locks CHS (10980).

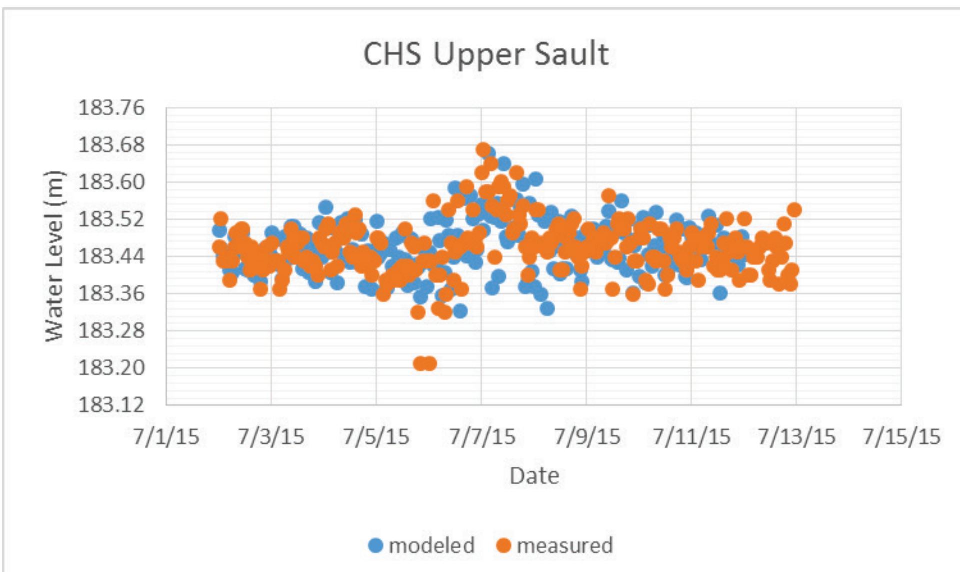


Figure 16. Calibration plot upper rapids radar.

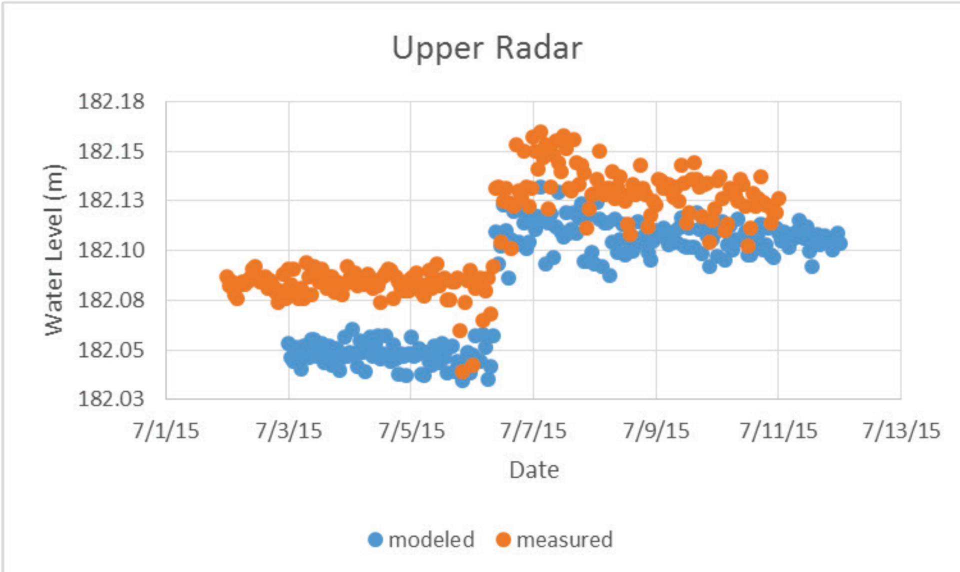


Figure 17. Calibration plot pressure sensor 2 (S/N 10351961).

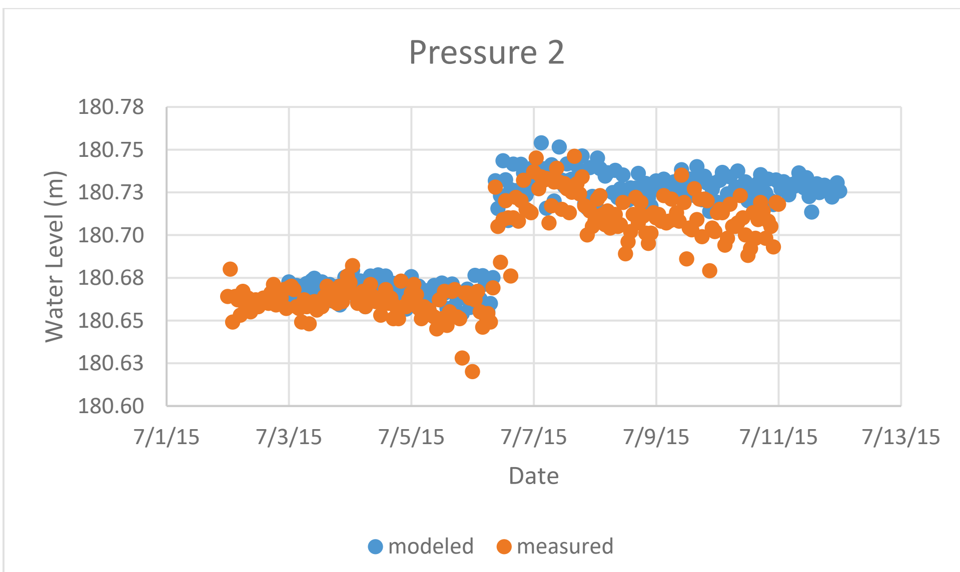


Figure 18. Calibration plot pressure sensor 3 (S/N 9870920).

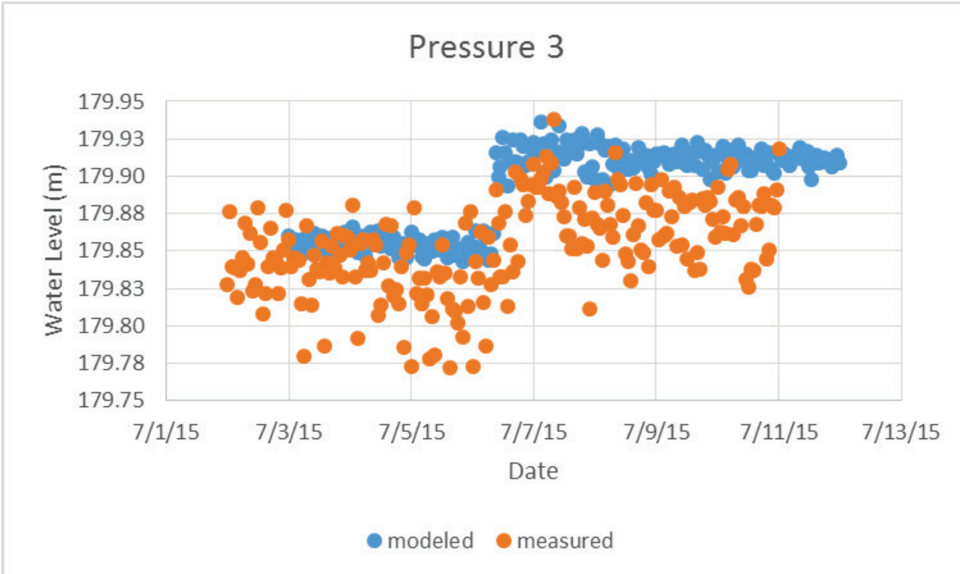


Figure 19. Calibration plot press sensor 4 (S/N 10662591).

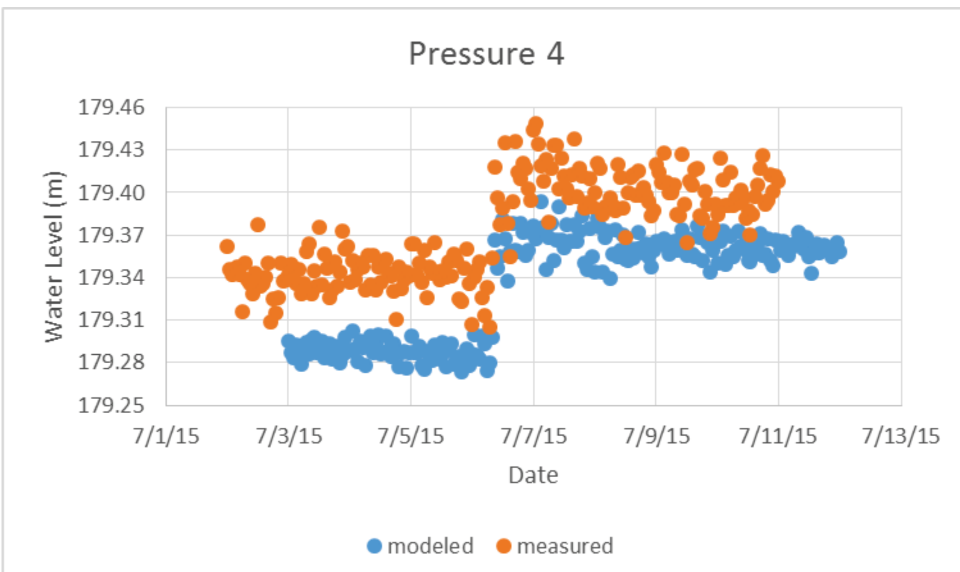


Figure 20. Calibration plot pressure sensor 5 (S/N 9858765).

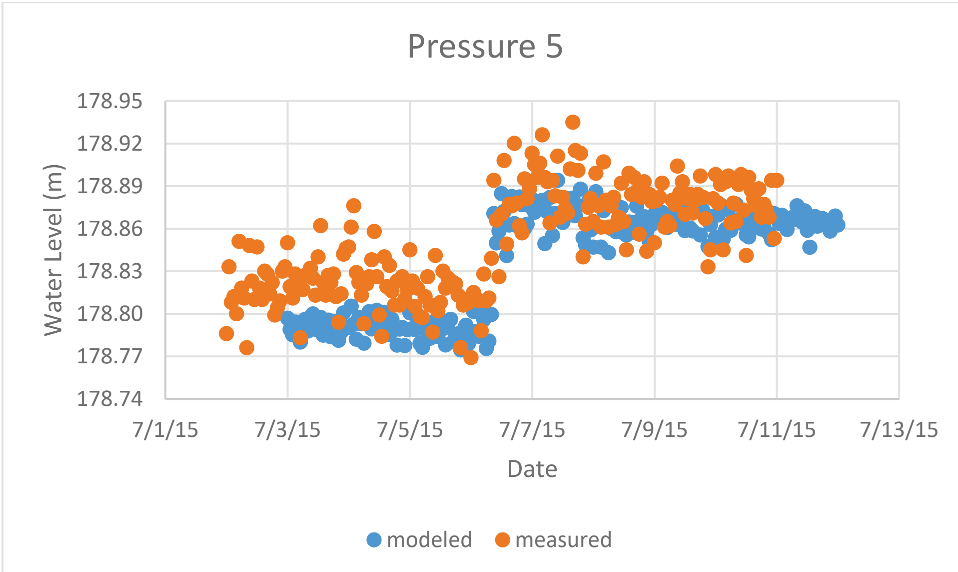


Figure 21. Pressure Sensor 6 (S/N 10662592).

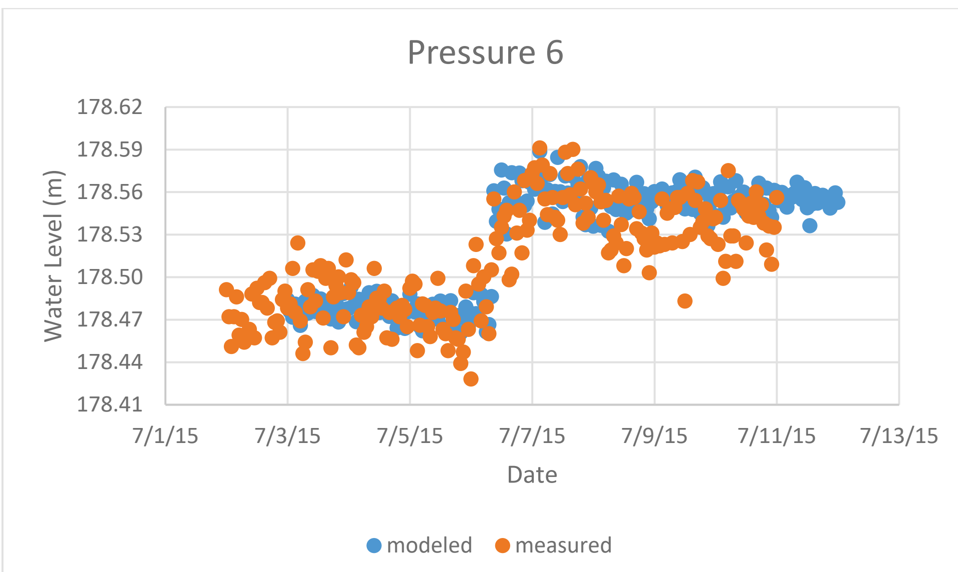


Figure 22. CHS gauge below the locks (11010).

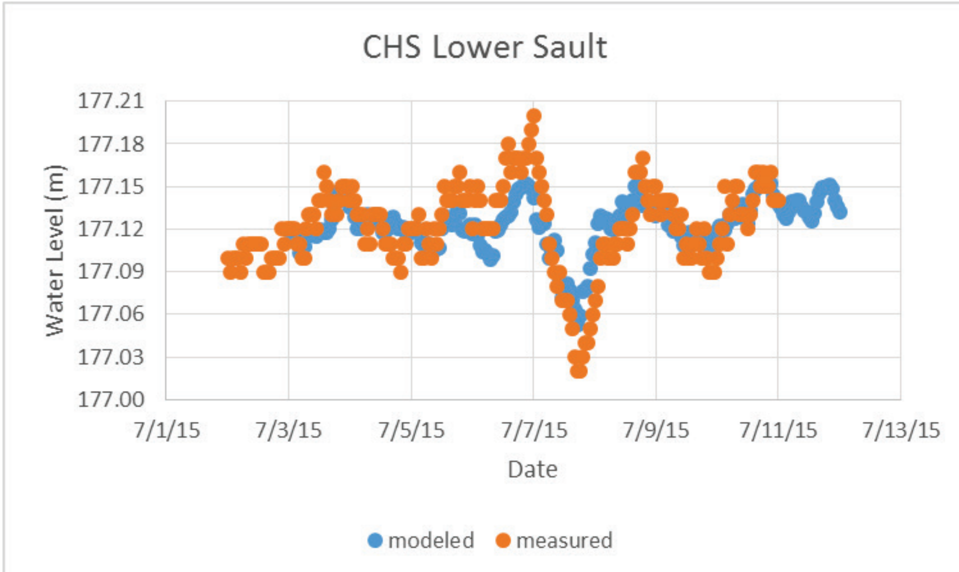


Figure 23. Calibration plot lower rapids radar.

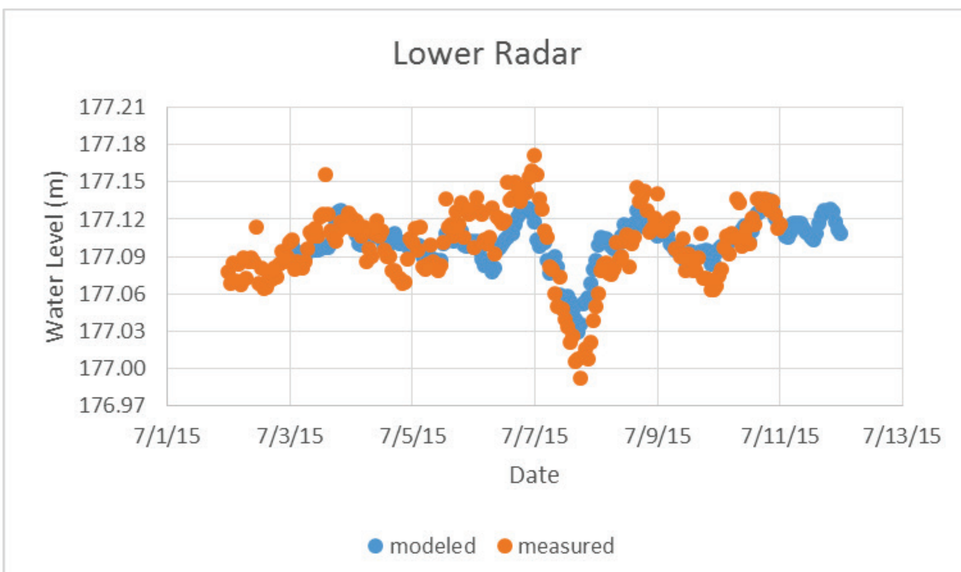
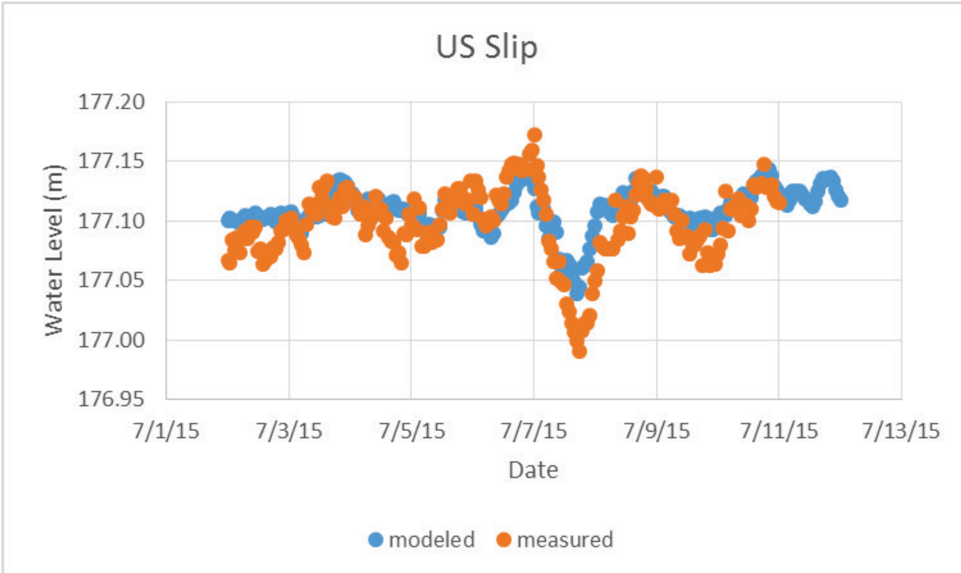


Figure 24. Calibration plot U.S. Slip NOAA (9076060).



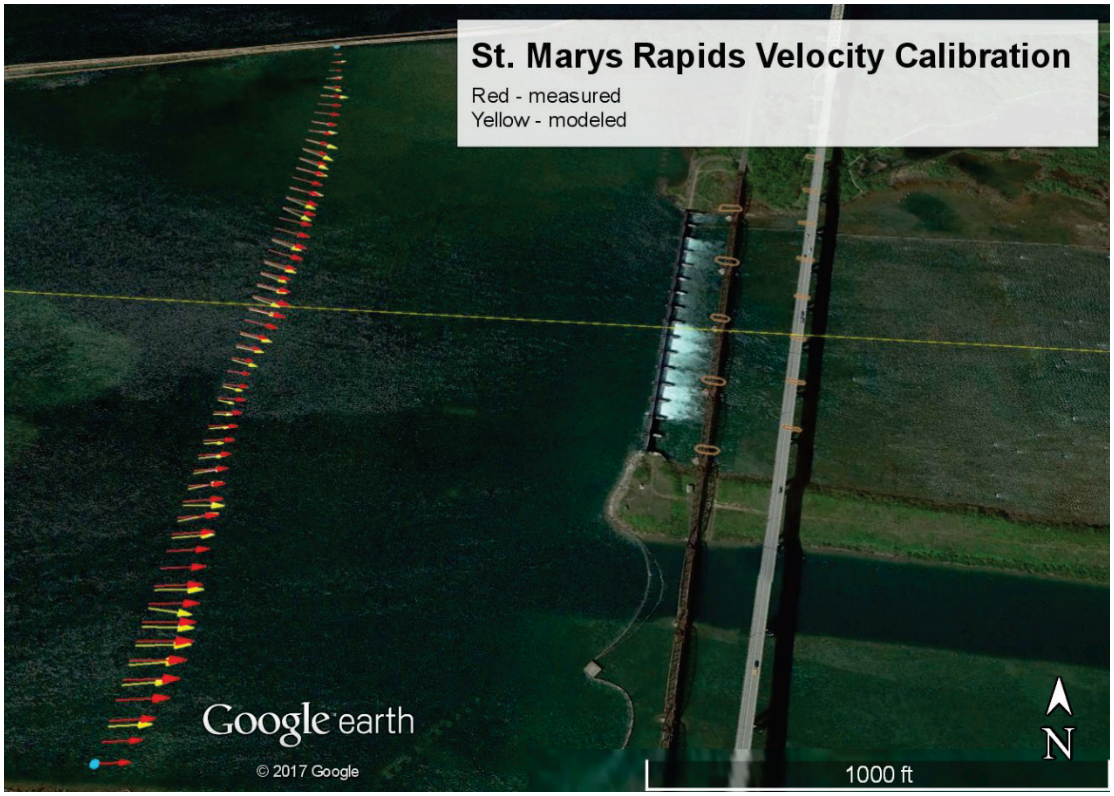
3.2.2 Discharge calibration

Discharge through the Comp Works was measured using two different methods depending on the number of open gates. When three gates or less are open, a direct measurement of discharge through the Comp Works is possible. Under these conditions, the discharge was measured at section 420. For gate settings greater than three, the measurement section moves upstream of the Comp Works where the flow is smoother. Gated flow was determined by subtracting the flow through the U.S. Government Power Plant from the entire cross section above the Comp Works (lines 595 and 580 in Figure 5, respectively). These data are also useful for velocity comparisons. Velocities measured at section 580 are shown in Figure 25. Discharges and velocity results (Table 1) match the magnitude and direction of the modeled velocities (Figure 25).

Table 1. Discharge measurements cubic meters per second (m^3/s) during calibration period in July 2015. Cross section numbers are shown in Figure 23.

Date	Full Cross Section 580		Hydropower Cross Section 595	
	modeled	measured	modeled	measured
07/13/15 1700	1100	1050	410	310
07/14/15 1600	1270	1140	400	320

Figure 25. Velocity comparison 13 July 2017 at 1700 hours upstream of the St. Marys River Comp Works.



3.3 Model validation

The model was validated in October 2015 and performed well relative to the calibration data (Table 2). Results are shown in Figures 26–36 for the same locations as the calibration plots in Section 3.2. The remainder of the validation graphs are provided in Appendix A.

Table 2. Calibration and validation performance of the model using October 2015 data.

	Calibration Data		Validation Data	
Gauge	Average error (m)	Standard Deviation (m)	Average error (m)	Standard Deviation (m)
Pt. Iroquois	-.068	.056	-.064	.050
SW. Pier	.001	.061	.017	.059
Upper Sault	.001	.057	.028	.060
Upper Radar	-.023	.036	-.018	.055
Pressure 2	.018	.035	-.005	.065
Pressure 3	.032	.035	.027	.047
Pressure 4	-.037	.047	-.020	.067
Pressure 5	-.012	.044	-.008	.071
Pressure 6	.015	.045	.004	.075
Lower Radar	.000	.034	-.007	.057
U.S. Slip	.009	.035	-.003	.055
Lower Sault	-.001	.034	-.011	.055
Little Rapids	.021	.034	.005	.049
Frechette	-.026	.037	-.032	.049
West Neebish	.025	.037	.015	.043
Rock Cut	-.011	.041	-.023	.054
Slab Dock	-.007	.039	-.015	.051
Detour village	-.006	.031	-.010	.038

Figure 26. SW Pier validation plot NOAA (9076070).

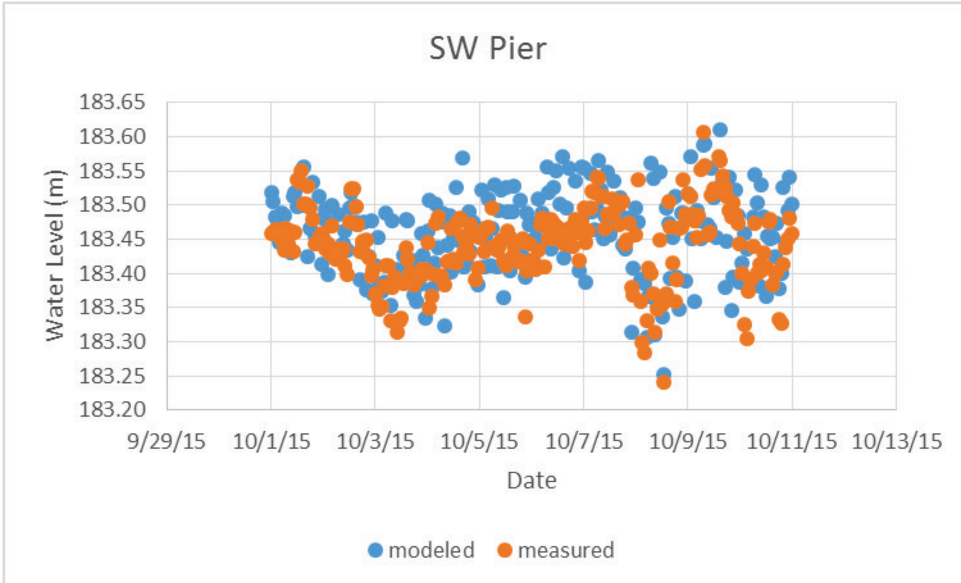


Figure 27. Validation plot, above the locks CHS (10980).

