Prepared in cooperation with the National Park Service, the St. Croix National Scenic Riverway, and the Denver Service Center

Hydrographic and Benthic Mapping—St. Croix National Scenic Riverway—Osceola Landing

Open-File Report 2020–1149

U.S. Department of the Interior
U.S. Geological Survey

Front and back covers. Photographs by Jayme Strange, U.S. Geological Survey, taken at the St. Croix River near the town of Osceola, Wisconsin.

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
meter (m)	1.094	yard (yd)
	Area	
square meter (m2)	0.0002471	acre
hectare (ha)	2.471	acre

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32.$$

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Abbreviations

ADCP	Acoustic Doppler Current Profiler
DEM	digital elevation model
GIS	geographic information system
GNSS/INS	global navigation satellite system/inertial navigation system
lidar	light detection and ranging
MBES	multibeam echosounder
NPS	National Park Service
SMBA	stationary moving-bed assessment
Sonar	sound navigation and ranging
SVP	sound velocity profiler
TPU	total propagated uncertainty
USGS	U.S. Geological Survey

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Abstract

High-resolution topographic and bathymetric mapping can assist in the analysis of river habitat. The National Park Service has been planning to relocate a boat ramp along the St. Croix River in Minnesota, across the river from the town of Osceola, Wisconsin, to improve visitor safety, improve operations for commercial use, enhance the overall visitor experience, and eliminate deferred maintenance at the landing. This landing grants access to the St. Croix River, which is a part of the National Park Service St. Croix National Scenic Riverway. Hydrographic and topographic surveys were needed to determine where the new location should be. The objective for these surveys was to provide baseline information in order to assess the direct effects of the landing relocation on physical habitat in areas adjacent to Osceola, Wisconsin. The study area for these surveys was about 18.5 hectares and located directly off the existing landing. Although the existing boat launch is referred to as the Osceola landing, it is located on the Minnesota side of the river and is the busiest National Park Service landing on the St. Croix River (National Park Service St. Croix National Scenic Riverway, 2020). This report documents methods and results of aquatic benthic mapping in a small area of the St. Croix River.

The hydroacoustic and topographic surveys were collected from October 16–17, 2019. The hydrographic surveys consisted of multibeam and sidescan sound navigation and ranging (sonars). The topographic shoreline survey consisted of light detection and ranging (lidar) captured by boat adjacent to riverbanks. Additionally, an acoustic Doppler current profiler was used to measure flow velocities. The water level was higher than normal, and therefore had faster flow during the hydroacoustic surveys. Multibeam, lidar, and sidescan surveys occurred the first day, and the velocity mapping and ground truthing was conducted the second day. Multibeam and lidar provided derivative datasets that included bathymetry and a topobathy with a spatial resolution of 1 foot. From these data, additional data could be measured including slope and terrain ruggedness. Sidescan (acoustic reflectance measures) provided imagery that was used to help with interpretation of the river bottom.

Outcomes from these combined datasets were substrate and bedform maps. Much of the area was covered in sand ripples or small dunes. A small area running adjacent to the deeper valley or cut down the river consisted of harder substrates, such as cobble and gravel. Large woody debris piles were found throughout the study area. Multiple stationary moving-bed tests were completed, and no corrections were recommended for the conditions occurring during survey. Mussel presence was noted in some of the underwater videos. The physical parameters of depth, flow, bedforms, and substrate derived from the datasets provided baseline measures for a benthic habitat map. Further analysis of benthic habitat might be possible with additional biological and chemical data.

Purpose and Scope

The National Park Service (NPS) has been planning the relocation of the boat ramp near the town of Osceola, Wisconsin, within the St. Croix National Scenic Riverway. Before reconstruction, the NPS wanted to complete hydrographic and topographic surveys and benthic mapping of the St. Croix River adjacent to the Osceola boat ramp in Minnesota to mitigate potential impacts to mussels or benthic habitat. Understanding what constitutes mussel habitat is important for identifying suitable habitat for the conservation and restoration of freshwater mussels. Currently, the landing is located directly south of the Osceola Road/State Highway 243 Bridge. Existing conditions of substrate and distribution and the presence of underwater structures were unknown before these surveys.

River habitat refers to the environment in which organisms live, and the environment consists of physical and chemical parameters. Physical habitat parameters are typically defined in terms of water depth, waterflow velocity, and substrate composition (Gaeuman and Jacobson, 2005). Chemical parameters typically consist of temperature, dissolved oxygen, and pH. However, the combination of one or both parameters cannot provide a complete habitat description because river habitat is a number of smaller connected habitats, each relying on the other to function properly. Therefore, habitat analyses typically combine hydroacoustic measurements of physical variables with assessments of biological and water quality variables to map and model habitat suitability. This study focuses on the physical habitat of the St. Croix River near the Osceola boat ramp (specifically the geomorphic character of the riverbed), the water velocity, and the character and composition of surface substrates. A complete habitat analysis that includes biological and chemical parameters was beyond the scope of the study.

Benthic mapping and benthic habitat mapping are often used synonymously to describe seafloor mapping for the purpose of benthic habitat identification, but are actually different in the types of physical and biotic parameters each provide. This project can only provide benthic mapping data, the identification of geologic features (surficial sediment), and geomorphology (bedforms) and cannot provide the ecological habitat of chemical or organismal parameters. Mapping and geospatial analysis of benthic environments in turbid rivers are becoming more attainable due to advances in technology, cost reductions, and navigation of shallow water systems. The complex relationships that exist among physical benthic variables require advanced, integrated analysis techniques to enable scientists and others to visualize patterns and allow inferences to be made about benthic processes. Research in benthic environments relies heavily on remote sensing techniques to collect data because these environments are not readily viewed by the eye. Sound navigation and ranging (sonar), also known as hydroacoustics, is a remote sensing method that uses sound waves to detect objects in the water column and on the riverbed. The reflection of sound waves from the riverbed can be used to measure water depth, as an indication of texture and hardness, and can be used to assess physical properties of habitat such as water depth, flow, geomorphology, and substrate type.

Several hydroacoustic instruments were used to map the bathymetry, water velocity, and substrate characteristics in the study area. A multibeam echosounder (MBES) was used to produce high-resolution bathymetry and backscatter data that were used to obtain information about the sediment composition and physical properties of the riverbed. Multiple types of information were derived from multibeam data, including elevation or water depth, slope, backscatter, and terrain ruggedness measures. Backscatter is the measure of acoustic reflectivity (in other words measure of energy obtained from the echo intensity), which can be related directly to the bed type (for example sand or cobble) (Lurton and Larmarch, 2015). Sidescan sonar was collected because it provides a picture of the physical bed characteristics based on differences in acoustic reflectance signature (Blondel and Murton 1997, Fish and Carr 2001). Sidescan sonar is ideal for turbid waters like the St. Croix River, because water characteristics such as suspended sediment and light penetration do not affect the acoustic sensor (Andrews, 2003), and sidescan imagery is used to help interpret substrate type. An acoustic Doppler current profiler (ADCP) was used to measure river current velocities, which are a desired component needed to model physical (depth) and hydraulic variables (flow) in relation to native mussel habitat. ADCPs are designed to simultaneously measure water velocities at multiple depths through most of the water column (Gaeuman and Jacobson, 2005), and the derived velocity measurements are especially useful for habitat mapping. ADCPs can also