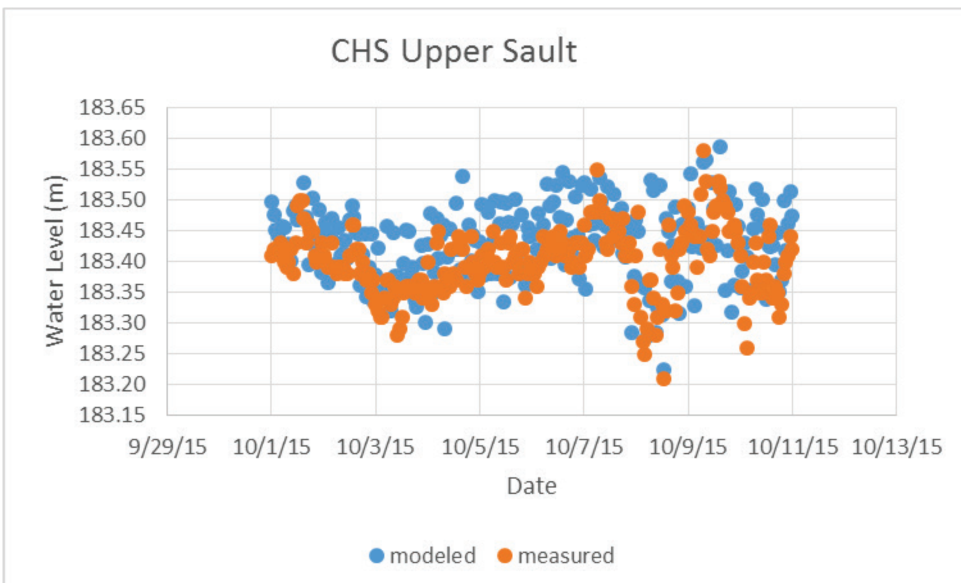


Figure 28. Validation plot upper rapids radar.

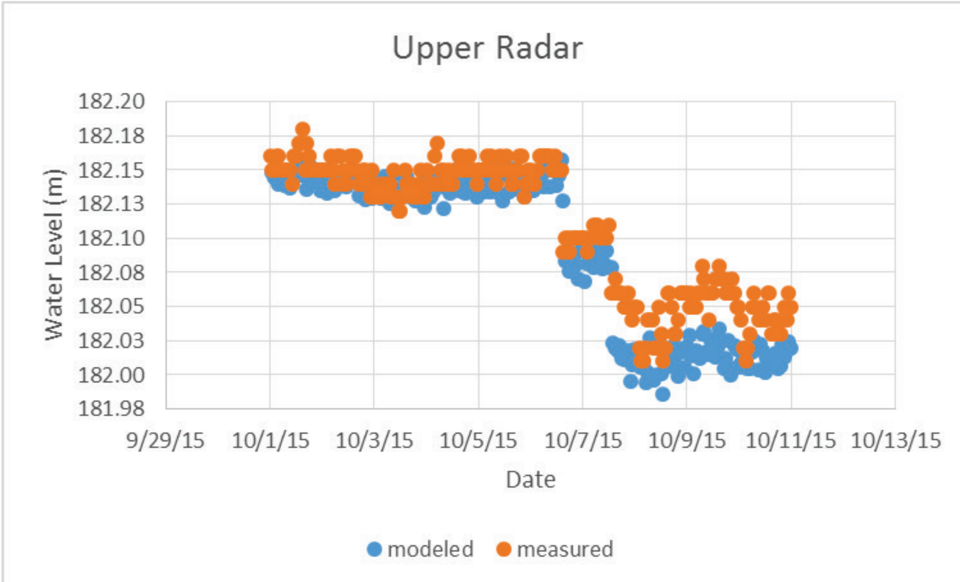


Figure 29. Validation plot pressure sensor 2 (S/N 10351961).

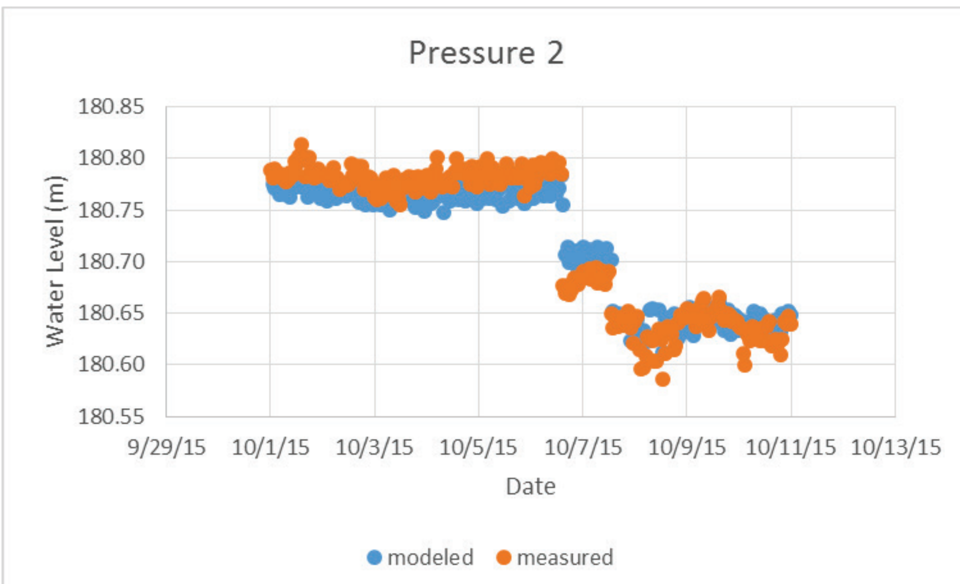


Figure 30. Validation plot pressure sensor 3 (S/N 9870920).

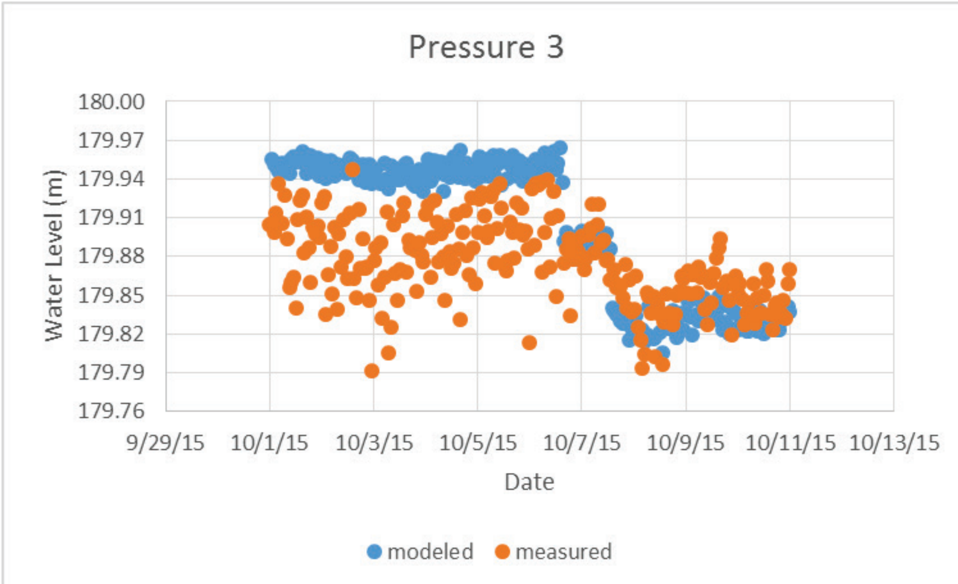


Figure 31. Validation plot pressure sensor 4 (S/N 10662591).

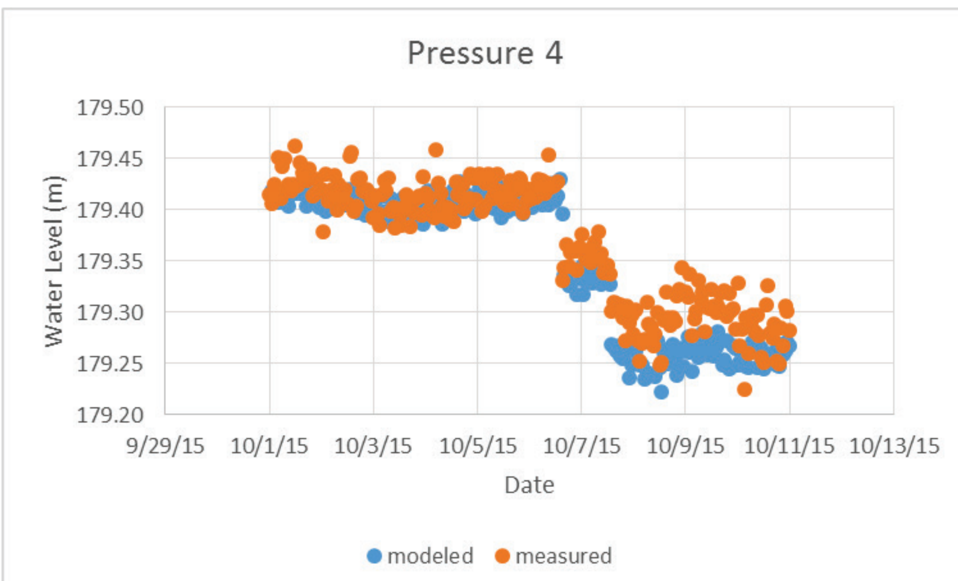


Figure 32. Validation plot pressure sensor 5 (S/N 9858765).

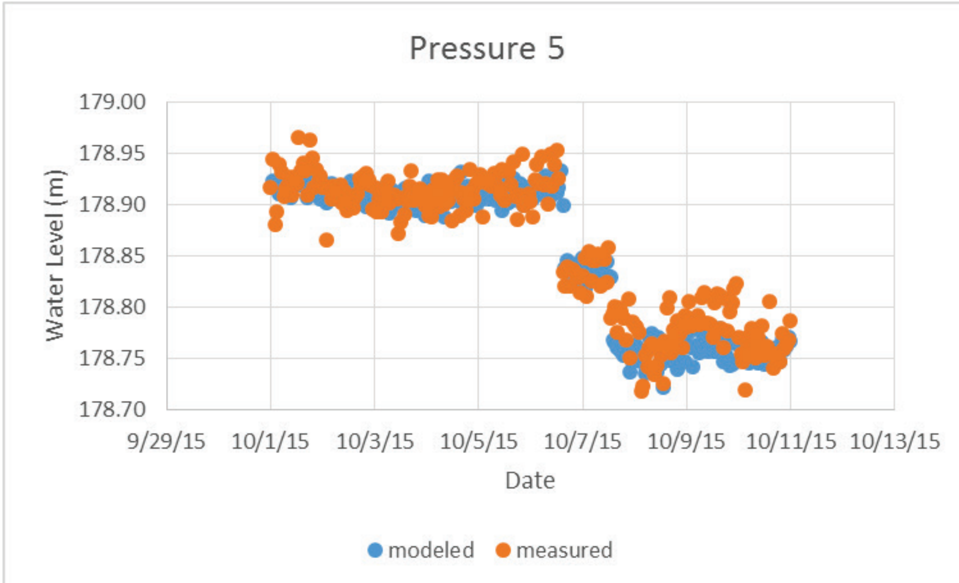


Figure 33. Validation plot pressure sensor 6 (S/N 10662592).

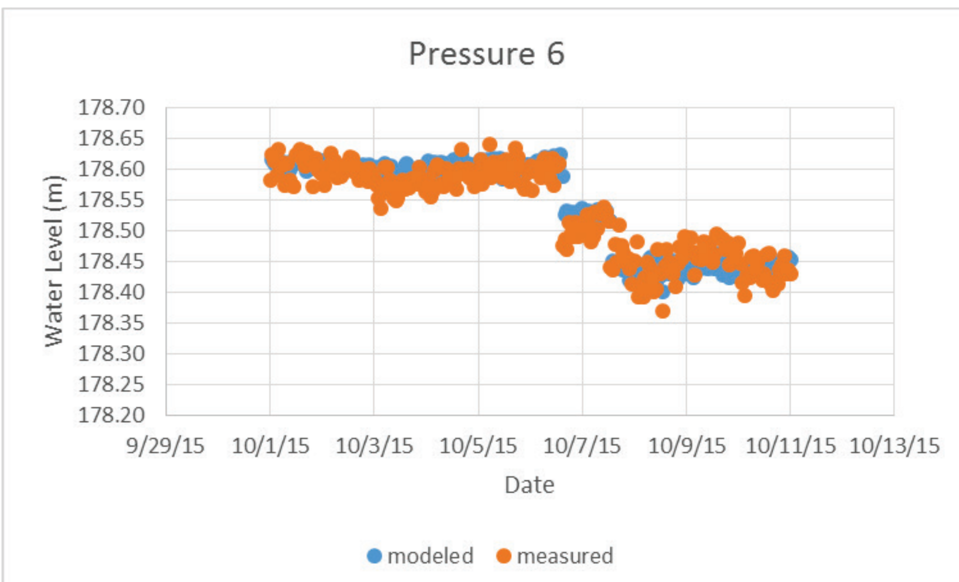


Figure 34. Validation graph CHS gauge below the locks (11010).

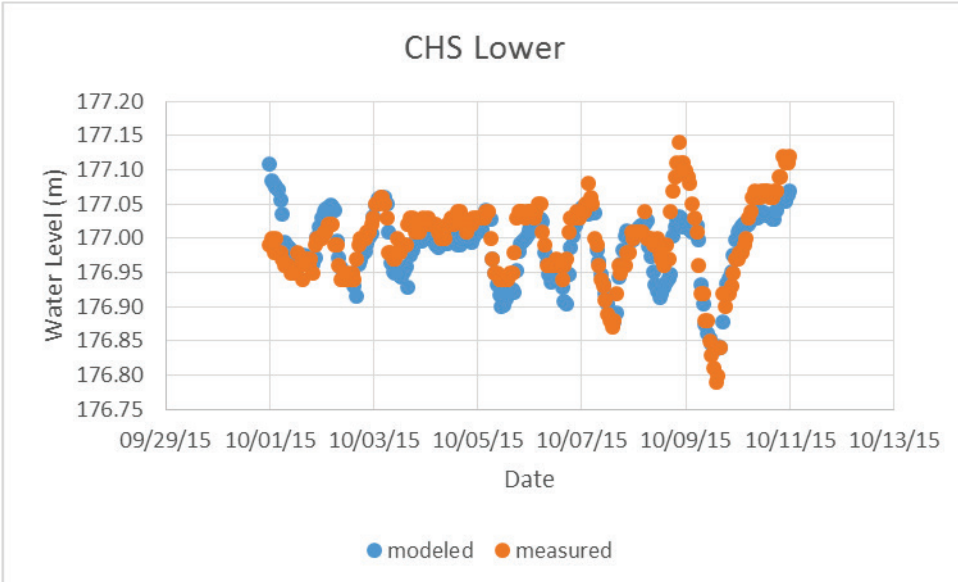


Figure 35. Validation plot lower rapids radar.

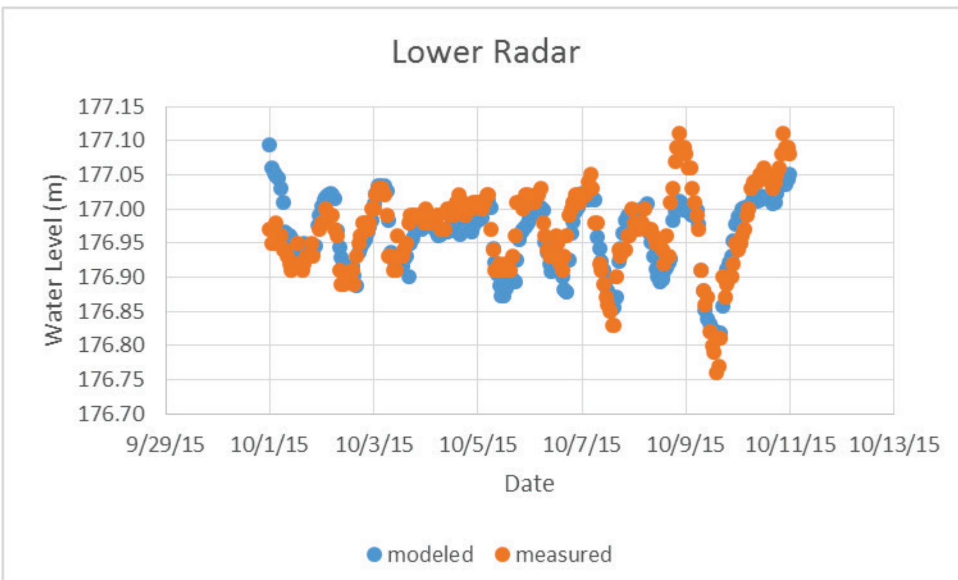
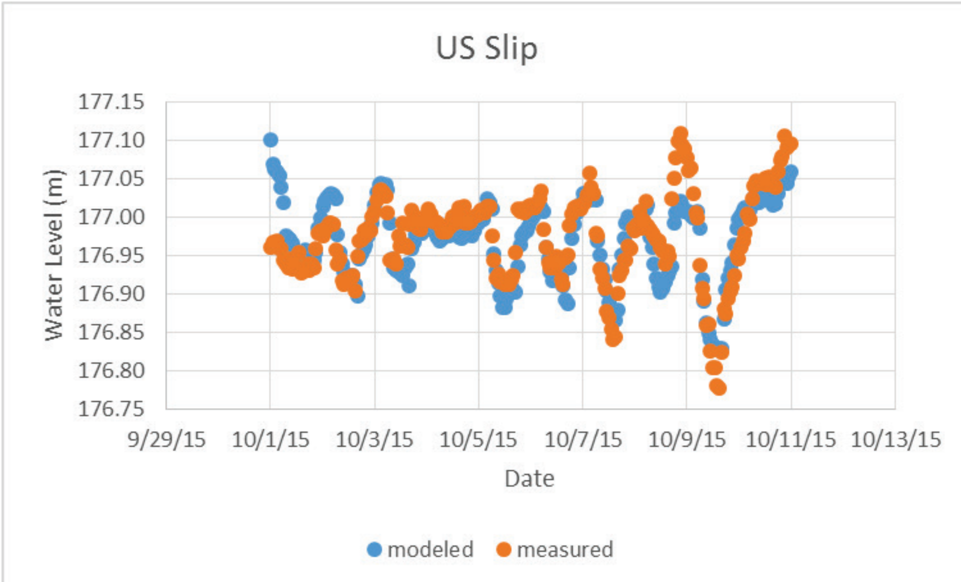


Figure 36. Validation plot U.S. slip NOAA (9076060).



3.4 Modeling results

Each gate change that occurred in 2015 was modeled until steady state conditions were achieved. Overall, twenty-two scenarios were analyzed. In each scenario, the daily average water level for each lake boundary was adjusted, the allocated flow through each power plant and navigation structure were applied, and the height of the gate opening on the Comp Works were adjusted. Table 3 tracks the conditions for each scenario. Gate 1 remained at a fixed setting to maintain the minimum 15 m^3/s flow on the north side of the fisheries dike as required by the regulation plan.

These modeled scenarios were analyzed to accomplish the following three objectives:

- Objective 1: Rates of Change - Optimize gate operations to minimize water level rate of change in the rapids. Rates of change should be below 10 cm/h (Bain et al. 2010).
- Objective 2: Habitat Classifications - Classify available habitat in the rapids based on required depth and velocity to support fish spawning for various species.
- Objective 3: Integrated Ecosystem Response Modeling - Provide hydrodynamic output for eco-hydraulic modeling performed by Environment and Climate Change Canada. The eco-hydraulic modeling more fully investigates changes in aquatic habitat and is capable of predicting habitat and species change in response to the physical

environment and stimuli. Once published, this work will provide a more detailed habitat classification than is provided in the second objective, and it will include an egg survivability classification.

Table 3. Conditions modeled for each run in 2015. Gate openings (in cm) make up the bulk of the table. The last two columns contain the water levels (WL) used in the simulation conditions modeled for each run in 2015. C = closed gate.

			Gate Settings (cm)																	
Run Name	Date	Gate Equivalent Opening	Canadian Gates								US Gates								Superior WL	Huron WL
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16		
15-1	30-Apr-15	½	20	C	C	C	C	C	20	20	20	20	C	C	C	C	C	C		
15-2	1-May-15	2	20	C	31	31	31	31	31	31	31	31	31	31	31	31	C	C	183.48	176.56
15-3	7-May-15	2	20	C	31	31	31	31	31	31	31	31	31	31	31	31	C	C	183.48	176.56
15-4	8-May-15	3.5	20	C	62	62	62	62	62	62	62	62	62	62	62	62	C	C	183.49	176.56
15-5	2-Jun-15	3.5	20	C	62	62	62	62	62	62	62	62	62	62	62	62	C	C	183.59	176.64
15-6	3-Jun-15	4	20	C	62	62	62	62	62	62	71	71	71	71	71	C	71	5	183.6	176.64
15-7	7-Jun-15	4	20	C	62	62	62	62	62	62	71	71	71	71	71	C	71	5	183.62	176.64
15-8	8-Jun-15	4.3	20	C	71	71	71	71	71	71	71	71	71	71	71	C	71	5	183.62	176.65
15-9	5-Jul-15	4.3	20	C	71	71	71	71	71	71	71	71	71	71	71	C	71	5	183.65	176.71
15-10	6-Jul-15	4.3	20	71	71	71	71	71	71	71	71	71	71	71	71	C	71	5	183.67	176.72
15-11	13-Jul-15	4.3	20	71	71	71	71	71	71	71	71	71	71	71	71	C	71	5	183.68	176.72
15-12	14-Jul-15	5.5	20	89	89	89	89	89	89	89	89	89	89	89	89	C	89	5	183.70	176.72
15-13	5-Aug-15	5.3	20	89	89	89	89	89	89	89	76	76	76	76	76	C	76	5	183.68	176.74
15-14	6-Aug-15	5	20	76	76	76	76	76	76	76	76	76	76	76	76	C	76	5	183.68	176.73
15-15	6-Oct-15	4.5	20	63.5	63.5	63.5	63.5	63.5	63.5	63.5	76	76	76	76	76	C	76	5	183.63	176.62
15-16	7-Oct-15	4	20	63.5	63.5	63.5	63.5	63.5	63.5	63.5	63.5	63.5	63.5	63.5	63.5	C	63.5	C	183.63	176.61
15-17	28-Oct-15	4	20	63.5	63.5	63.5	63.5	63.5	63.5	63.5	63.5	63.5	63.5	63.5	63.5	C	63.5	C	183.55	176.53
15-18	29-Oct-15	3.3	20	51	51	51	51	51	51	51	51	51	51	51	51	C	51	C	183.58	176.54
15-19	2-Nov-15	3.3	20	51	51	51	51	51	51	51	51	51	51	51	51	C	51	C	183.57	176.56
15-20	3-Nov-15	2	20	33	33	33	33	33	33	33	33	33	33	33	33	C	33	C	183.58	176.54
15-21	4-Nov-15	1.5	20	20	20	20	20	20	20	20	20	20	20	20	20	C	20	C	183.57	176.55
15-22	5-Nov-15	1/2	20	C	C	C	C	C	20	20	20	20	C	C	C	C	C	C	183.56	176.55

3.4.1 Rates of change – objective 1

According to Bain et al (2010), water level rates of change in the St. Marys rapids should be limited to less than 10 cm/hour to avoid stranding juvenile fish. This rate of change is interpreted as the time required to make a gate change, so as to keep the steady-state difference in the pre-and-post gate change water level below 10 cm/hour. For example, steady state scenarios were run to capture conditions in the St. Marys rapids associated with Run 15-11 and Run 15-12 (Table 3). After steady state conditions were achieved, water surface elevations were compared and subtracted. Average and maximum change in water surface elevation was computed over the entire rapids based on the 45,000 nodes defining it. The time required to change the gate opening so no node in the rapids experiences a rate of change greater than 10 cm/hour is expressed in Equation 3, where WL_1 is the water level after the gate change, WL_2 is the water level before the gate change, and ΔT is the time over which to make the gate change.

$$\boldsymbol{\Delta T\ (hours)} = \frac{\boldsymbol{MAX(|WL_2 - WL_1|)}}{\boldsymbol{0.1\ meters\ per\ hour}} \tag{3}$$

In the runs analyzed for 2015, when the rate of change exceeded 10 cm/hour, more than 90% of the rapids could have been below the recommended 10 cm/hour rate of change had the gate changes occurred over a 3-hour period. The exception is the transition out of, or into, the one-half gate setting, as expected, these changes require longer transitions to meet the required rate of change. The transition from one-half gate setting to an approximate three gate setting on 1 May 2015 are captured in Figures 37 – 41. For the 1 May 2015 gate change, opening the gates over the course of at least 5 hours would ensure the majority of the rapids remain below the required threshold for water level rate of change.

Figure 37. Water level rate of change from one-half gate setting to an approximate three gate setting over a 1-hour period on 1 May 2015.

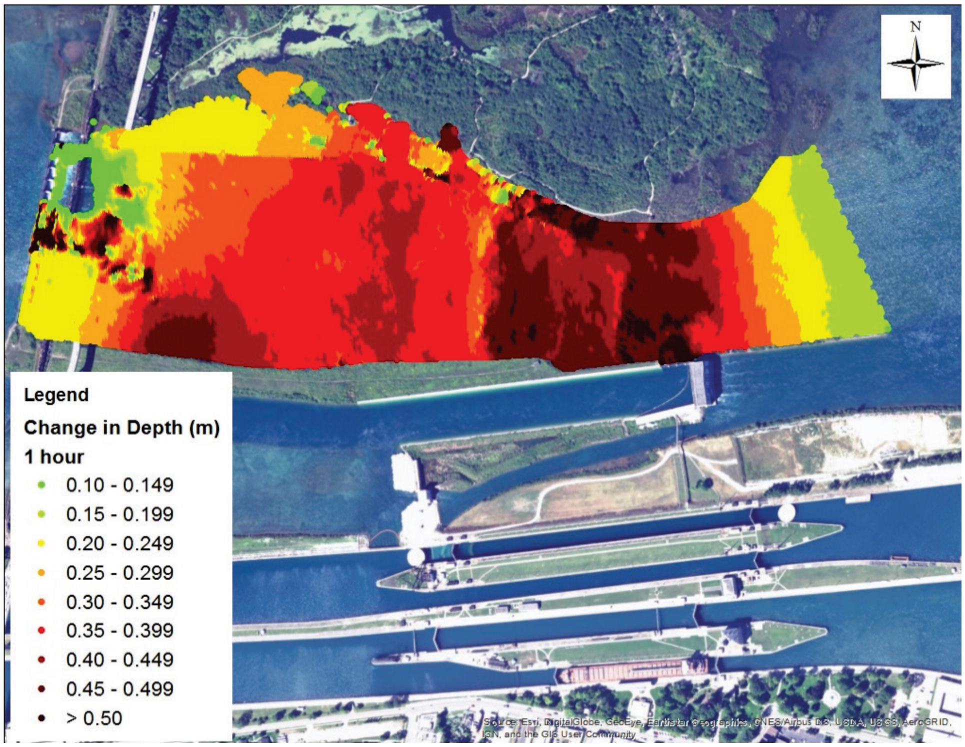


Figure 38. Water level rate of change from one-half gate setting to an approximate three gate setting for a gate opening occurring over a 2-hour period on 1 May 2015.

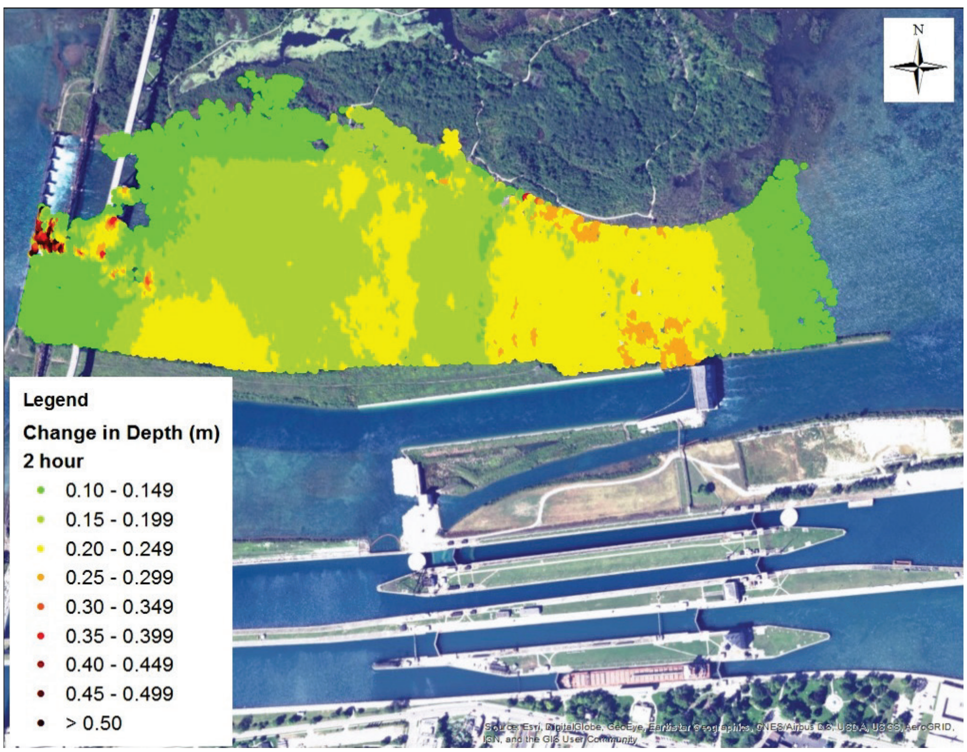


Figure 39. Water level rate of change from one-half gate setting to an approximate three gate setting for a gate opening occurring over a 3-hour period on 1 May 2015.

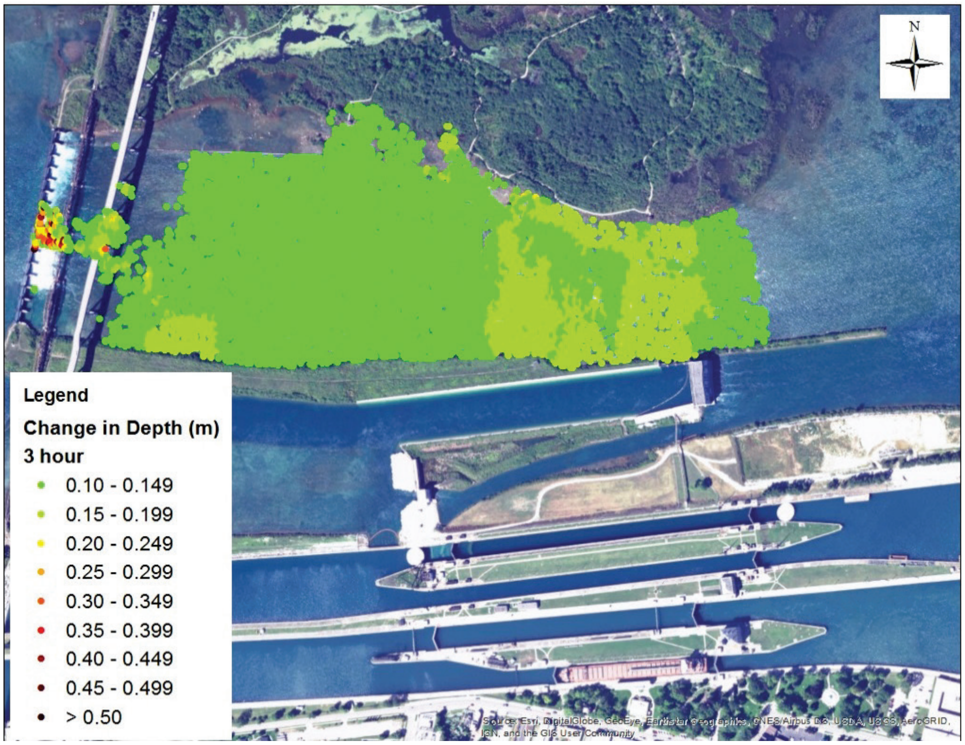


Figure 40. Water level rate of change from one-half gate setting to an approximate three gate setting for a gate opening occurring over a 4-hour period on 1 May 2015.

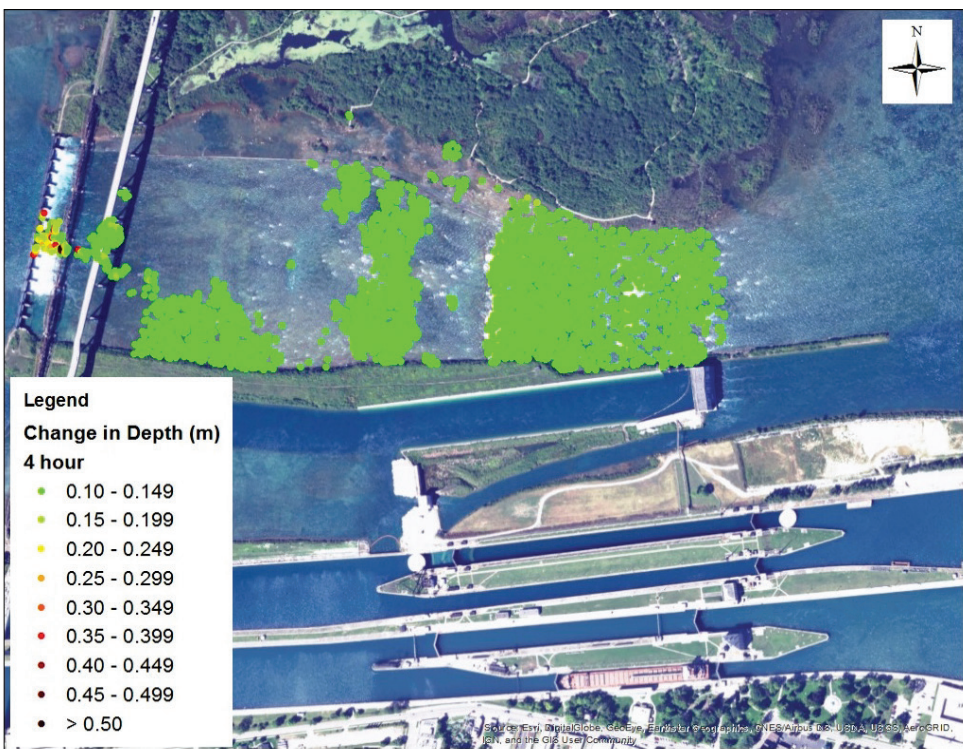
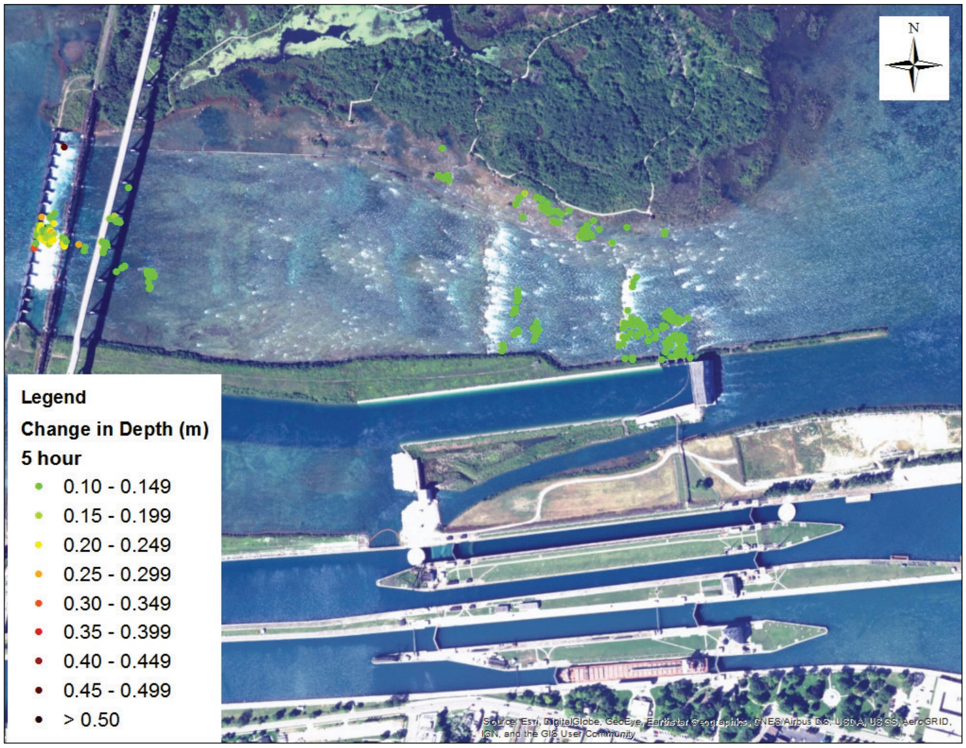


Figure 41. Water level rate of change from one-half gate setting to an approximate three gate setting for a gate opening occurring over a 5-hour period on 1 May 2015.



The rate of change in the rapids was greater than recommended on 14 July 2015. Gates were generally adjusted from 71 cm open to 89 cm open. Maps showing the portion of the rapids with rates of change in excess of the recommended rate are shown in Figure 42 and Figure 43. Making this gate change over 3 hours will ensure the water level in entire rapids will adhere to the Bain et al. (2010) recommendation.

Figure 42. Water level rate of change from 71 cm setting to an 89 cm gate opening occurring over a one hour period on 14 July 2015.

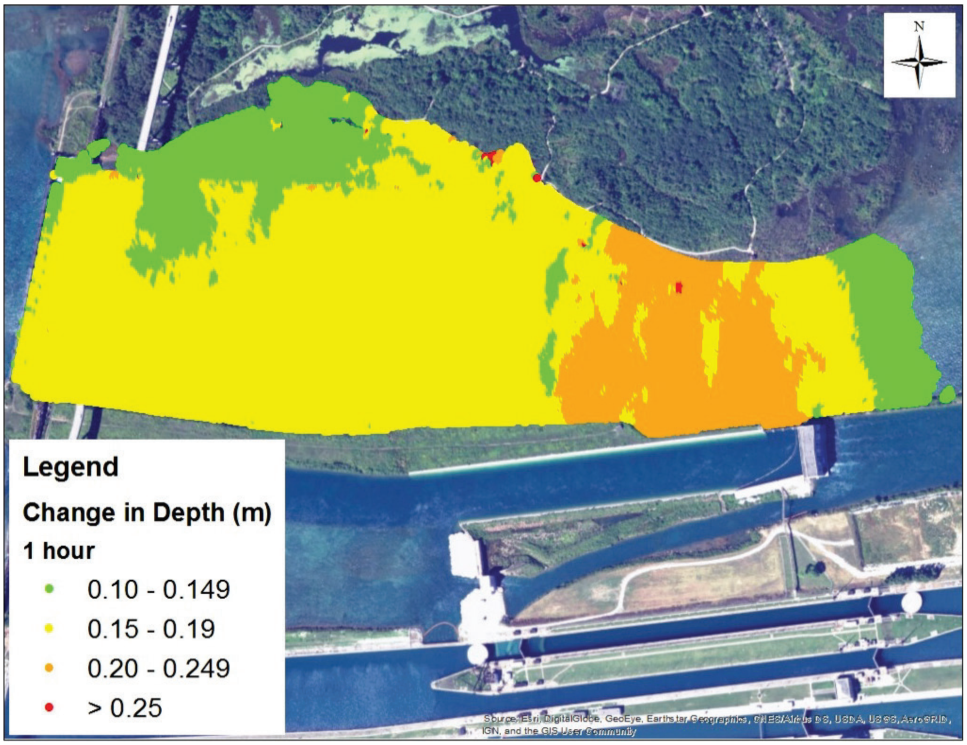
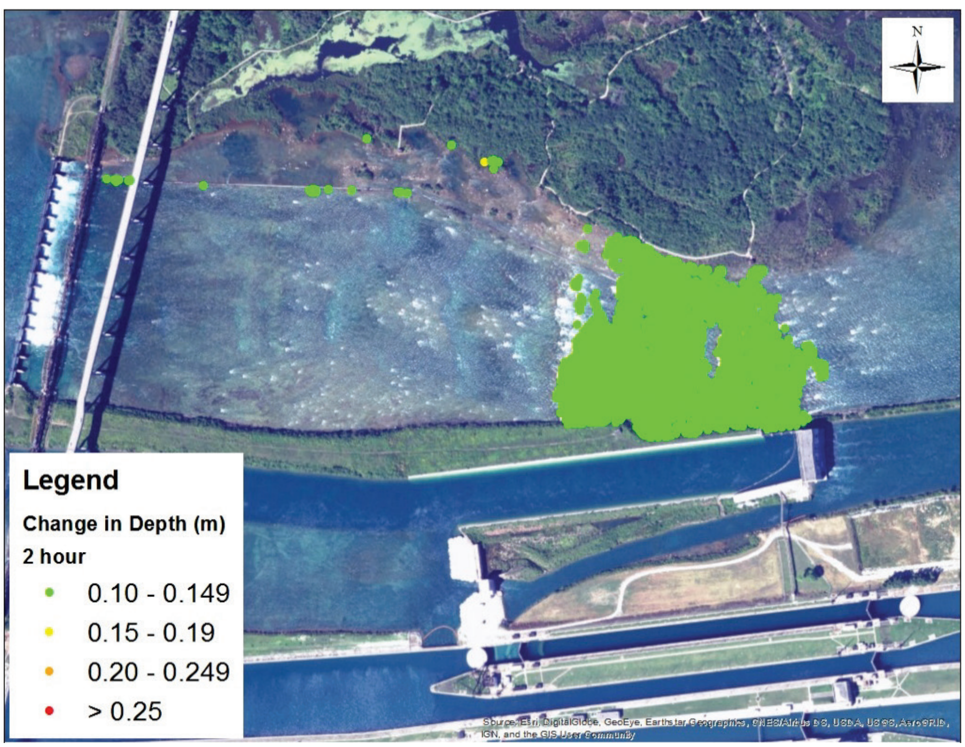


Figure 43. Water level rate of change from a 71 cm setting to an 89 cm gate opening occurring over a two hour period on 14 July 2015.



3.4.2 Habitat classifications – objective 2

Gate openings are generally made uniformly across the Comp Works (Table 3). This is done so as not to preferentially wet or dry one part of the rapids over another, but rather let the natural bathymetry dictate wet and dry locations within the rapids. For each gate setting and water level combination described in Table 3, depth maps, velocity maps, and the intersection of depth and velocity maps were generated. Water depths between 0 – 20 cm were grouped together as these depths would likely support minimal spawning activities. Depths greater than 20 cm should support the majority of spawning activities for recreationally and commercially important fish species. For example, some of the more recreationally important fish species occurring in the St. Marys rapids include the following: Atlantic salmon (*Salmo salar*) documented to spawn most commonly at depths of 20–50 cm (Louhi et al. 2008), walleye (*Sander vitreus*) spawn in 60–180 cm depths (McMahon et al. 1984), and lake sturgeon (*Acipenser fulvescens*) spawn in 60–450 cm (Lane et al 1996) (Table 4). Similar to water depth, the water velocity expected to support the majority of spawning activity is likely greater than 30 centimeters per second (cm/s), supported by examining the previously mentioned fish species: Atlantic salmon 35–65 cm/s (Louhi et al. 2008), walleye 60–90 cm/s (McMahon et al. 1984), and lake sturgeon 40–90 cm/s (Lane et al. 1996) (Table 4). Areas with water velocities less than 30 cm/s may still provide nursery habitat for these same species.

Table 4. Water habitat requirements for select fish species utilizing the St. Marys rapids for spawning.

Common Name	Scientific Name	Water Velocity (cm/s)	Depth (cm)	Substrate	Source
Walleye	*Sander Vitreus*	60–90	60–180	gravel, rubble	McMahon et al. 1984
Lake sturgeon	*Acipenser fulvescens*	40–90	60–450	Cobble, boulders, gravel, rubble	Lane et al 1996b
Atlantic salmon	*Salmo salar*	35–65	20–50	Pebbles (16–64 mm)	Louhi et al. 2008

The depth (Figure 44) and velocity (Figure 45) maps were combined to identify usable fish habitat in the rapids as listed in Table 4 (Figure 46). Each color scheme in these three figures represents a constant range of water depths. The blue colors are water depths between 20 cm and 50 cm. The darker the yellow, the greater the velocity. No color (gray) indicates the area is likely not suitable for spawning because the water depth is shallow (less than 20 cm) or the water velocity is too fast (greater than 200 cm/s).

Hydrodynamic output was categorized into depths and velocities, these ranges were loosely chosen to represent depths and velocities a variety of species may find suitable for some portion of their lifecycle. Depth and velocity information individually, or jointly, may define rearing habitat. The inclusion of substrate type will help define spawning sites. The next series of figures are intended to provide information regarding appropriate locations in the rapids for various portions of a fish's lifecycle.

Depth and velocity for Run 15-1 with the Comp Works gates at one-half gate equivalent are shown in Figure 44 and Figure 45. The intersection of these two parameters are shown in Figure 46 and the total available area for each depth and velocity range is provided in Table 5. The one-half gate setting provides a broad range of conditions in terms of depth and velocity; however, many areas are left dry under this condition and are subject to high rates of change upon gate openings.

Figure 44. Depth map, Run 15-1.

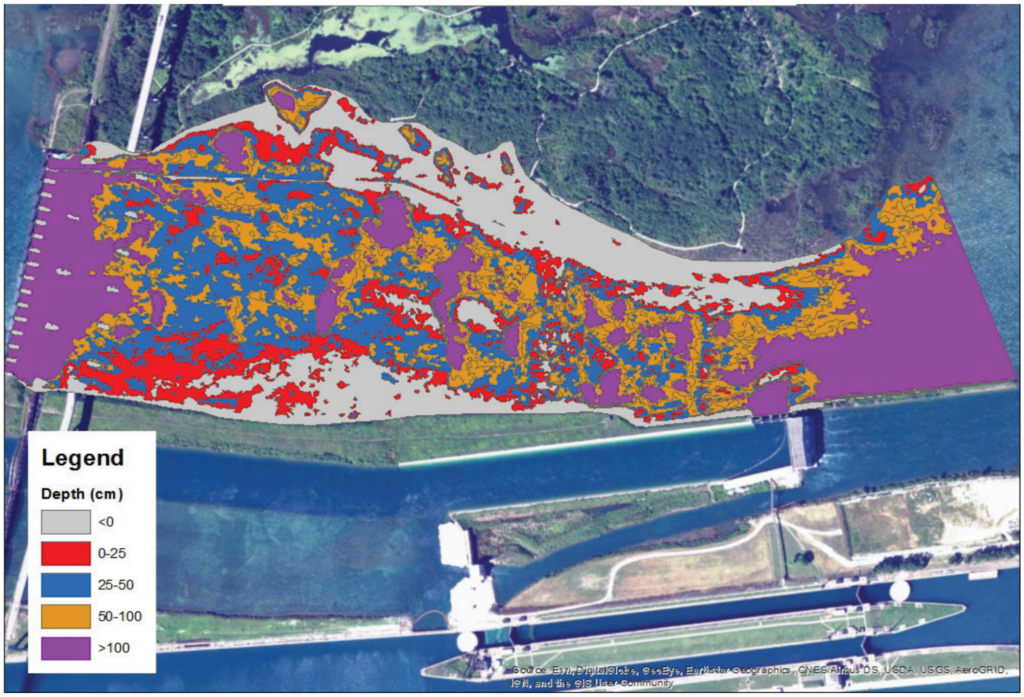


Figure 45. Velocity map, Run 15-1.

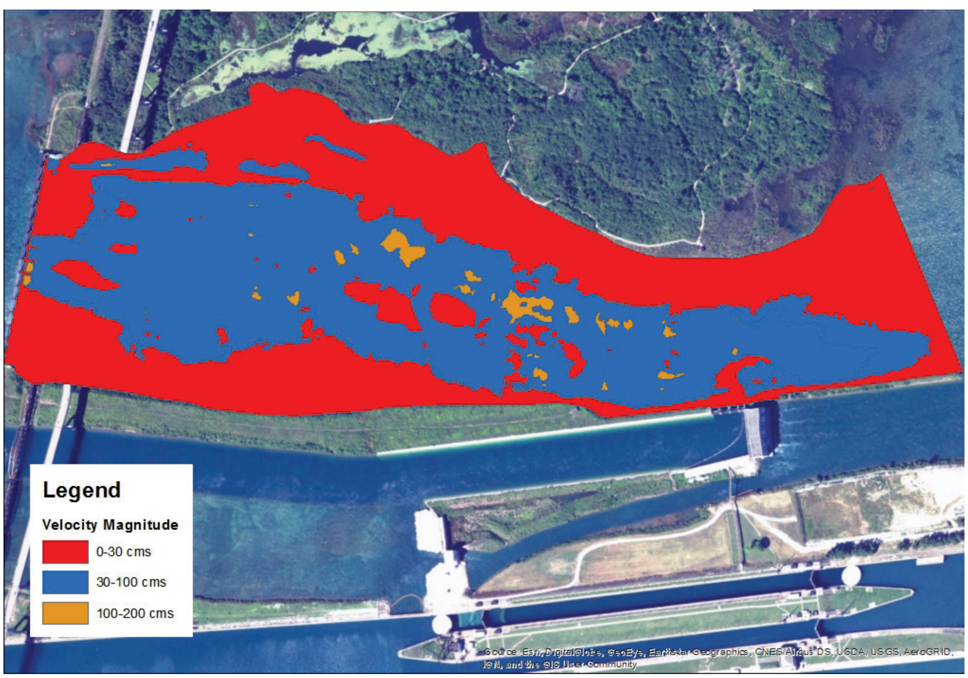


Figure 46. Depth and velocity intersection map, Run 15-1.

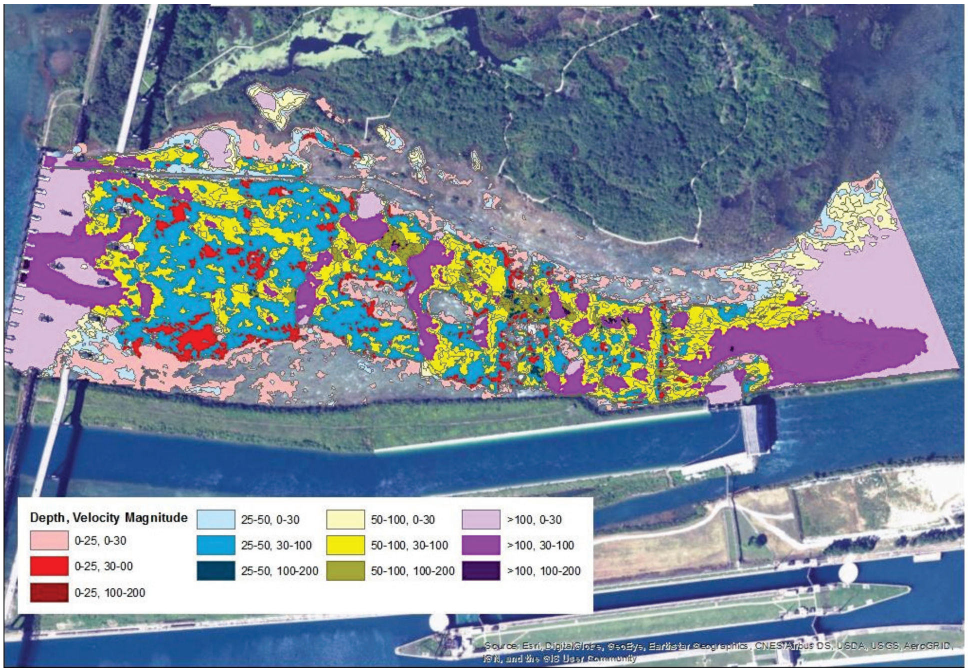


Table 5. Hectares for each depth/velocity category for Run 15-1

Depth (cm)	Velocity (cm/s)			
	0–30	30–100	100–200	>200
0–25	3.57	1.49	0.01	0.00
25–50	1.52	5.67	0.10	0.00
50–100	1.67	6.02	0.44	0.00
>100	4.53	4.71	0.08	0.00

Depth and velocity for Run 15-2 with the Comp Works gates at the two gate equivalent are shown in Figure 47 and Figure 48. The intersection of these two parameters are shown in Figure 49 and the total available area for each depth and velocity range is provided in Table 6. Two gates open still provides a broad range of conditions in terms of depth and velocity, and the shoal on the south side of the rapids becomes usable habitat for several fish species.

Figure 47. Depth map, Run 15-2.

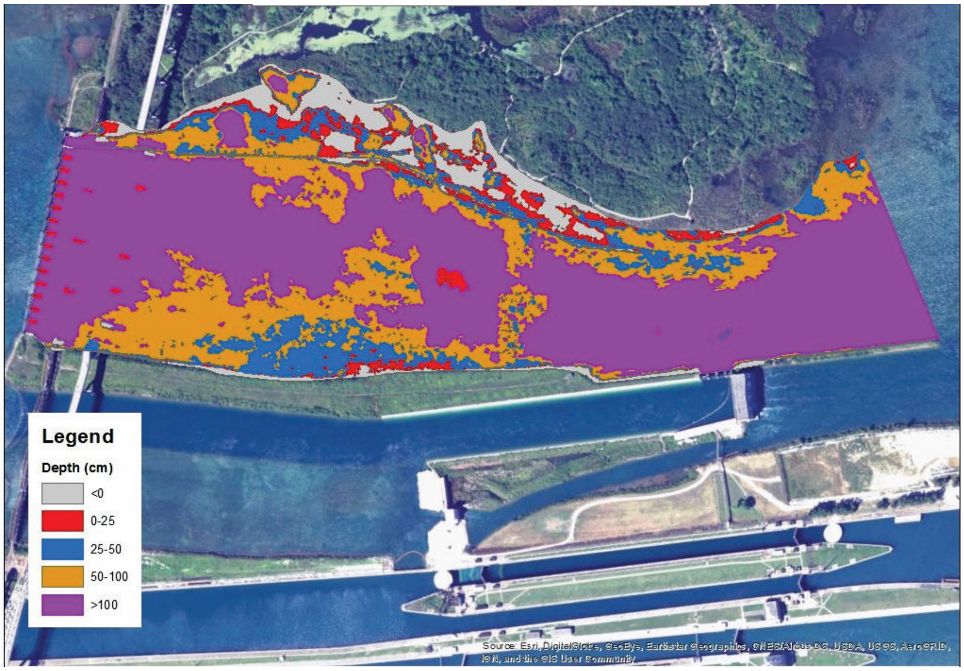


Figure 48. Velocity map, Run 15-2.

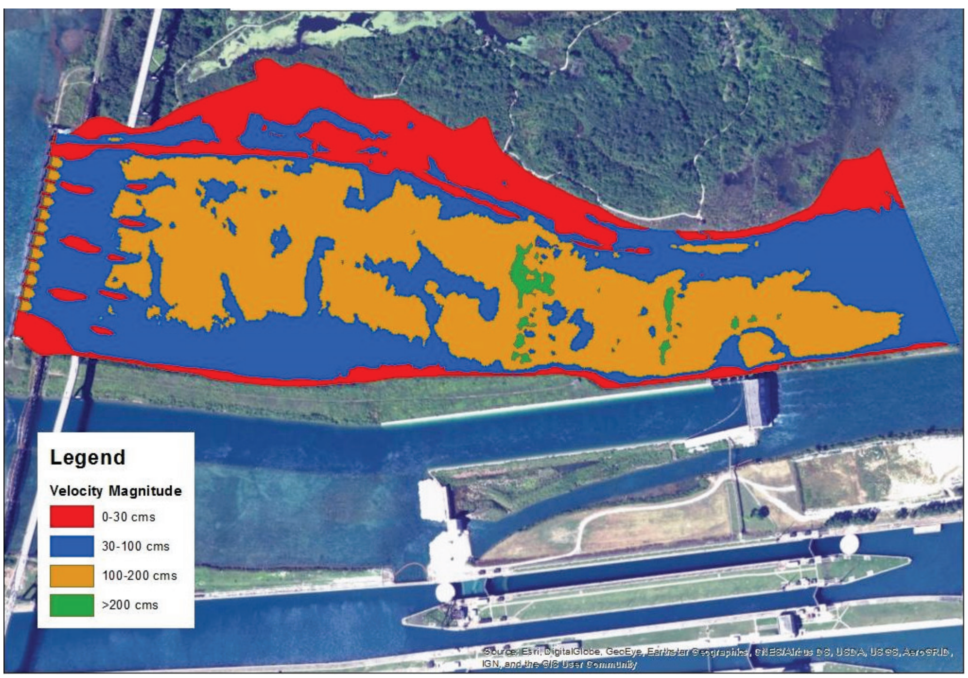


Figure 49. Depth and velocity intersection map, Run 15-2.

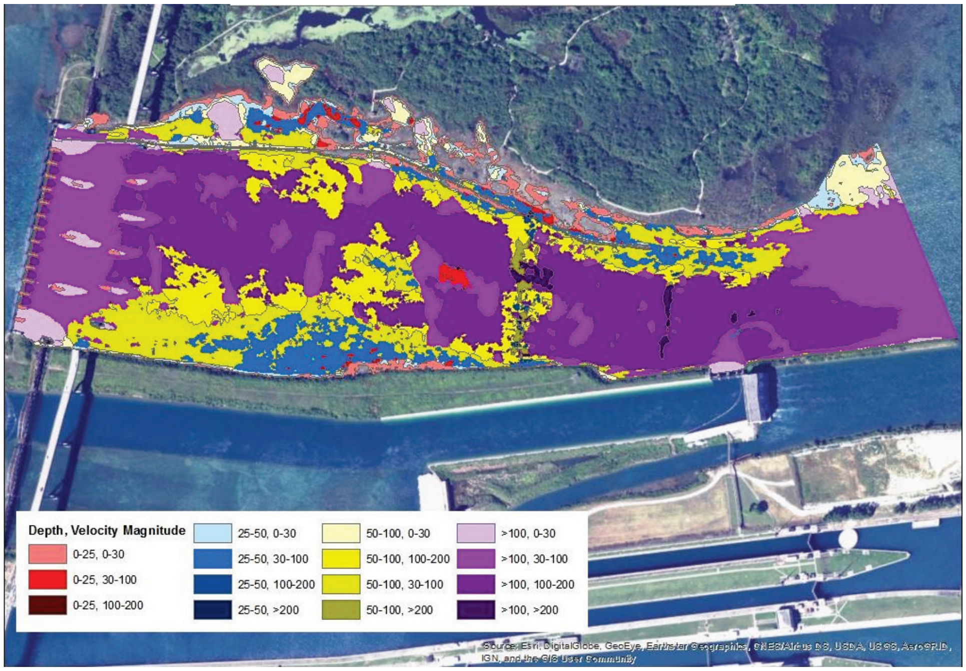


Table 6. Hectares for each depth/velocity category for Run 15-2.

Depth (cm)	Velocity (cm/s)			
	0–30	30–100	100–200	>200
0–25	1.68	0.40	0.01	0.00
25–50	1.03	2.28	0.10	0.01
50–100	1.22	4.28	3.28	0.14
>100	1.18	7.56	11.89	0.23

Depth and velocity for Run 15-5 with the Comp Works gates at the three gate equivalent are shown in Figures 50 and 51. The intersection of these two parameters are shown in Figure 52 and the total available area for each depth and velocity range is provided in Table 7. With three gates open, broad portions of the rapids have depths greater than 1 m, and the shoal on the south side of the rapids retains some variability in depth. At this gate setting, large portions of the rapids are becoming more homogeneous in terms of velocity.

Figure 50. Depth map, Run 15-5.

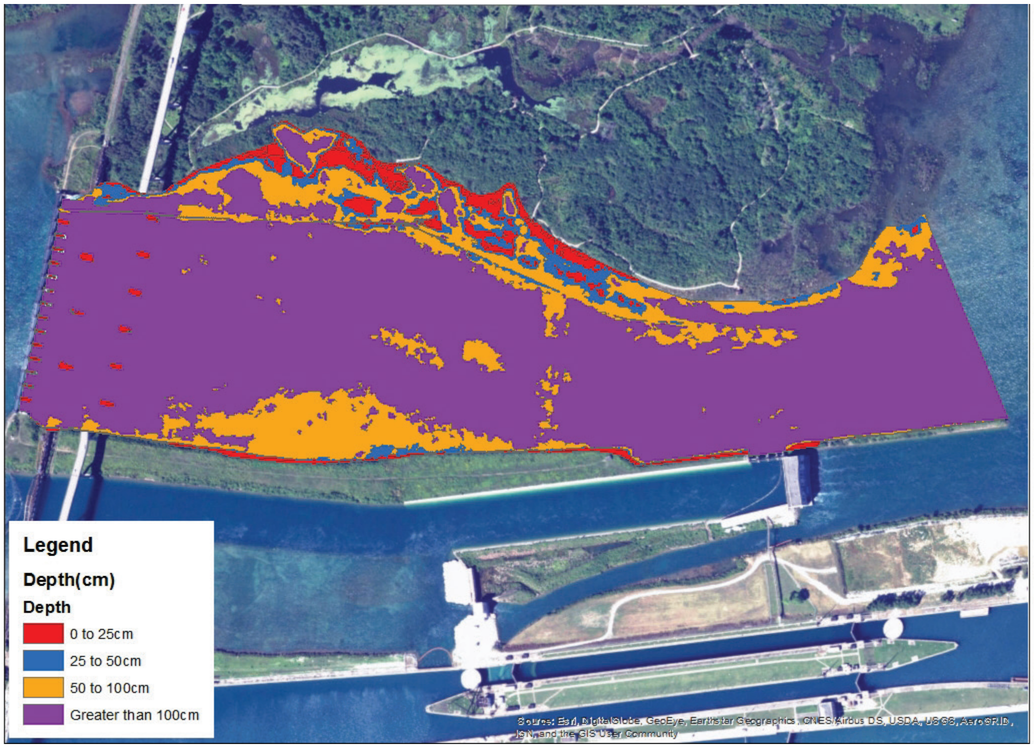


Figure 51. Velocity map, Run 15-5.

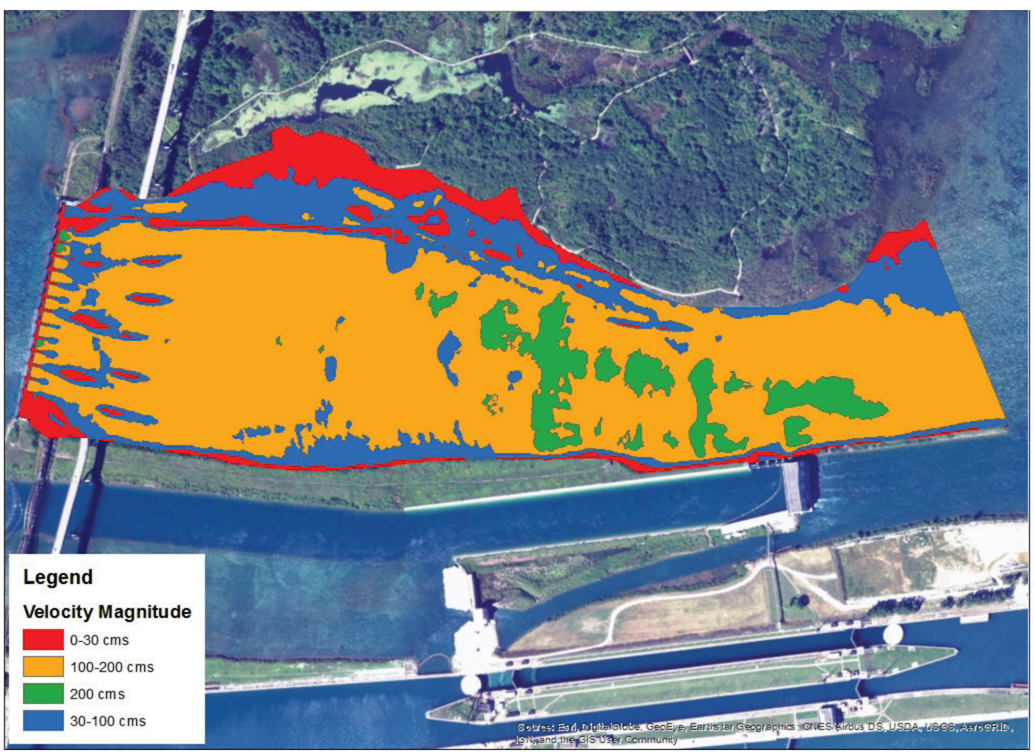


Figure 52. Depth and velocity intersection map, Run 15-5.

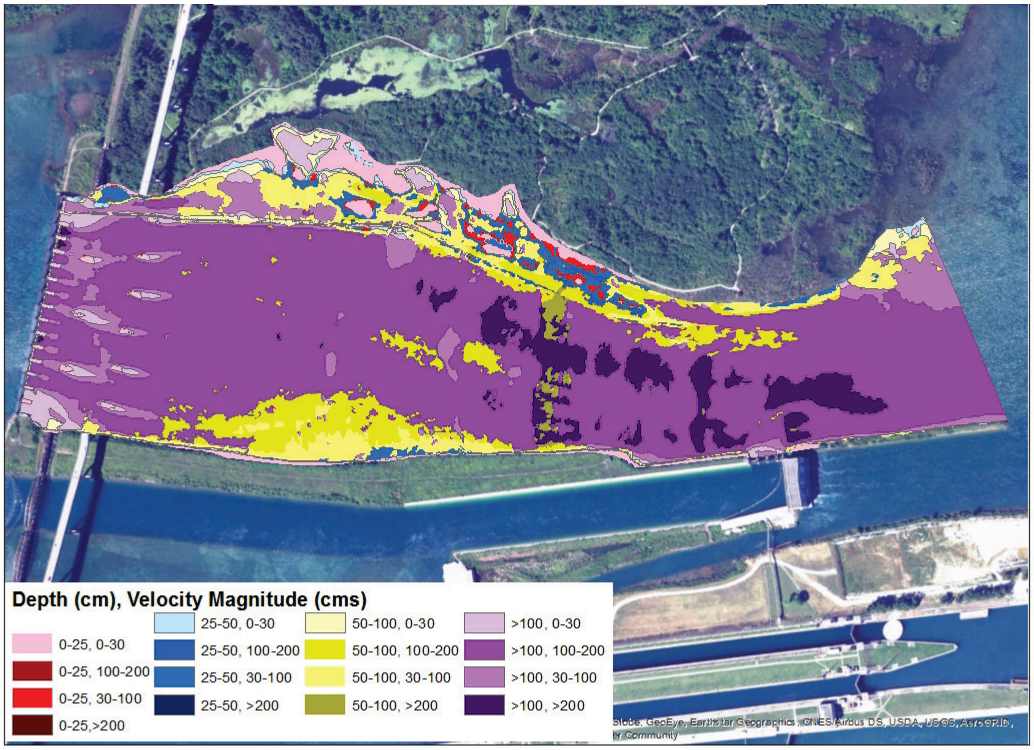


Table 7. Hectares for each depth/velocity category for Run 15-5.

Depth (cm)	Velocity (cm/s)			
	0–30	30–100	100–200	>200
0–25	1.57	0.39	0.007	0
25–50	0.39	0.95	0.16	0.0007
50–100	0.72	2.84	2.79	0.23
>100	0.98	3.27	21.10	2.53

Depth and velocity for Run 15-12 with the Comp Works gates at approximately 5.5 gate equivalent are shown in Figures 53 and 54. The intersection of these two parameters are shown in Figure 55 and the total available area for each depth and velocity range is provided in Table 8. With 5.5 gates open, nearly the entire rapids have depths greater than 1 m, including the shoal on the south side of the rapids, and velocities are largely in the 1 to 2 m/s range.

Figure 53. Depth map, Run 15-12.

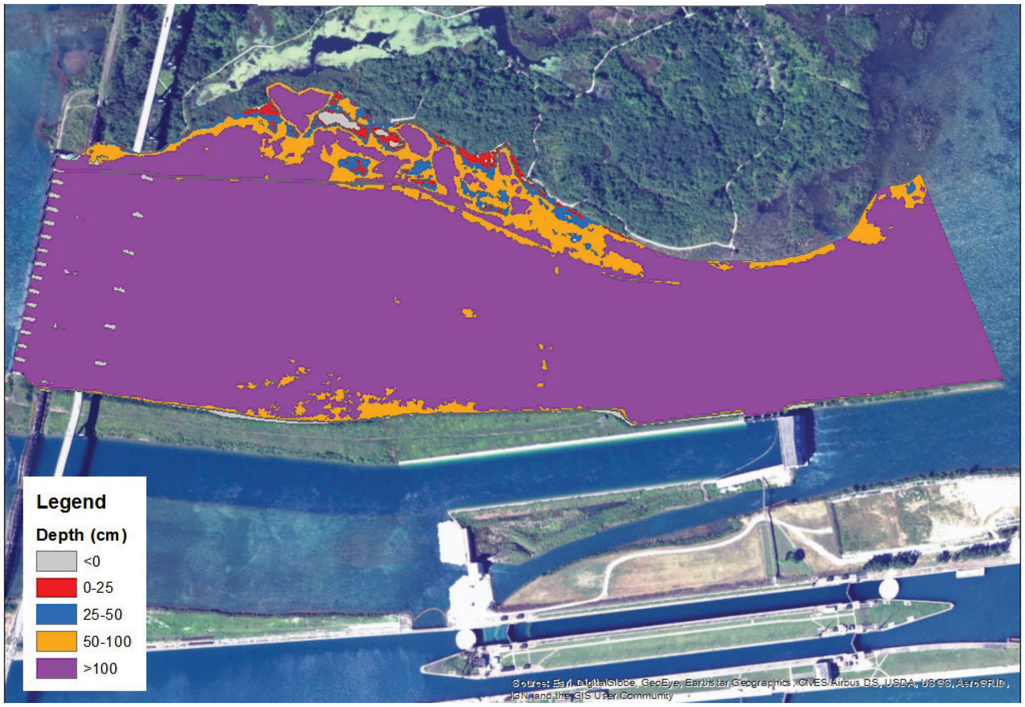


Figure 54. Velocity map, Run 15-12.

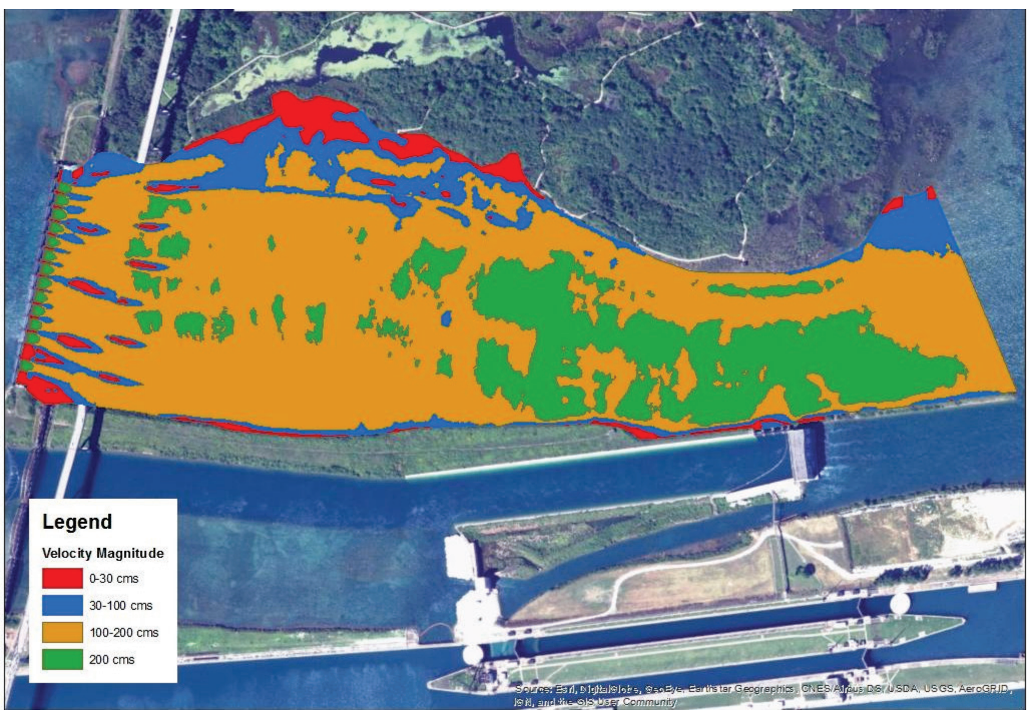


Figure 55. Depth and velocity intersection map, Run 15-12.

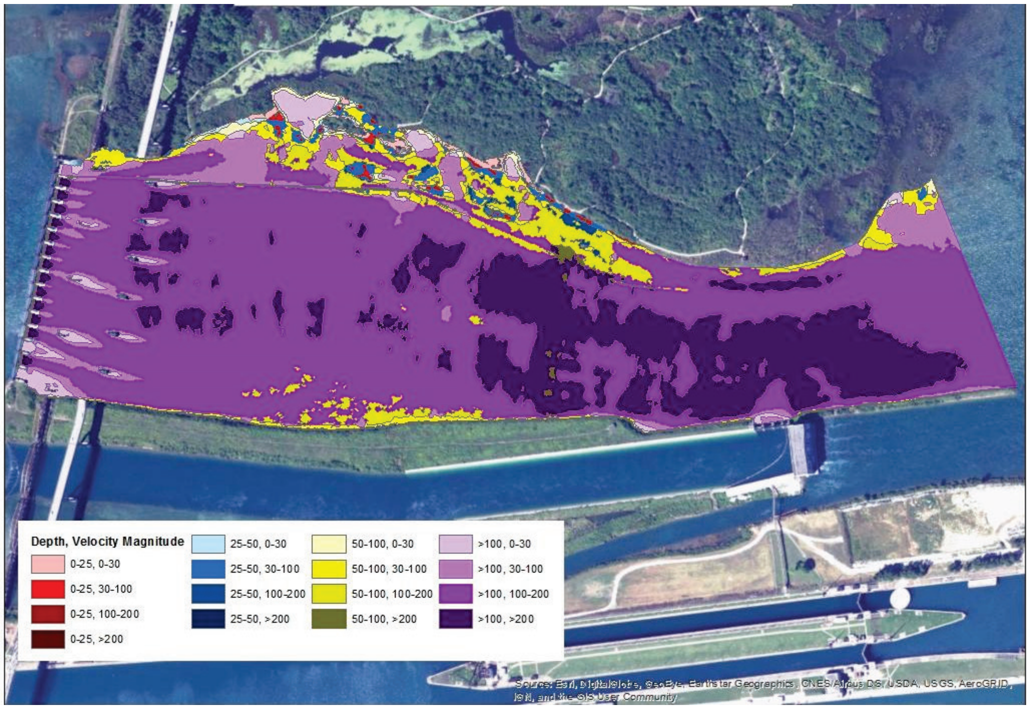


Table 8. Hectares for each depth/velocity category for Run 15-12.

Depth (cm)	Velocity (cm/s)			
	0–30	30–100	100–200	>200
0–25	0.25	0.17	0.01	0.00
25–50	0.16	0.44	0.18	0.00
50–100	0.30	1.24	1.85	0.07
>100	0.85	2.70	20.77	8.50

Depth and velocity for Run 15-18 with the Comp Works gates at the three gate equivalent are shown in Figures 56 and 57. The intersection of these two parameters are shown in Figure 58, and the total available area for each depth and velocity range is provided in Table 9. With three gates open, nearly the entire rapids have depths greater than 1 m including the shoal on the south side of the rapids. Velocities are largely in the 1 to 2 m/s range.

Figure 56. Depth map, Run 15-18.

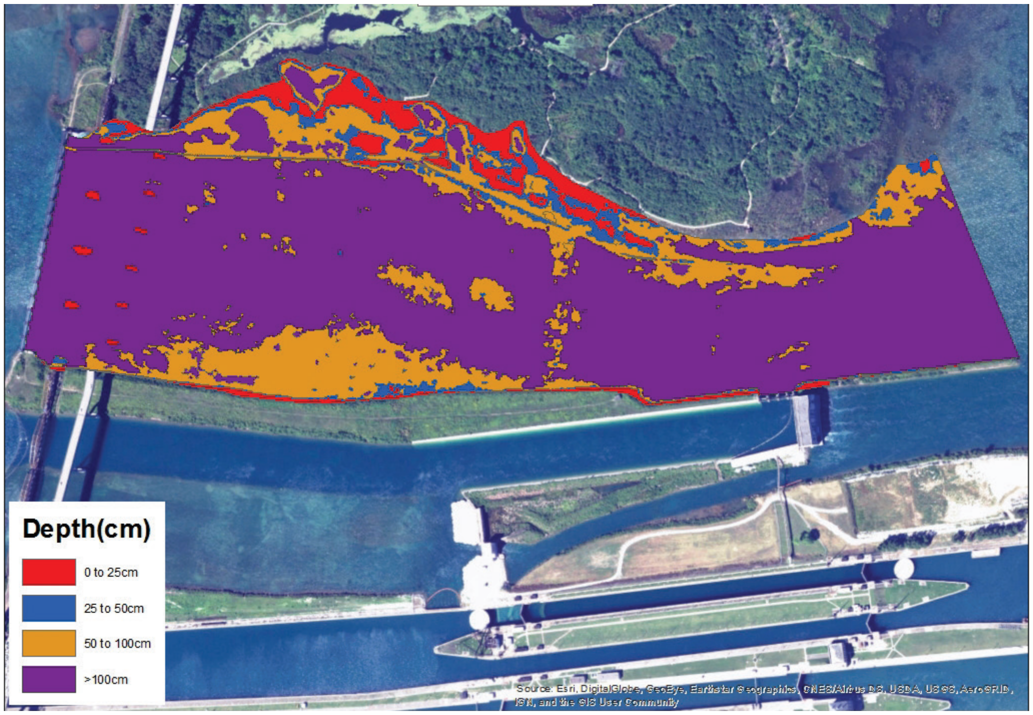


Figure 57. Velocity map, Run15-18.

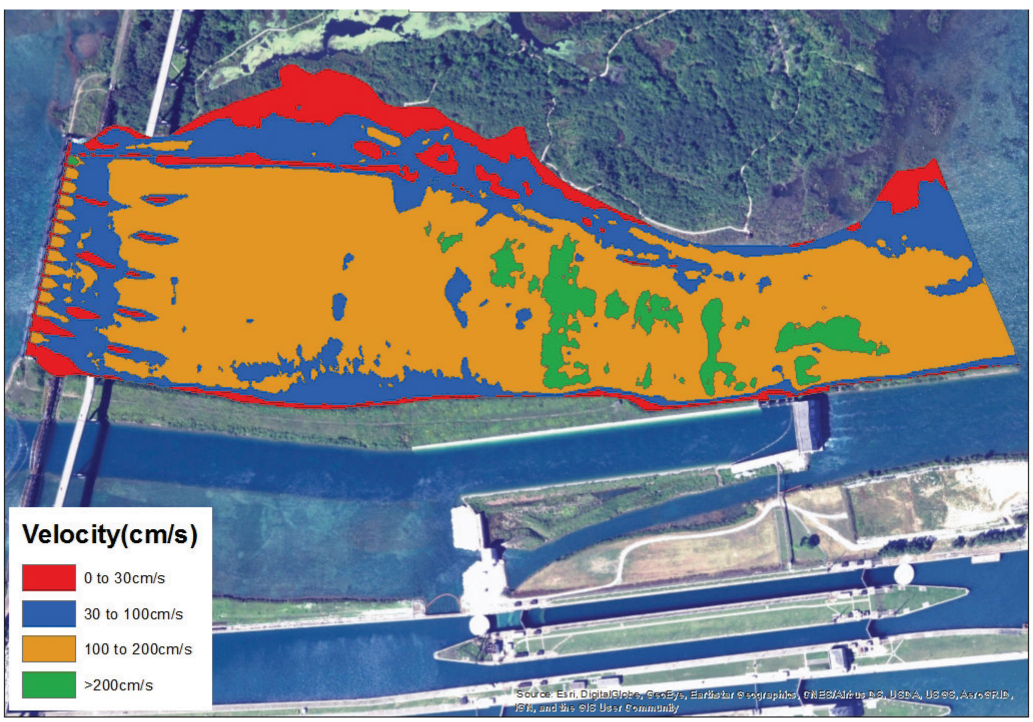


Figure 58. Depth and velocity intersection map, Run 15-18.

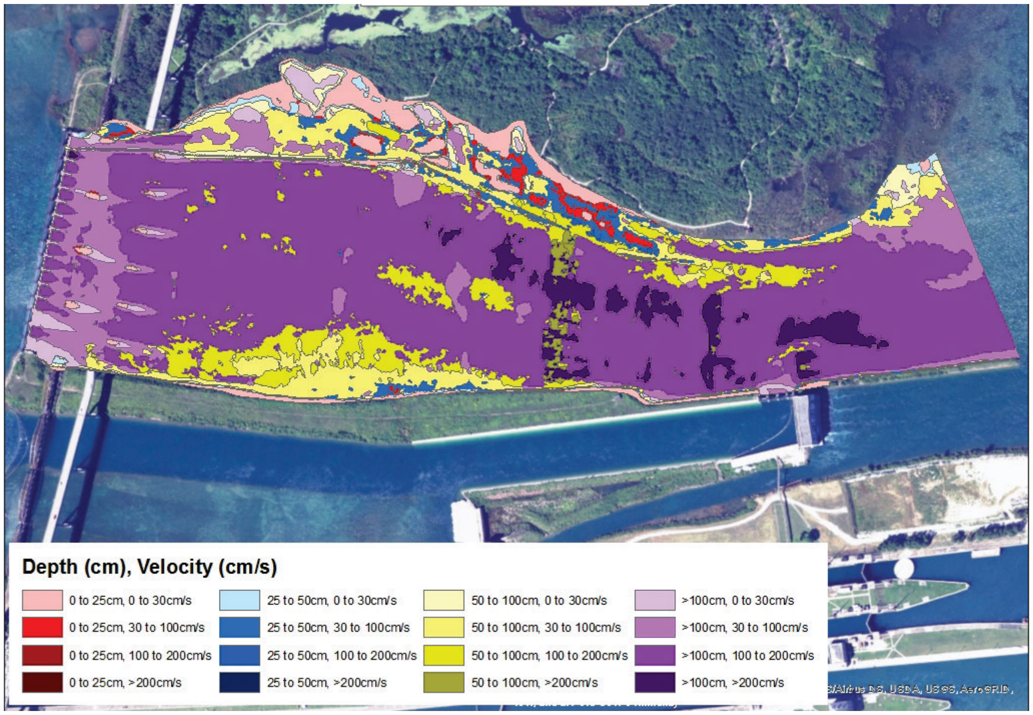


Table 9. Hectares for each depth/velocity category for Run 15-18.

Depth (cm)	Velocity (cm/s)			
	0–30	30–100	100–200	>200
0–25	1.94	0.46	0.0037	0.00
25–50	0.50	1.10	0.10	0.006
50–100	0.81	3.32	2.99	0.25
>100	0.94	4.24	19.50	1.84

These data are essential for properly informing an initial gate regulation plan after the four U.S. gates were automated. In the future, when the regulation plan requires an increase in discharge through the rapids, the four automated gates can be used to slowly increase the water level. With additional water in the rapids, other gates can be manually adjusted with a reduced risk of stranding or washout of various fish species. For gate settings less than four full gates opened, the initial change can be accomplished with the automated gates. Additional gates can be opened manually and the automated gates readjusted to a final location. A similar process could be followed when the regulation plan requires a decrease in flow through the rapids, the manual gates would be closed first, and the gate change would be completed using the automated gates. These scenarios require further modeling to fully develop a gate operation plan that meets water level needs and maximizes fish habitat.

3.4.3 Integrated ecosystem response modeling – objective 3

Living species use habitats, or niches, that can be defined by underlying ranges of environmental conditions to which they are adapted. Consequently, biota distribution in the environment is closely linked to that of these suitable conditions and can be predicted by physical or biological variables. These variables are useful predictors of the probability of occurrence of a species in the landscape.

Many computational approaches exist to assess complex relationships between environmental variables and species habitat. The choice of a modeling method should ideally be made on the basis of the goal being pursued. That choice, in turn, dictates the type and amount of data necessary to reach that goal. However, the choice of a method is often contingent on both the quantity and the quality of the biological and environmental data available. The limited amount of biological data available for the present study left few choices for habitat modeling.

Habitat Suitability Indices were used as habitat models for the St. Marys River rapids. Periods when each fish species is most sensitive to given water levels/flow fluctuations were identified to ensure the incorporation of appropriate modeled time frames. Habitat suitability index models are combinations of preference curves for key environmental variables, for instance, water depth and velocity. Each preference curve represents the tolerance of a species to the mean value and/or variation of a physical variable. Habitat suitability index values are standardized between 0 (unbearable conditions) and 1 (outstanding conditions). With this approach, a habitat suitability index close to 0 represents a poor habitat, while a value of 1 represents a highly suitable habitat. By combining multiple preference curves, each node of the Integrated Ecosystem Response Model can be calculated for a given species under various scenarios of gate openings or management strategies. The final result comes in the form of a map comparing the distribution of potential habitat.

In this study, the following two management strategies were compared: 1) A non-deviation strategy which applied the fully open gate strategy in use prior to 2014, and 2) the partial gate strategy currently in use (deviation scenario). For the period between April and December 2015, simulations under both gate operation strategies were performed. Results were accumulated over the modeling period, and an assessment of change in habitat as a result of the management practice was performed.

Integrated response modeling was performed for the following four species within the St. Marys rapids: lake sturgeon (*Acipenser fulvescens*), walleye (*Sander vitreus*), sea lamprey (*Petromyzon marinus*), and lake whitefish (*Coregonus clupeaformis*). Lake sturgeon, an endangered species, is a spring spawning top predator that was historically observed spawning in the St. Marys rapids. Walleye, another spring spawner and top predator, is a recreationally important species for sport fishing in the area. Sea lamprey spawns during summer and is an invasive and parasitic species. Lake whitefish is a fall spawner that was historically fished in the area. The following sections outline the biology, model development, and modeling results for lake sturgeon as an example of how the Comp Works gates can be more efficiently operated to optimize lake sturgeon habitat. A full report, with additional details about lake sturgeon and the other three indicator species, are available in Bachand et al. (2017).

3.4.4 Lake sturgeon

Once abundant in the Great Lakes and the St. Marys River, the lake sturgeon population is suspected to be around 1% of its former size (Harkness and Dymond 1961). Consequently, lake sturgeon are a conservation priority in the Great Lakes Basin (e.g., Holey et al. 2000; Harris et al. 2009). The numbers of lake sturgeon in the St. Marys River population are around 500 individuals (Bauman et al. 2011) and it may be genetically distinct from other lake sturgeon in the Upper Great Lakes (Gerig et al. 2011).

A major barrier to lake sturgeon recovery in the Great Lakes is the lack of suitable spawning sites (Daugherty et al. 2008). The St. Marys River has potential sites meeting requirements as lake sturgeon spawning grounds (Goodyear et al. 1982). However, the maintenance of these spawning habitats is conditional on the flow regime for maintaining adequate water velocity and depth.

The St. Marys rapids area was historically a spawning ground for the lake sturgeon (Goodyear et al. 1982). Unfortunately, no database with spawning observations in the St. Marys rapids is known to exist.

The aforementioned, non-deviation strategy involves changing the gate setting once during the spawning period. On that occasion, it goes from 5 fully opened gates to 4 fully opened gates. Both gate settings have an extra gate opened at 20 cm. During the egg incubation period, the gate setting is also changed once 4 days before the end of the incubation period. Here, another fully-opened gate was closed.

Under the deviation scenario, 14 gates were opened with different opening sizes at the beginning of the spawning period. The gate setting then changed twice during this period. During the egg incubation period, 15 gates were opened with different opening sizes, and the setting did not change for the rest of the period (Table 10).

Table 10. Mean surface area of habitat suitable for lake sturgeon spawning and egg survival in St. Marys River under the non-deviation and deviation scenario.

Scenario	Spawning (ha)	Egg survival (ha)
No Deviation	2.36	2.28
Deviation	1.31	1.31

To evaluate the possible impact of water management in St. Marys rapids on lake sturgeon reproduction, habitat suitability indices associated with physical habitat for spawning and egg survival were developed. To ensure prediction of suitable habitat (i.e., where conditions are appropriate) during those periods, the distribution of suitable habitat was limited to specific ranges of water velocity, water depth, and other physical variables during modeled periods.

Based on the literature, the model considered as suitable habitat for lake sturgeon spawning sites where

- the mean water depth was between 0.10 and 5.00 m,
- the mean water velocity was between 0.30 and 0.90 m/s,
- the bottom slope in the flow direction was positive, and
- the substrate composition included gravel.

After the prediction of habitat suitable to lake sturgeon spawning, the model considered that lake sturgeon eggs would not be able to survive at Integrated Environmental Response Model grid points where maximum water velocity exceeds 2.00 m/s, or where maximum water depth exceeds 5 m during the egg incubation period. Also, if a grid point was dried during the same period, it was classified as habitat not suitable for egg survival.

Lake sturgeon spawning habitat under the non-deviation scenario is located downstream of the gates 1–3 on the Canadian side. The spawning habitat follows Whitefish Island's shoreline. On the U.S. side, the spawning habitat lies downstream of gates 14–16. The south shoreline presents less habitat than the north. There also appears to be some suitable habitat in a few spots located in the middle of the rapids (Figure 59).

Under the deviation scenario, the mean surface area of lake sturgeon spawning habitat (1.31 ha) is reduced by about 45% compared to the non-deviation scenario (2.36 ha) (Table 10). Most of the sites in the middle and the south part of St. Marys rapids are no longer suitable for spawning by lake sturgeon as predicted by the Integrated Environmental Response Model. This reduction of habitat seems to be related to the distribution of water velocities. Under the non-deviation scenario, high water velocities (>1.50 m/s) would have been concentrated in the middle of the rapids, whereas under the deviation scenario, high water velocities are also evenly distributed near the shorelines, where the spawning habitat would be suitable under the non-deviation scenario (Figure 60).

The mean predicted surface areas suitable to lake sturgeon egg survival is also reduced by around 43% under the deviation scenario (1.31 ha) compared to the non-deviation scenario (2.28 ha) (Table 10). The spatial distribution of the latter difference is similar as that predicted for the spawning habitat (Figure 61).

Figure 59. Predicted spatial distribution (in dark blue) of habitat suitable for lake sturgeon spawning in St. Marys rapids according to the no deviation (top) and deviation (bottom) gate scenario (year 2015).

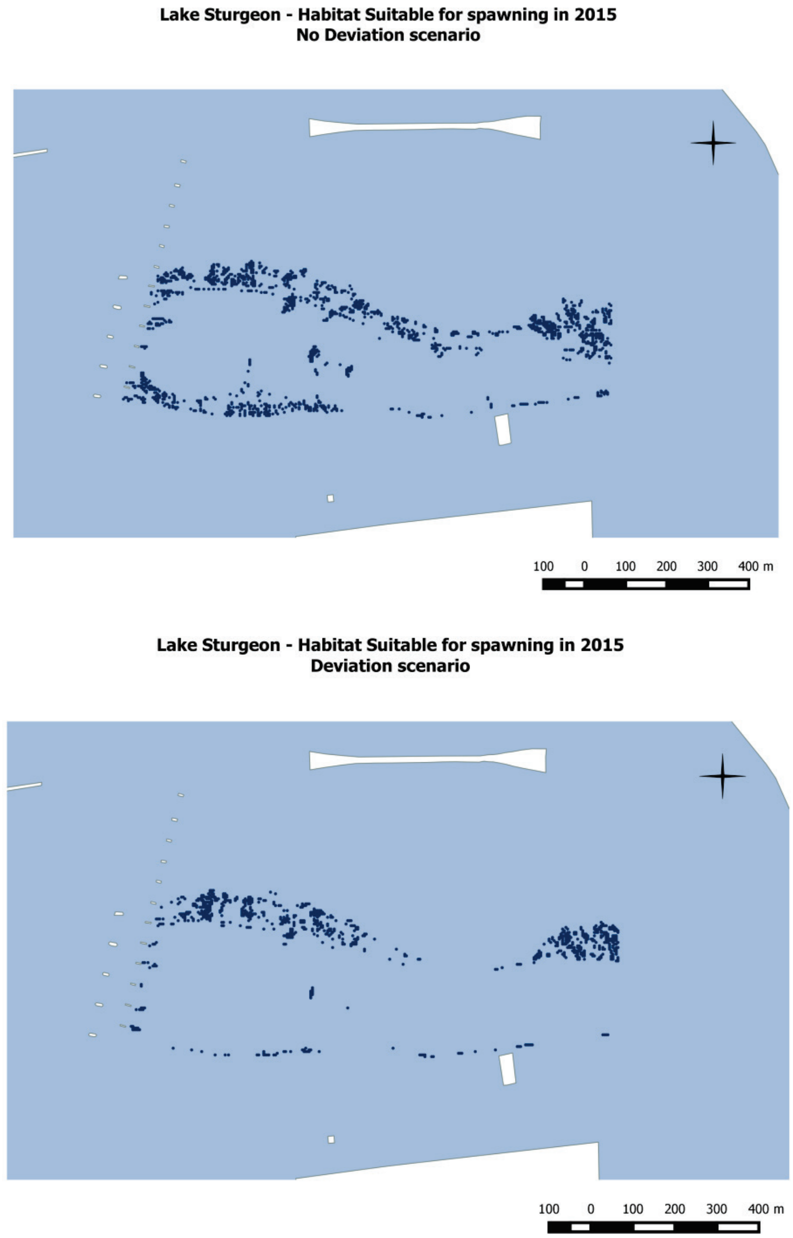


Figure 60. Spatial distribution of mean water velocity during the spawning period of lake sturgeon in the St. Marys rapids under the no deviation (top) and deviation (bottom) scenario (year 2015).

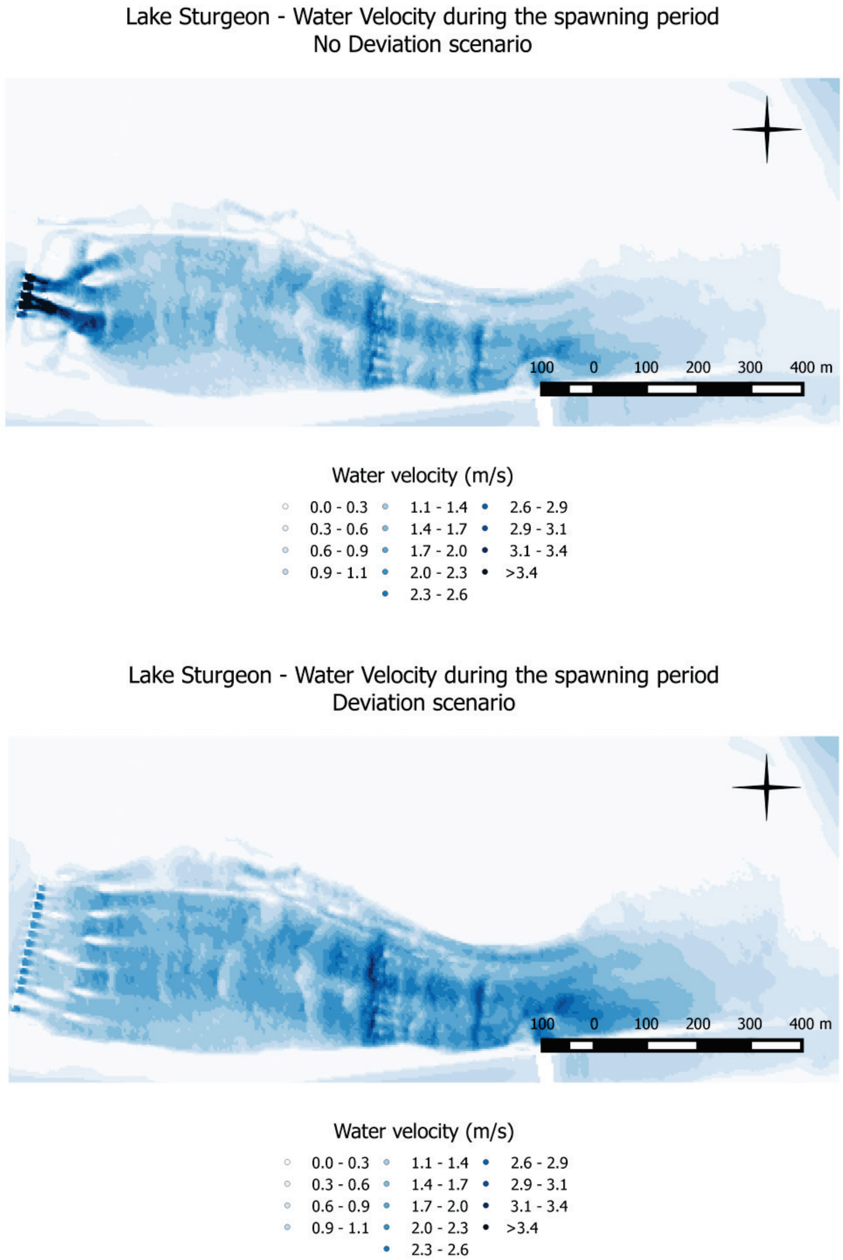
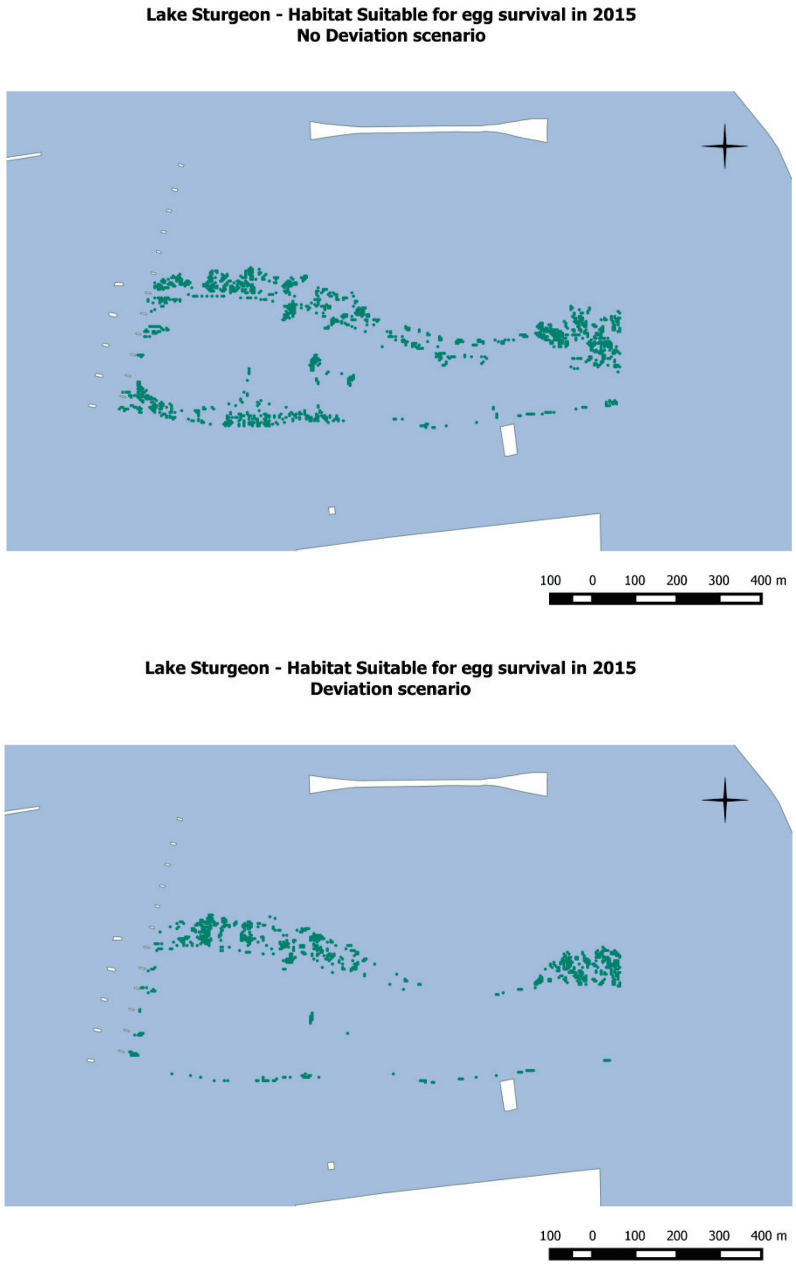


Figure 61. Habitat suitable to lake sturgeon egg survival (shown in dark green areas) for 2015 in the St. Marys rapids according to the no deviation (top) and deviation (bottom) gate scenario.



Under the non-deviation scenario, around 0.08 ha of habitat suitable to lake sturgeon spawning is unsuitable to egg survival due to the possibility of stranding, causing egg loss (Table 10). Under the deviation scenario, no difference was observed between the surface of habitat suitable to lake sturgeon spawning and egg survival (Table 11).

Table 11. Number of sites (points) lost between spawning and egg incubation period.

	Total		Causes (loss by)		
Scenario	Nodes suitable for spawning	Nodes suitable for egg survival	Water depth >5.0m	Water velocity >1.40 m/s	Stranding
No Deviation	1475	1425	0	0	50
Deviation	819	819	0	0	0

Results from this initial lake sturgeon habitat model suggests that the deviation scenario decreased the amount spawning habitat when compared to the non-deviation scenario. Under the deviation scenario, 13 to 14 gates are partially opened during the spawning period, which create greater water velocities beyond lake sturgeon tolerable range for spawning. Under the non-deviation scenario, only 5 or 6 gates are opened during the spawning period. It creates even greater water velocities, but only in the middle of the rapids, allowing suitable spawning habitat near the shorelines.

4 Conclusions

Using a hydraulic model to investigate the outcome of various water management strategies is an effective way to ensure the chosen strategy meets USACE project objectives. The St. Marys Adaptive Hydraulics model was created and applied to determine the length of time gate changes need to occur to ensure the water level rate of change in the St. Marys rapids are below the maximum rate of change of 10 cm/hour recommended by Bain et al. (2010). These conditions should minimize the potential adverse effects on aquatic life, especially fish, immediately downstream of the Comp Works during a gate change event.

This model gives the USACE the capability to test various gate changes and water level change rates based on various Lake Superior water levels. Hydraulic data evaluated in 2015 resulted in some gate change events exceeding the recommendation by Bain et al. (2010). Based on the hydraulic model, these events could have met the recommendation in more than 95 % of the St. Marys rapids if the gate change event was to occur over a 3-hour period. Changing to or from the half gate setting will likely require the gate change to occur over a 6-hour period.

On the U.S. side of the Comp Works, four of the eight sluice gates are being retrofitted to create the capability to remotely control gate change events. Remote control will enable operators to more gradually change gate position on a time scale that better addresses environmental objectives. Prior to this new capability, a minimum of three workers spending three to six hours per gate change were required to manually change gate settings with counterweights and roller trains. Knowledge gained of the relationship between gate rate of change and water level rate of change presented in this report will be valuable information that can be used to develop a more informed gate operation plan for the Comp Works.

The St. Marys rapids provide spawning and rearing habitat for a wide variety of fish species. The automation of the four U.S. gates and the revised operation of the remaining manually operated gates is consistent with EWN®, where operational efficiencies can not only improve water flow, but also greatly improve the benefits associated with the fisheries habitat at the rapids in the future.

While the switch to partial gate strategy was intended to increase habitat opportunities throughout the rapids, the initial strategy of opening each gate a similar height above the sill reduces viable habitat, at least for lake sturgeon. After a full assessment of each indicator species, additional modeling is recommended to more fully characterize the bottom substrate for use by the fish species of interest.

It is important to note the results from this work were based on a substrate map developed from high resolution aerial imagery with limited field verification. Field verification occurred during a brief visit to the rapids in June 2017. At that time, only a small portion of the rapids were visible and safely accessible.

5 Future Work

More detailed substrate information is currently being collected. High resolution imagery was acquired using a UAS by the SAJ. This imagery requires field verification before substrate can be appropriately remotely sensed in the rapids. The next time the Comp Works are at minimal gate setting during a part of the year when it is safe to wade, substrate calibration data will be collected. Substrate classification will be performed and these intersections will be recomputed.

In addition to classifying areas in the rapids based on water depth and velocity (the addition of substrate will be included in future work), partners at Environment and Climate Change Canada are using these modeling outputs as a forcing to an eco-hydraulic modeling tool. This tool, the Integrated Ecological Response Model, uses hydrodynamic output and other physical variables such as bottom slope, bottom curvature, and depth of photic zone in conjunction with biological models describing suitable locations for various vegetation types and suitable habitat for fauna of interest.

The Integrated Ecological Response Model is capable of analyzing locations within the rapids where various fish species will likely spawn, and locations where egg survival is likely. Further information regarding this modeling effort can be found in Bachand et al. 2017. The Canadian Report is concurrently nearing completion and will provide locations throughout the St. Marys rapids where four indicator fish species will spawn and where the eggs will survive. Currently, indicator species are walleye, sturgeon, whitefish, and the non-native sea lamprey. Spawning and egg survivability maps should be generated for each gate opening in 2015 and compared with alternative gate management options.

References

Bachand, M., S. Martin, G. Guénard, O. Champoux, and J. Morin. 2017. *Ecohydraulic modeling of St. Marys rapids: Evaluating the impact of gate opening scenarios on the spawning habitat suitability of four species*. Scientific Report – SR-113. Gatineau, QC: Environment and Climate Change Canada.

Bain, M., K. Arend, G. Steinhart, A. Moerke, and P. Varnakovida. 2010. *St. Marys River biological status and hydrologic performance indicators*. Environmental Working Group International Upper Great Lakes Study. http://www.iugls.org/DocStore/ProjectArchive/ECO_Ecosystem/ECO15_Bain_StMarysRiverEcosystemPIs/Reports/ECO15-R1_Bain_et-al_StMarysRiverSummary.pdf.

Bauman, J. M., A. Moerke, R. Greil, B. Gerig, E. Baker, and J. Chiotti. 2011. Population status and demographics of lake sturgeon (*Acipenser fulvescens*) in the St. Marys River from 2000 to 2007. *Journal of Great Lakes Research* 37(2):47–53. https://doi.org/10.1016/j.jglr.2010.12.003.

Berger, R. C., J. N. Tate, G. L. Brown, and G. Savant. 2014. *Guidelines for Solving Two-Dimensional Shallow Water Problems with the Adaptive Hydraulics Modeling System, AdH Version 4.4*. Vicksburg, MS: Coastal and Hydraulics Laboratory, Engineer Research and Development Center, Vicksburg, MS.

Daugherty, D. J., T. M. Sutton, and R. F. Elliot. 2008. Potential for reintroduction of lake sturgeon in five northern Lake Michigan tributaries: A habitat suitability perspective. *Aquatic Conservation: Marine and Freshwater Ecosystems* 18(5): 692–702. https://doi.org/10.1002/aqc.878.

Edmunds, H. 1931. Report on Discharge St. Marys River February 1911 to December 1930 inclusive, Report to District Engineer American Member Lake Superior Board of Control, 118:56-60, ASCE

Gerig, B., A. Moerke, R. Greil, and S. Koproski. 2011. Movement patterns and habitat characteristics of lake sturgeon (*Acipenser fulvescens*) in the St. Marys River, Michigan, 2007–2008. *Journal of Great Lake Research* 37(S2):54–60. https://doi.org/10.1016/j.jglr.2010.09.007.

Goodyear, C. D., T. A. Edsall, D. M. Ormsby Dempsey, G. D. Moss, and P. E. Polanski. 1982. *Atlas of the spawning and nursery areas of Great Lakes fishes. Volume III: St. Marys River*. FWS/OBS-82/52. Washington, DC: Great Lakes Fishery Laboratory, U. S. Fish and Wildlife Service. U.S. Department of the Interior.

Harkness, W. J. K., and J. R. Dymond. 1961. The lake sturgeon: The history of its fishery and problems of conservation. Ontario, Toronto, Ontario: Department of Lands and Forests.

Harris, R., B. Kinder, A. Marino, V. Parker-Geisman, and T. Patterson. 2009. The St. Marys River watershed: Planning for biodiversity conservation. Ann Arbor, Michigan: The University of Michigan, The Nature Conservancy of Michigan and the School of Natural Resources and Environment.

Holey, M. E., E. A. Baker, T. F. Thuemler, and R. F. Elliot. 2000. Research and assessment needs to restore lake sturgeon in the Great Lakes. Muskegon, Michigan: Great Lakes Fishery Trust Workshop.

Lane, J. A., C. B. Portt, and C. K. Minns. 1996. Nursery Habitat Characteristics of Great Lakes Fishes. Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 2338. *Environment Canada*.

Louhi, P., A. Maki-Petays, and J. Erkinaro. 2008. Spawning habitat of Atlantic Salmon and Brown Trout: General criteria and intragravel factors. *River Res. Applic.* 24: 330-339.

McMahon, T. E., J. W. Terrell, and P. C. Nelson. 1984. Habitat Suitability Information: Walleye (1984). US Fish & Wildlife Service, US Dept of the Interior FWS/OBS-82/10156.Sea Grant Michigan. 2016. *Restoring fish habitat: Projects in the St. Clair-Detroit River System*. (Accessed on 29 January 2016) http://www.miseagrant.umich.edu/explore/restoration/restoring-fish-habitat-st-clair-river/.

Mueller, D. S., C. R. Wagner, M. S. Rehmel, K. A. Oberg, and F. Rainville. 2013. Measuring discharge with acoustic Doppler current profilers from a moving boat (ver. 2.0, December 2013). U.S. Geological Survey Techniques and Methods, Book 3, Chapter A22. https://dx.doi.org/10.3133/tm3A22.

Swamee, P. K. 1992. Sluice gate discharge equations. *Journal of Irrigation and Drainage Engineering* 118(1):56–60. https://doi.org/10.1061/(ASCE)0733-9437(1992)118:1(56).

Appendix A: Calibration and Validation Graphs

Calibration Graphs

Figure A- 1. Calibration plot for Point Iroquois NOAA.

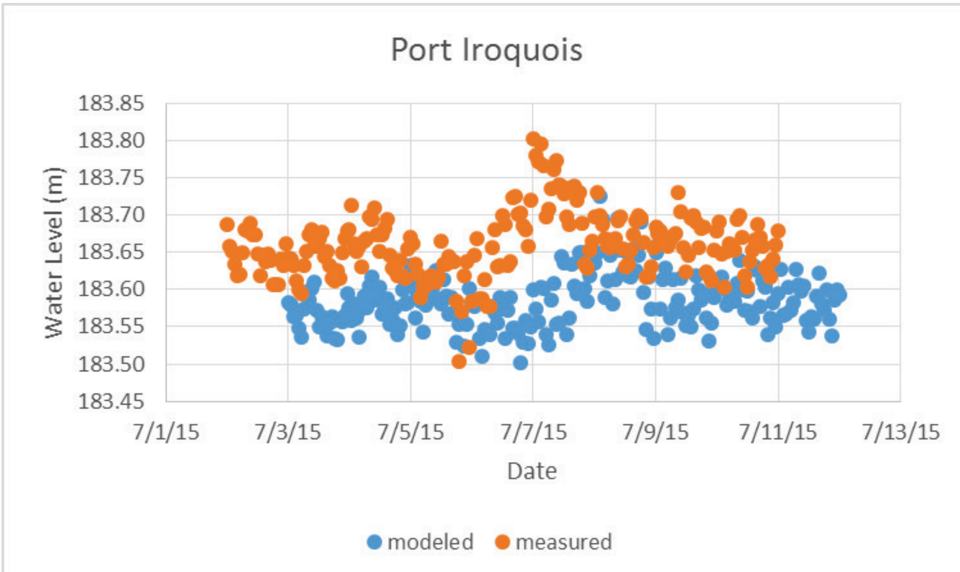


Figure A- 2. Calibration plot for SW Pier NOAA.

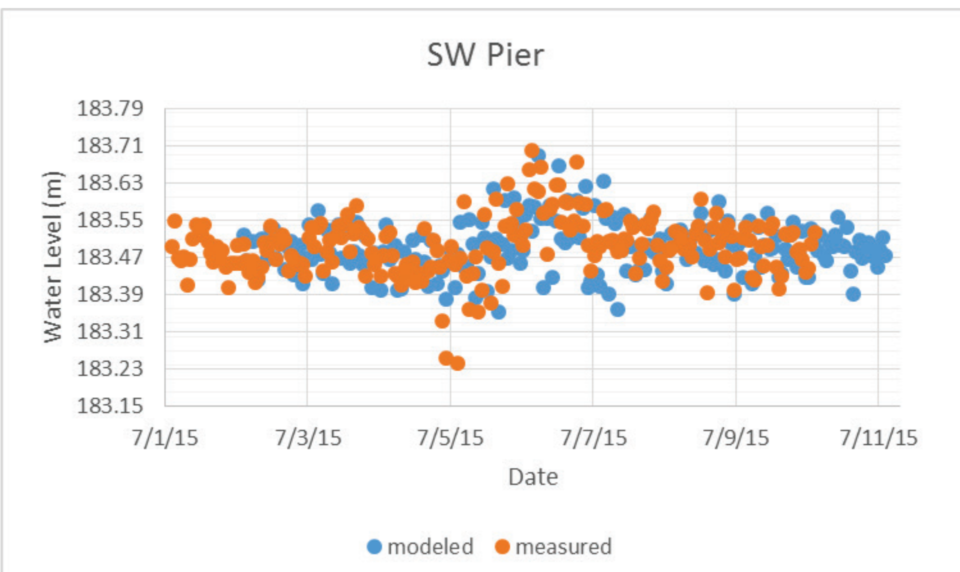


Figure A- 3. Calibration plot for Upper Sault CHS.

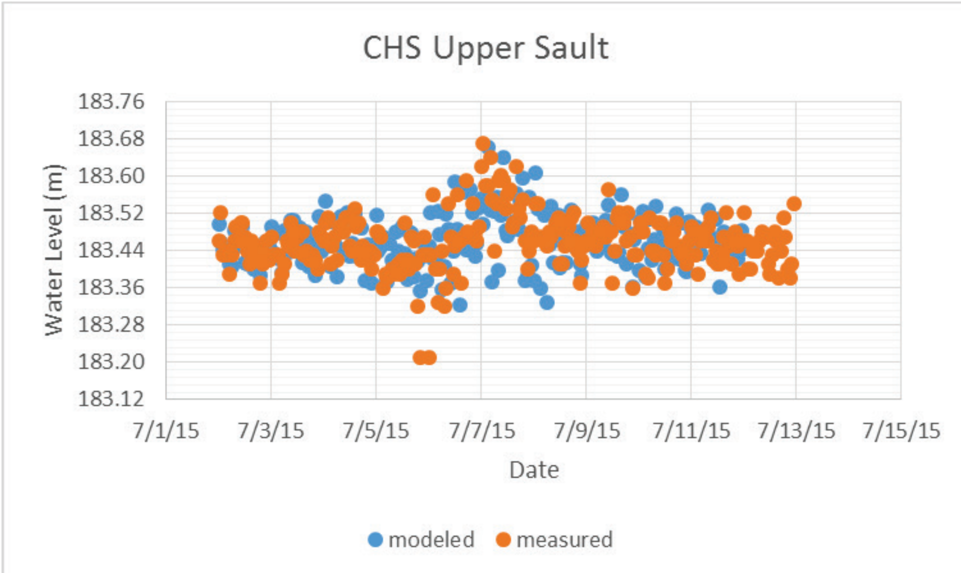


Figure A- 4. Calibration plot for Upper Radar USACE.

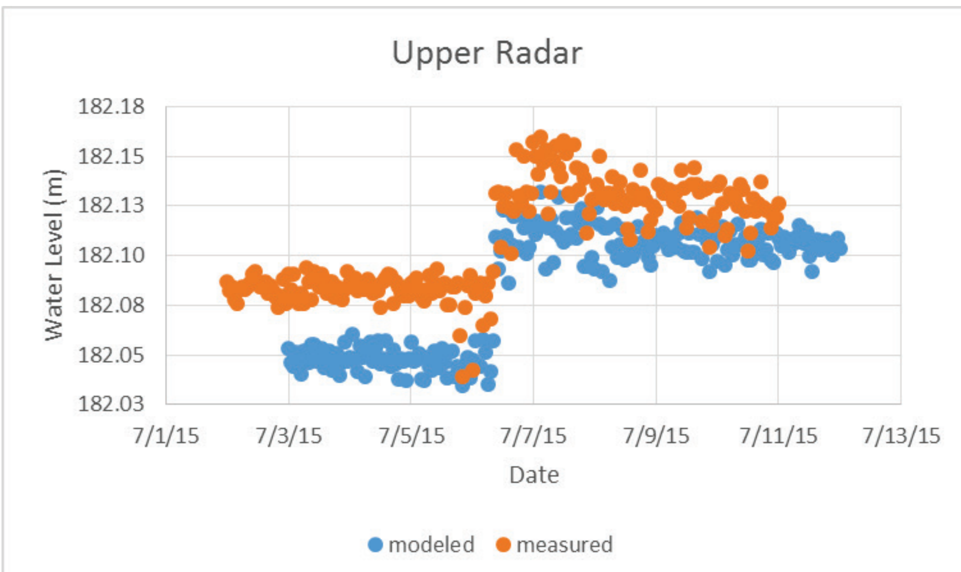


Figure A- 5. Calibration plot for Pressure Sensor 2 USACE.

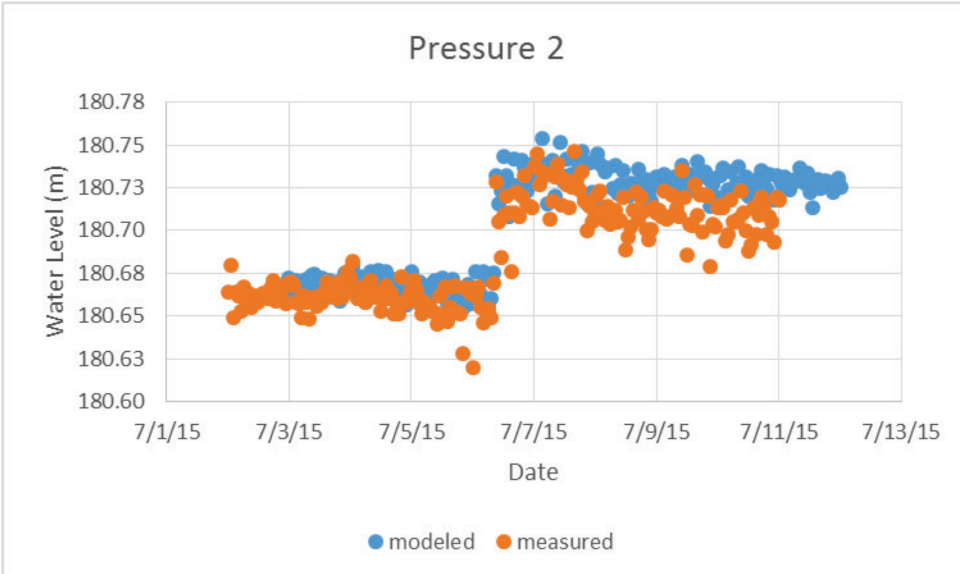


Figure A- 6. Calibration plot for Pressure Sensor 3 USACE.

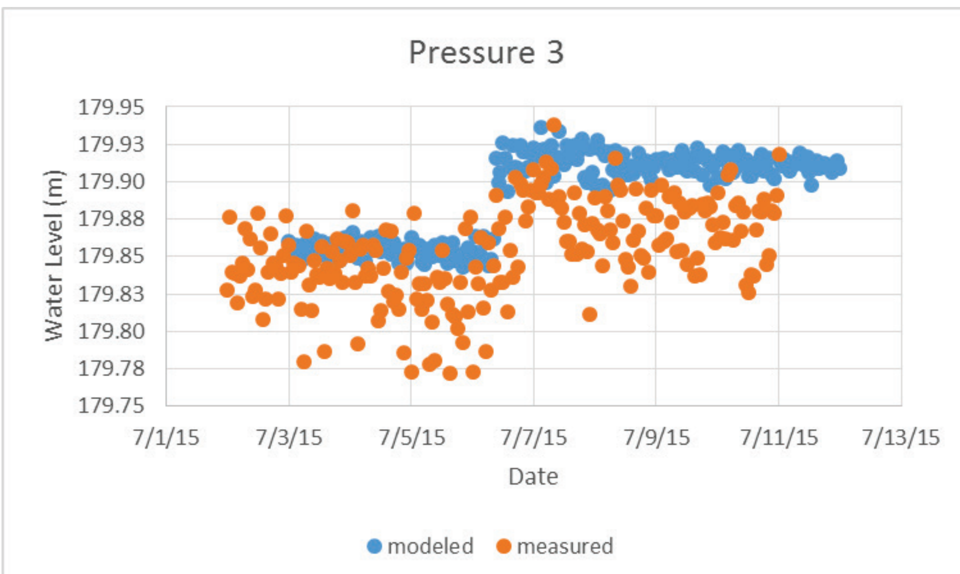


Figure A- 7. Calibration plot for Pressure Sensor 4 USACE.

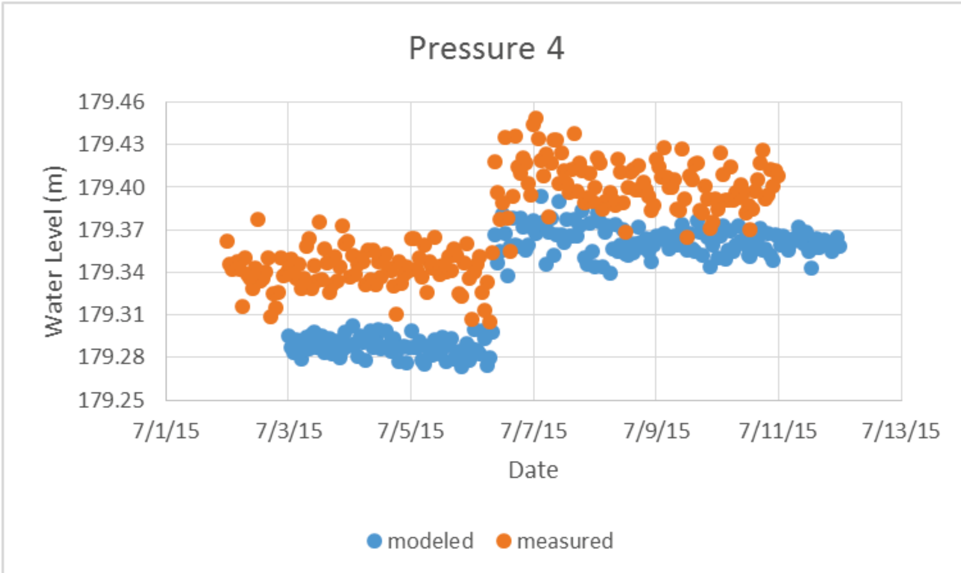


Figure A- 8. Calibration plot for Pressure Sensor 5 USACE.

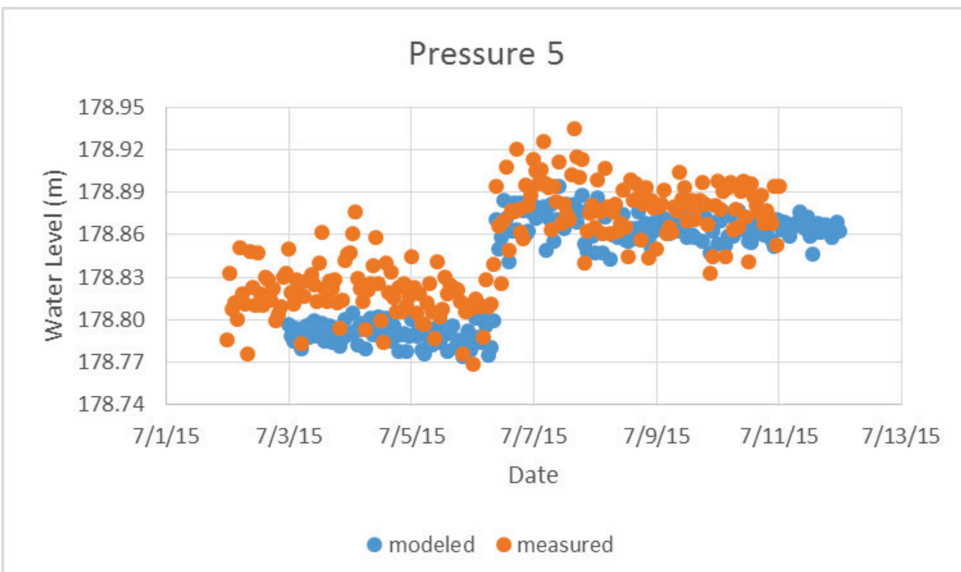


Figure A- 9. Calibration plot for Pressure Sensor 6 USACE.

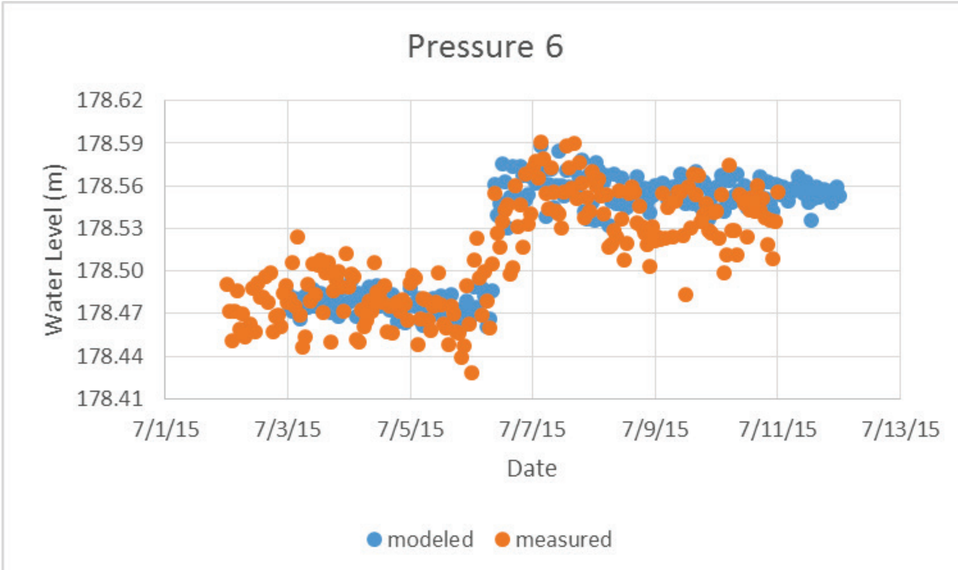


Figure A- 10. Calibration plot for Lower Sault CHS.

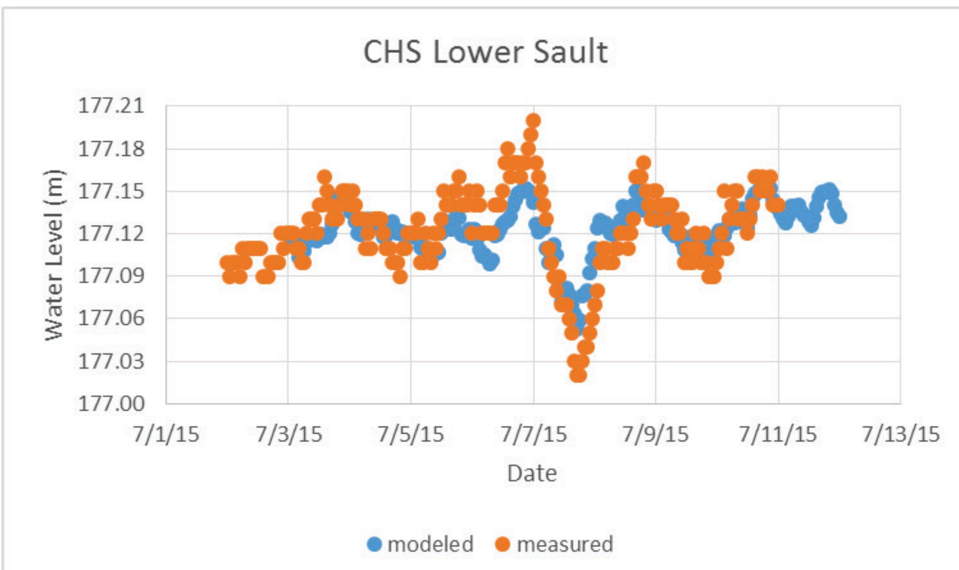


Figure A- 11. Calibration plot for Lower Radar USACE.

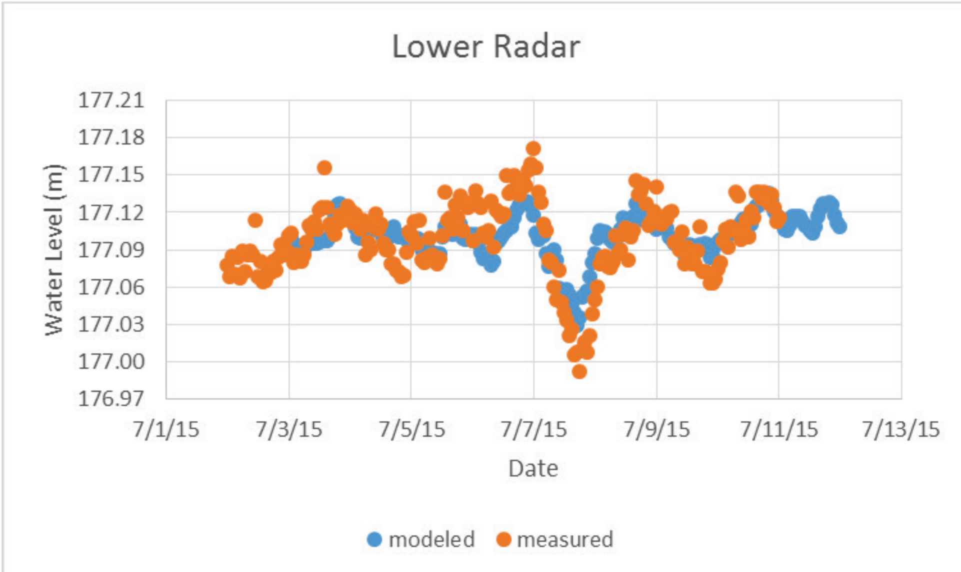


Figure A- 12. Calibration plot for U.S. Slip NOAA.

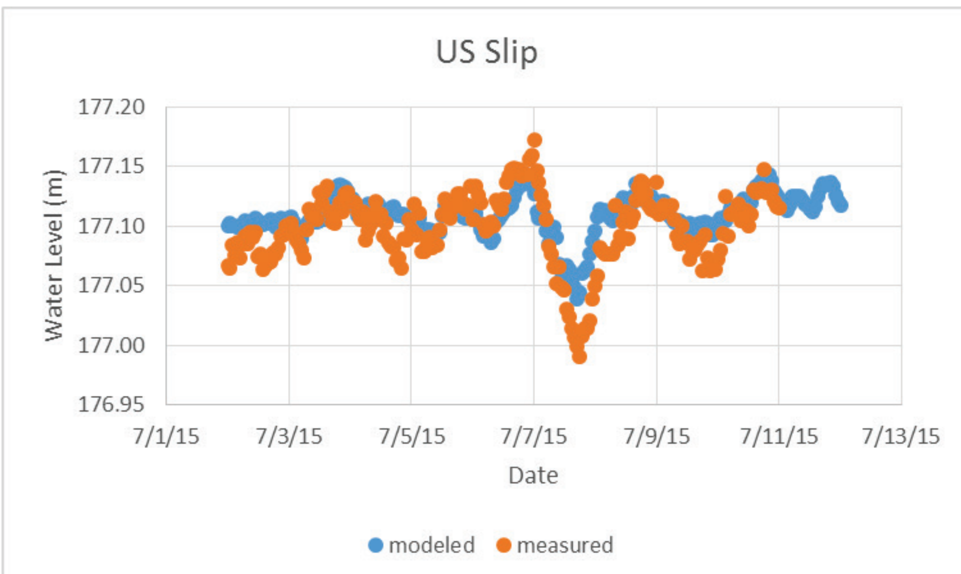


Figure A- 13. Calibration plot for Little Rapids.

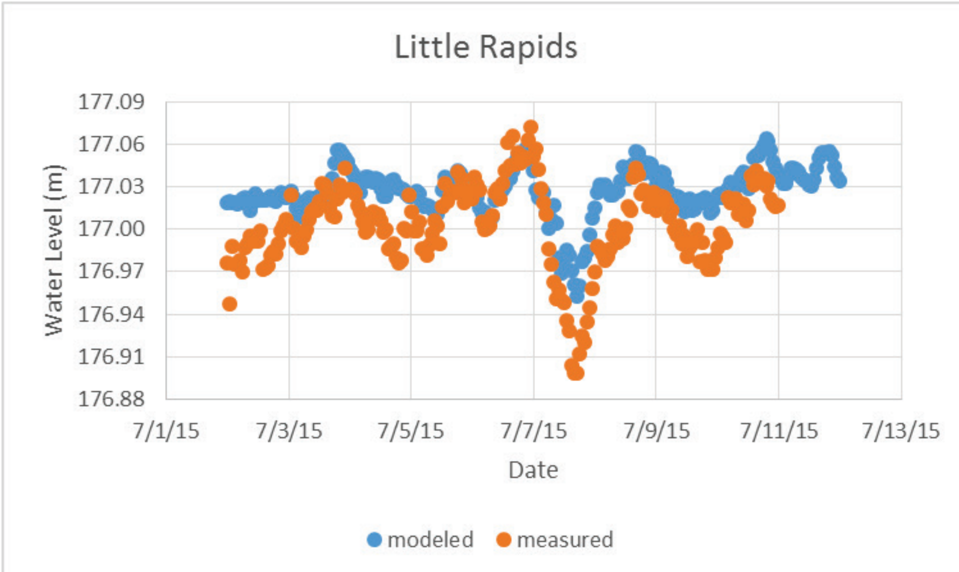


Figure A- 14. Calibration plot for Frechette NOAA.

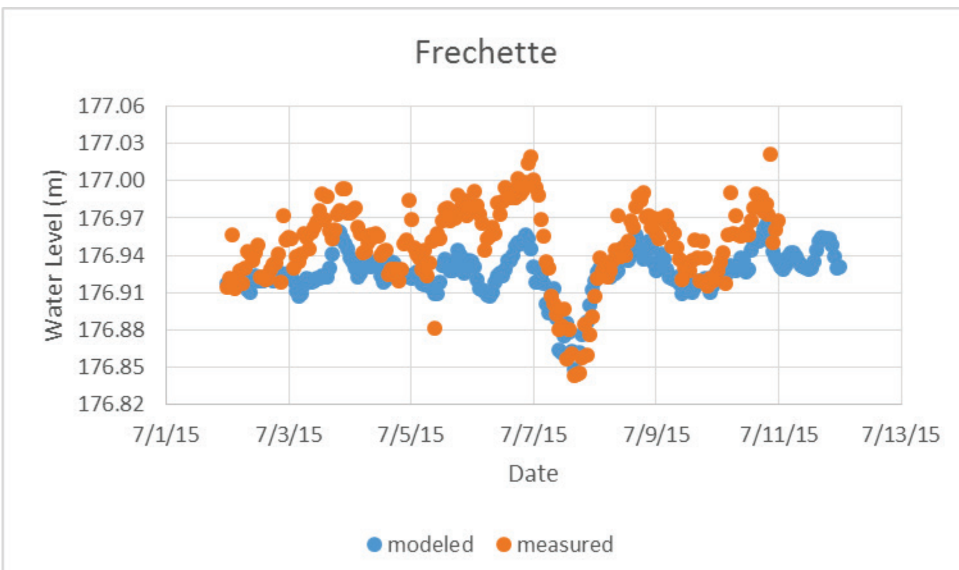


Figure A- 15. Calibration plot for West Neebish NOAA.

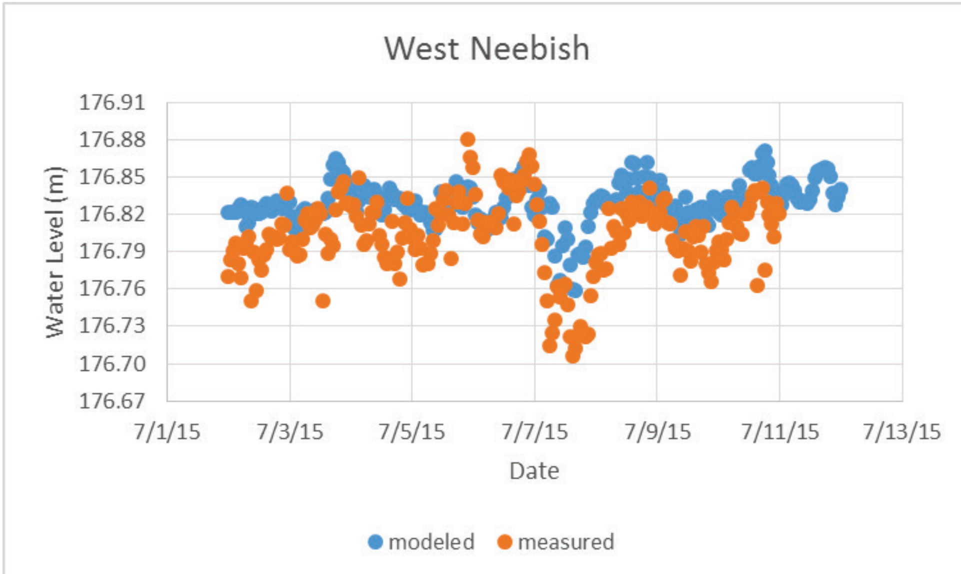


Figure A- 16. Calibration plot for Slab Dock USACE

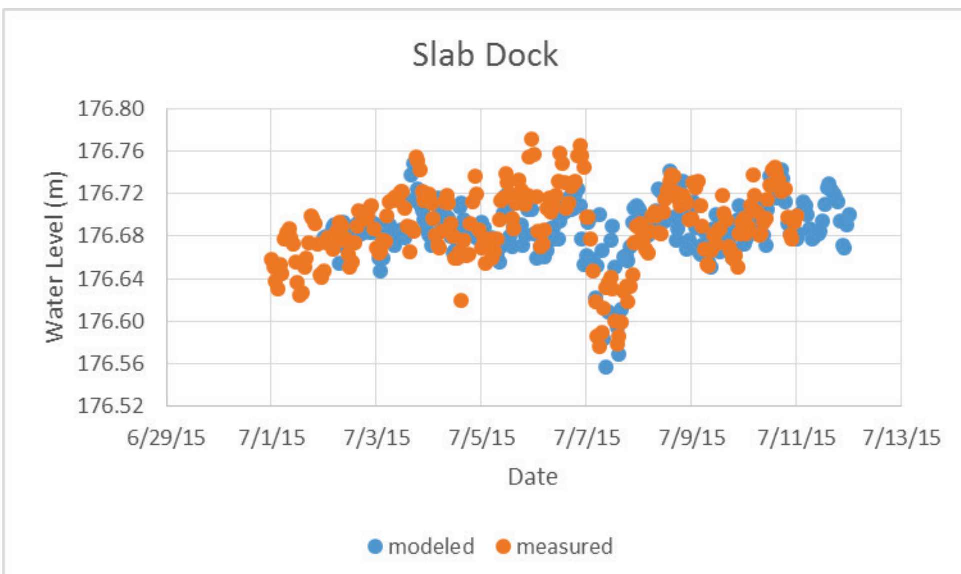


Figure A- 17. Calibration plot for Rock Cut NOAA.

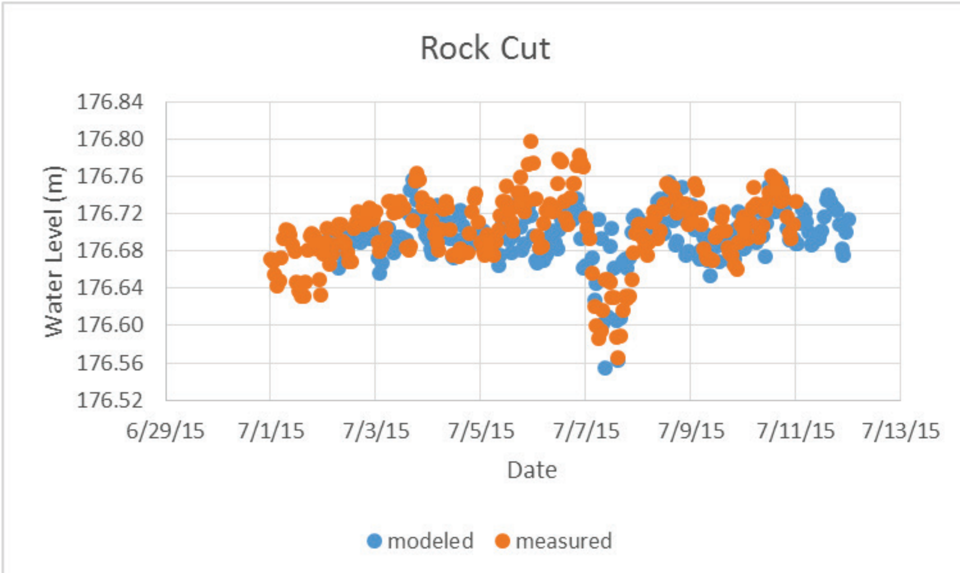


Figure A- 18. Calibration plot for Detour Village NOAA.

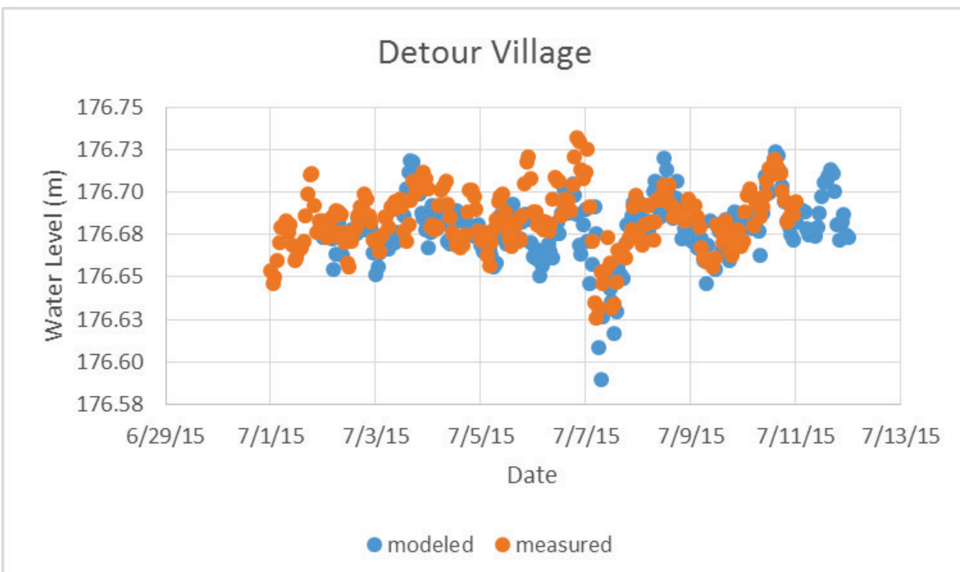
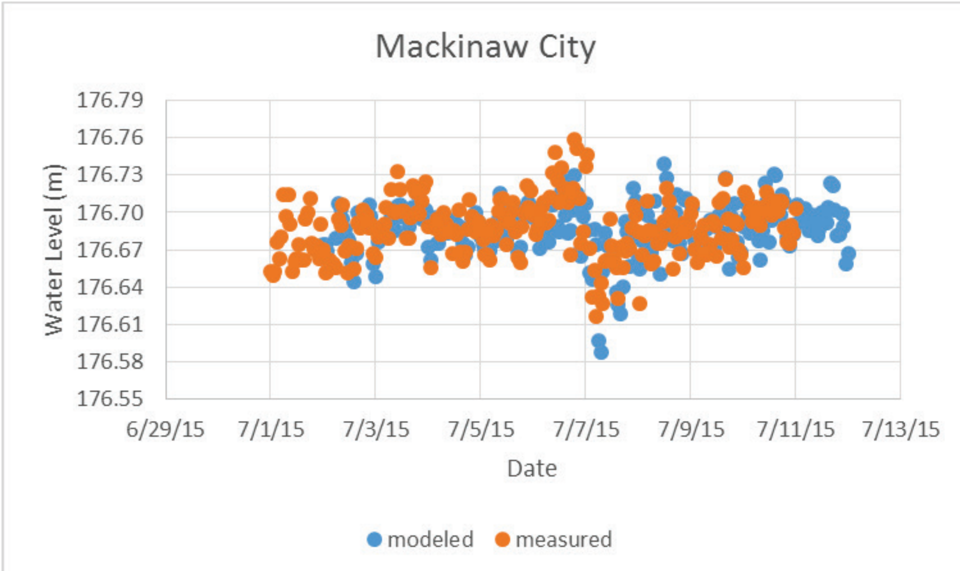


Figure A- 19. Calibration plot for Mackinaw City NOAA.



Validation Graphs

Figure A- 20. Validation plot for Point Iroquois NOAA.

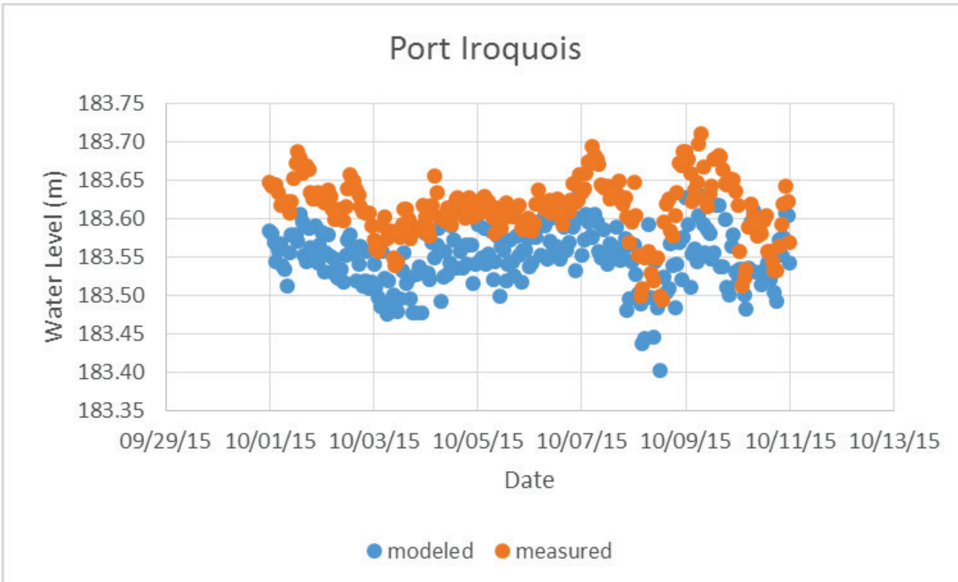


Figure A- 21. Calibration plot for SW Pier NOAA.

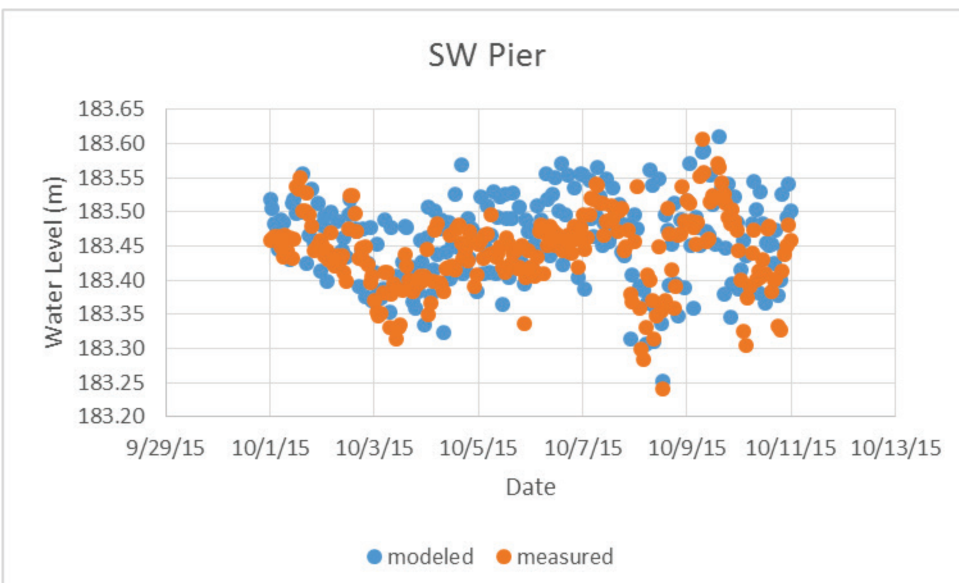


Figure A- 21. Calibration plot for Upper Sault CHS.

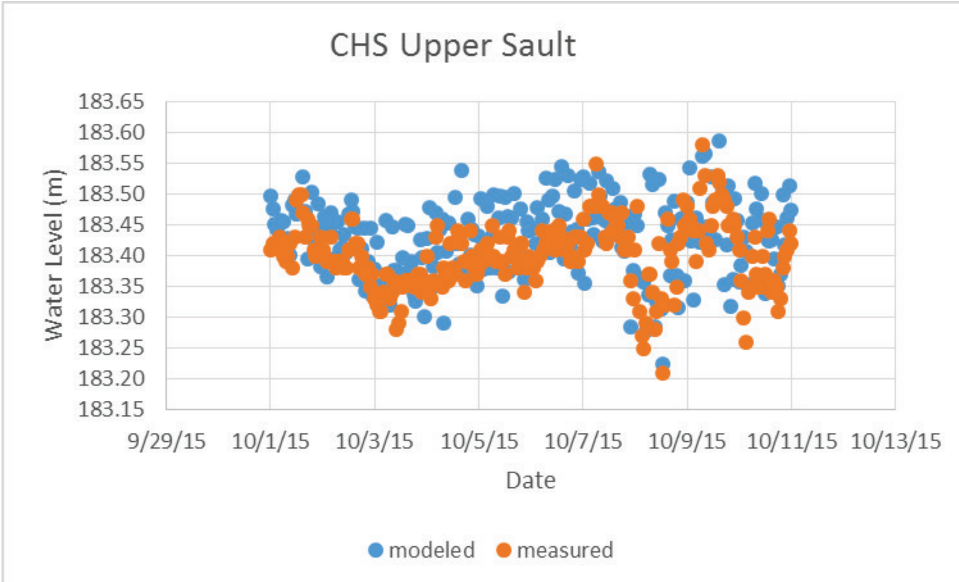


Figure A- 22. Calibration plot for Upper Radar USACE.

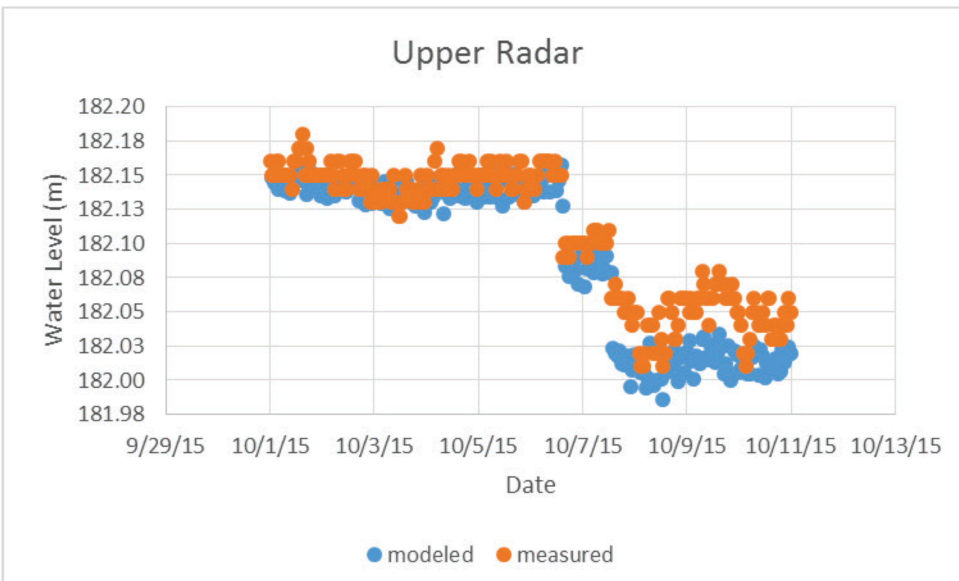


Figure A- 24. Calibration plot for Pressure Sensor 2 USACE.

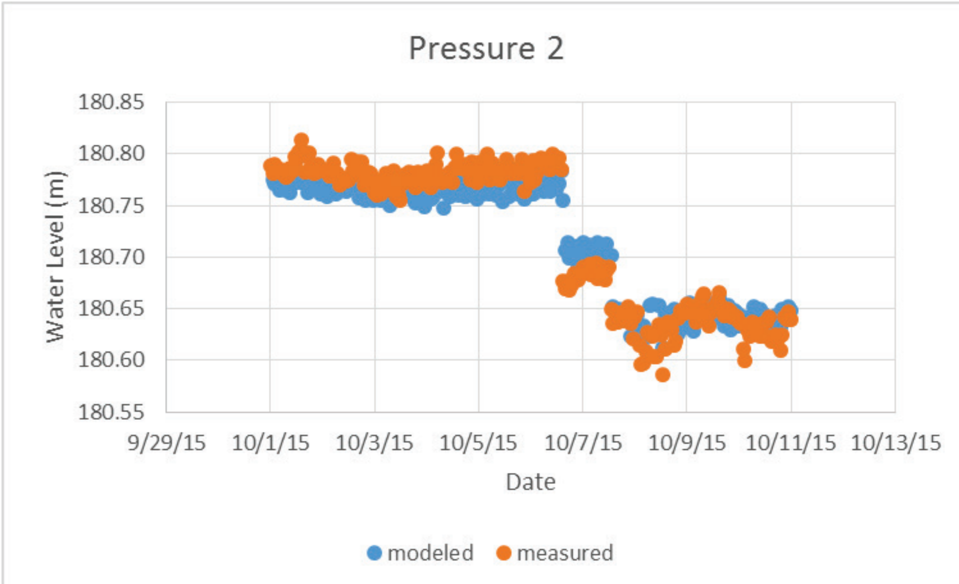


Figure A- 23. Calibration plot for Pressure Sensor 3 USACE.

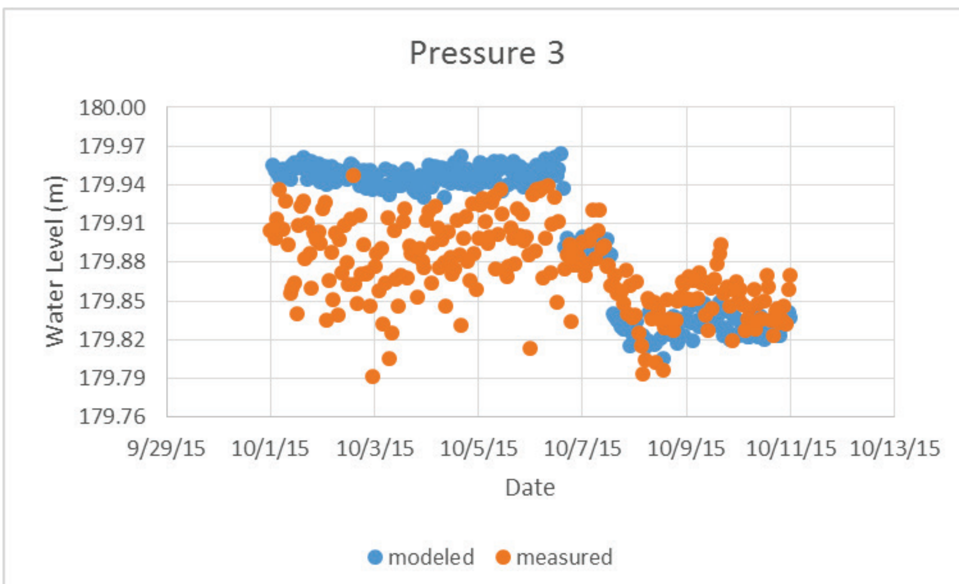


Figure A- 24. Calibration plot for Pressure Sensor 4 USACE.

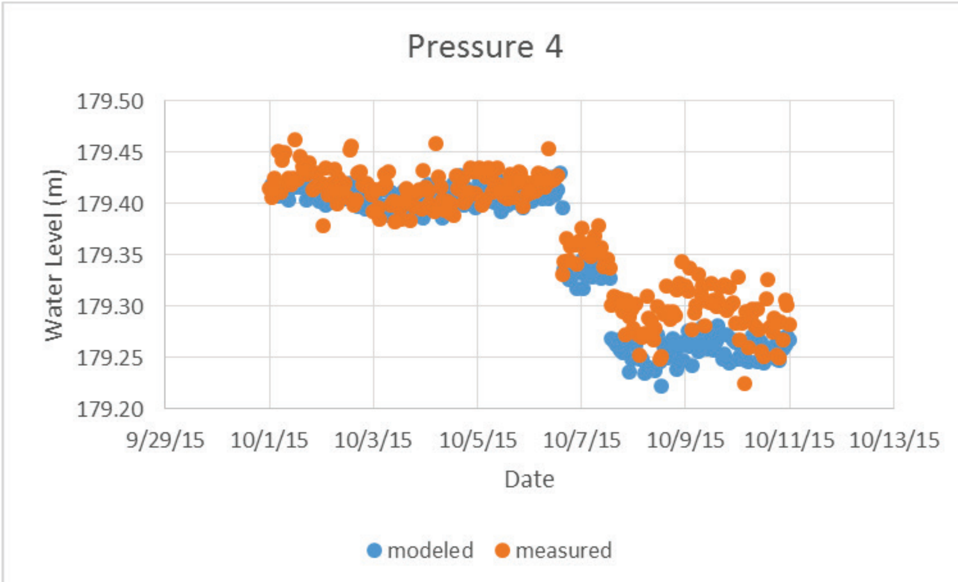


Figure A- 27. Calibration plot for Pressure Sensor 5 USACE.

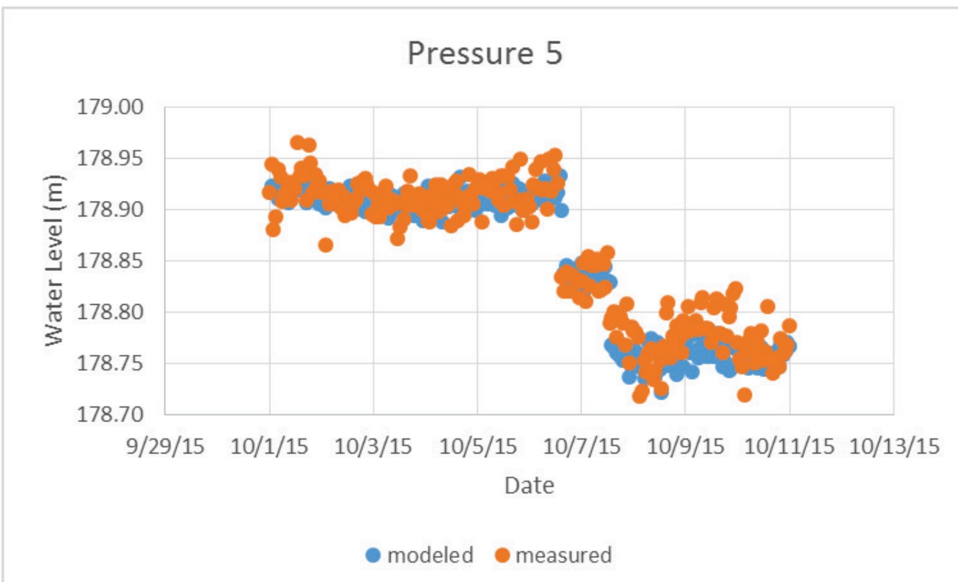


Figure A- 25. Calibration plot for Pressure Sensor 6 USACE.

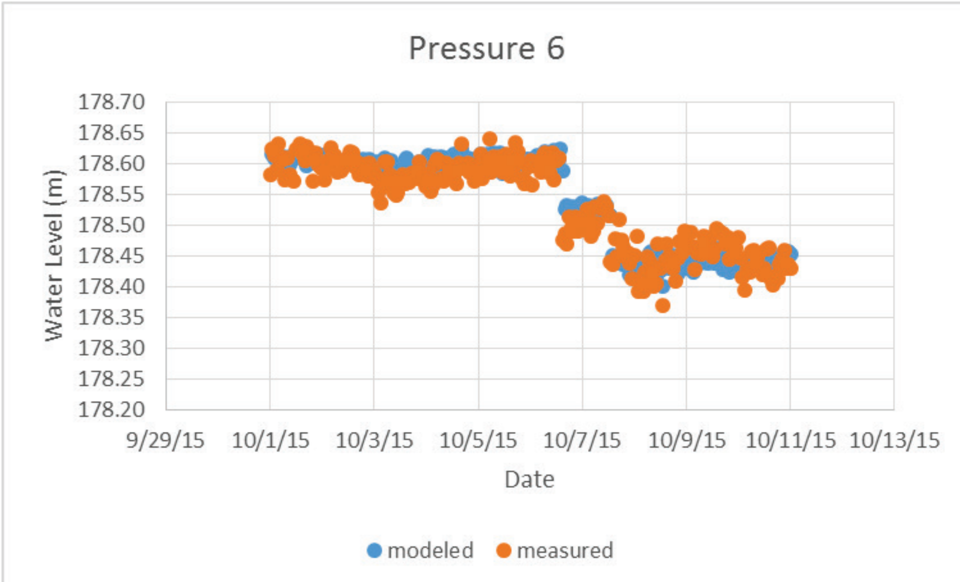


Figure A- 26. Calibration plot for Lower Sault CHS.

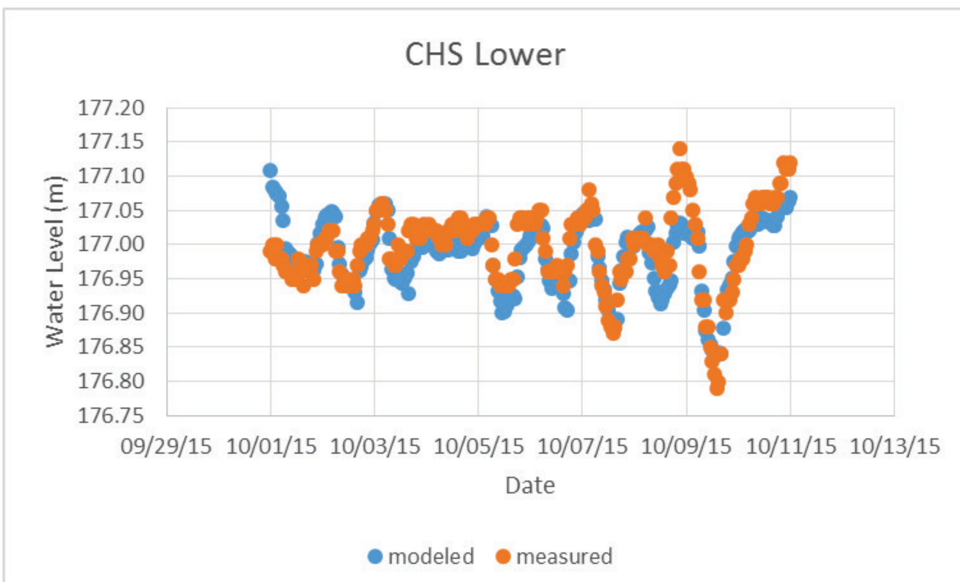


Figure A- 27. Calibration plot for Lower Radar USACE.

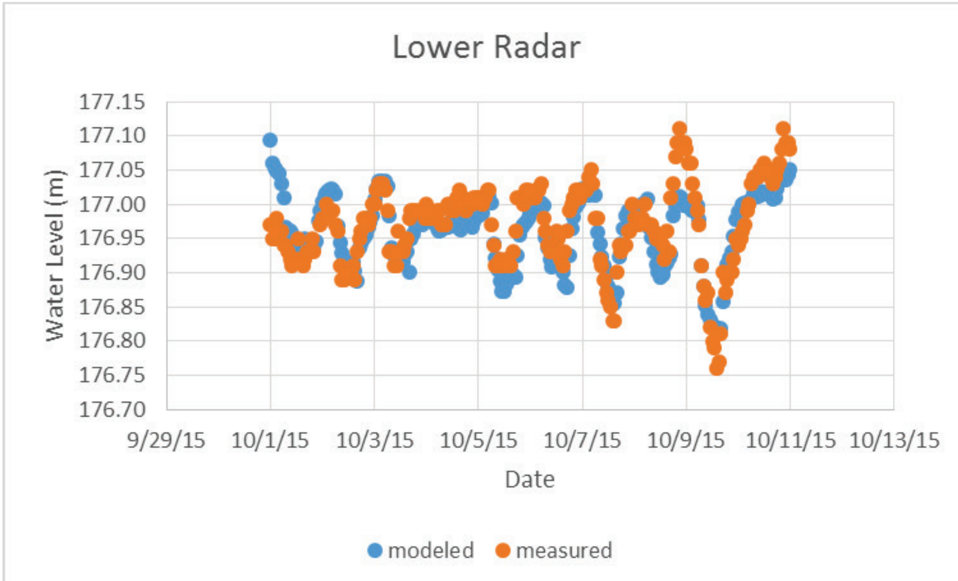


Figure A- 28. Calibration plot for U.S. Slip NOAA.

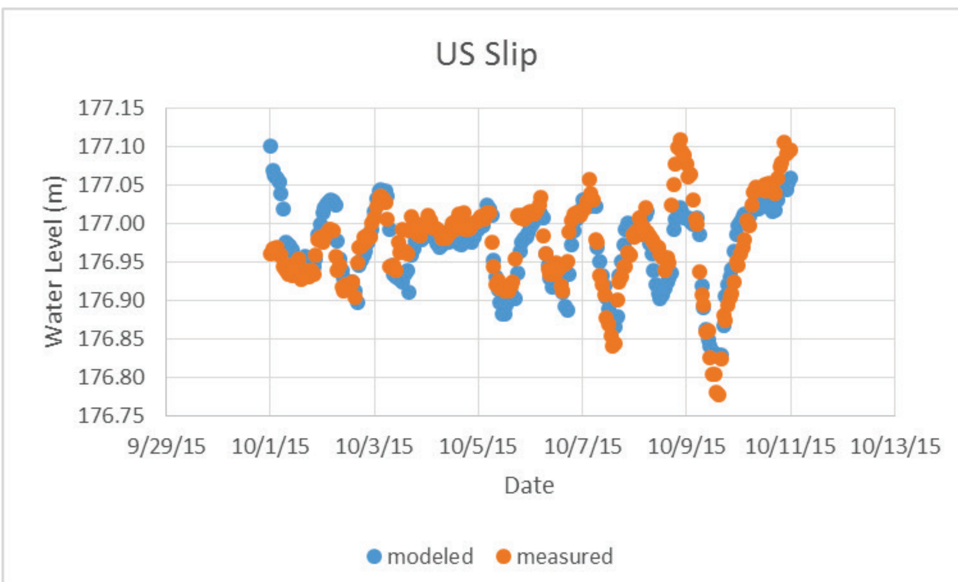


Figure A- 29. Calibration plot for Little Rapids NOAA.

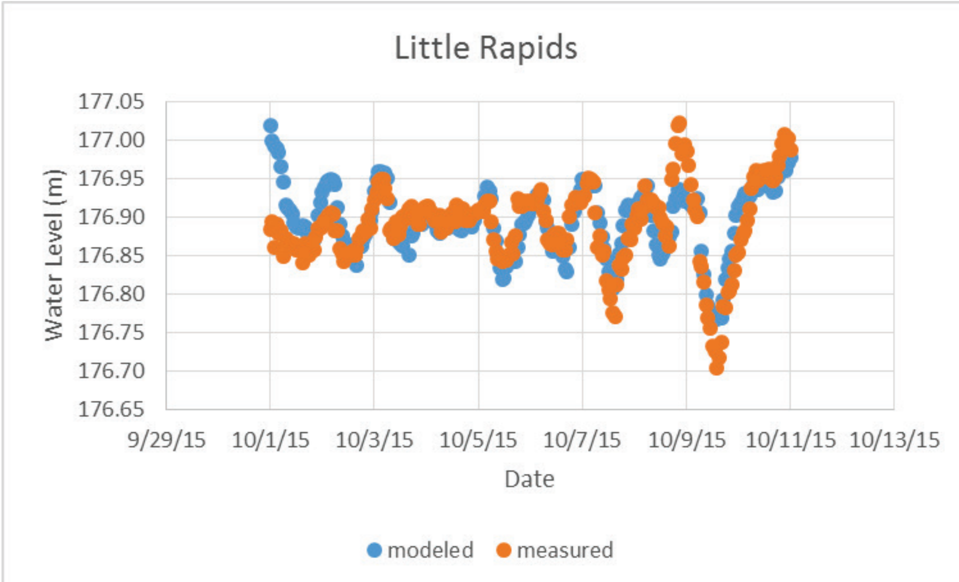


Figure A- 30. Calibration plot for Frechette NOAA.

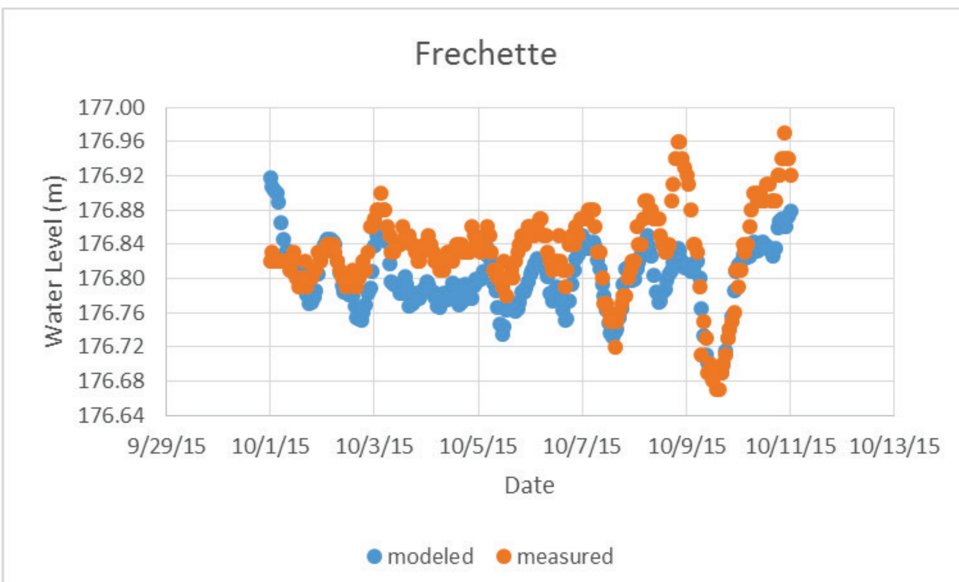


Figure A- 31. Calibration plot for West Neebish NOAA.

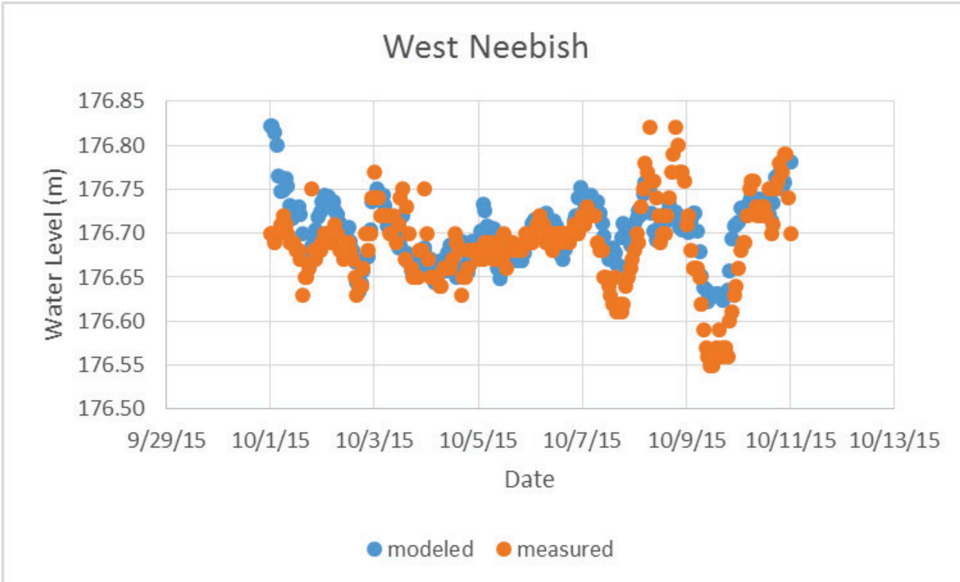


Figure A- 32. Calibration plot for Slab Dock USACE.

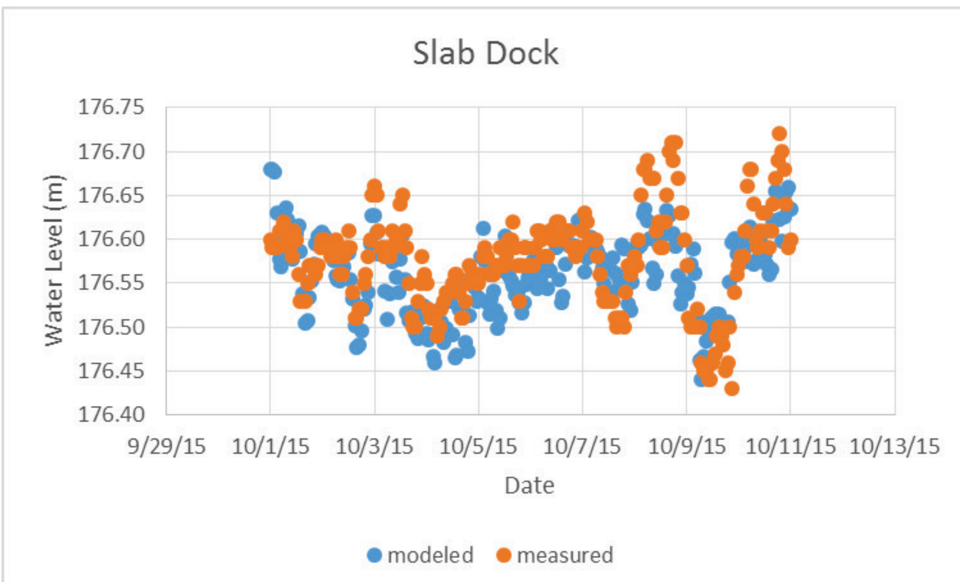


Figure A- 33. Calibration plot for Rock Cut NOAA.

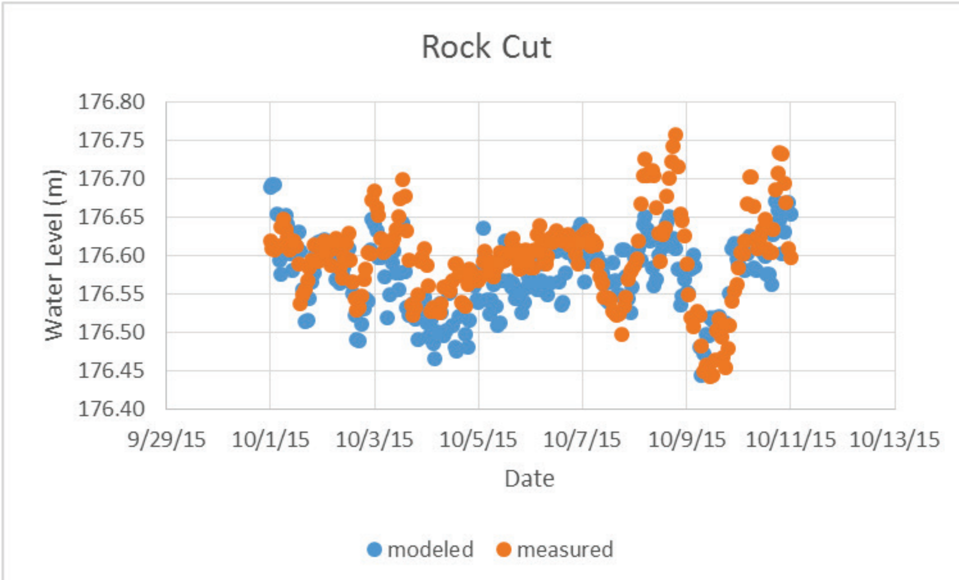


Figure A- 37. Calibration plot for Detour Village NOAA.

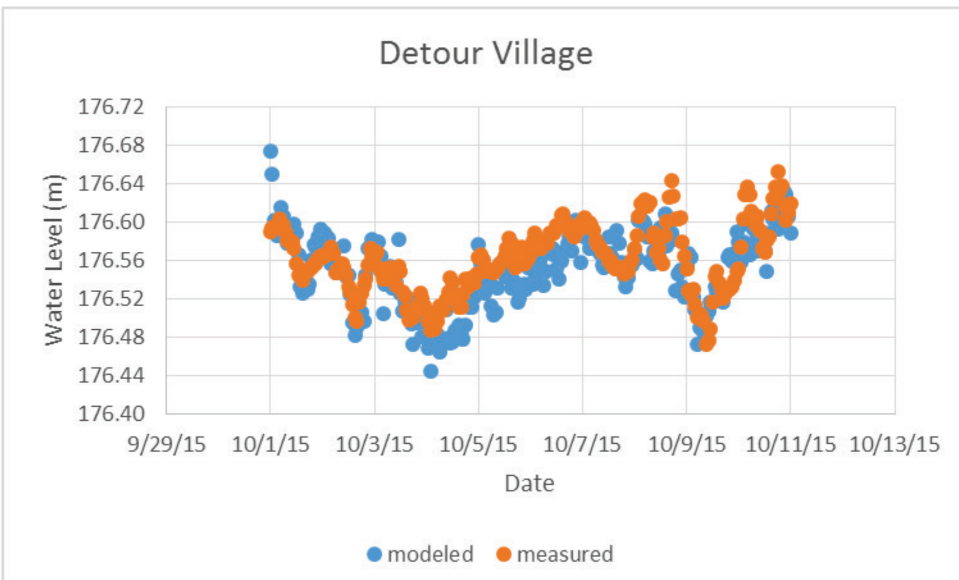
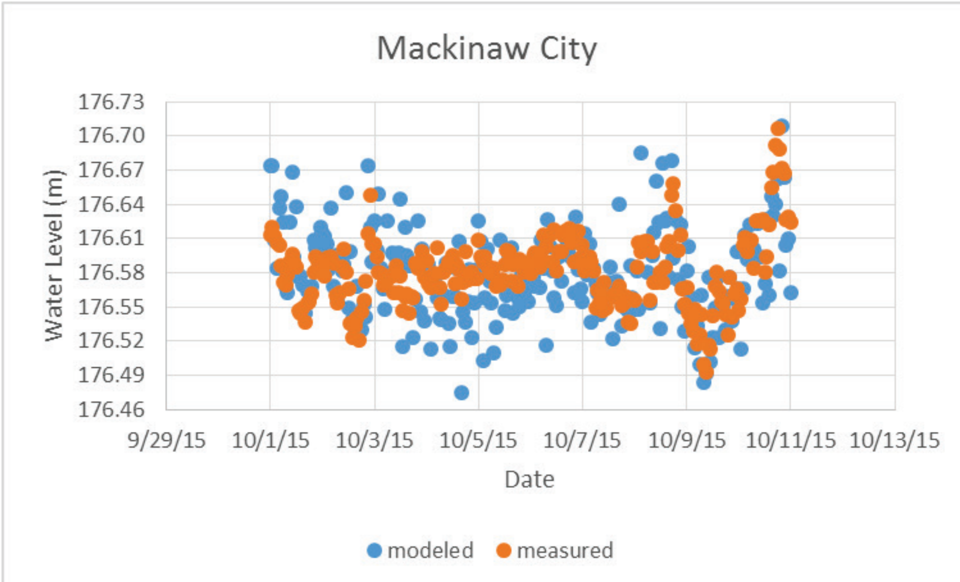


Figure A- 34. Calibration plot for Mackinaw City NOAA.



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14. ABSTRACT

The St. Marys rapids at the outlet of Lake Superior is a vital habitat for a wide range of aquatic species. The regulation of the outflows from Lake Superior by Compensating Works (i.e., a series of control structures) can lead to rapid changes in hydraulic characteristics, potentially creating adverse conditions for downstream biota. To accomplish more naturally varying flows, the U.S. Army Corps of Engineers (USACE) Detroit District (LRE) is constructing four remotely operated gates on the United States (U.S.) side of the Compensating Works. The gates will be capable of being opened slowly (over many hours) until a desired discharge is achieved. A two-dimensional (2-D) model was developed to evaluate multiple scenarios and analyze the total area available for fish spawning based on depth and velocity associated with a particular gate setting. The model also addressed the recommendation for water level rates of change associated with gate changes, suggesting that water level rates of change be held to less than ten centimeters (cm)/hour to avoid stranding juvenile fish. This is consistent with Engineering With Nature® (EWN) principles of maximizing habitat value of the rapids while maintaining water regulation objectives.

15. SUBJECT TERMS

Saint Marys River (Mich. and Ont.)
Rivers--Regulation
Hydraulic structures
Hydraulic models
Water levels
Fish habitat improvement

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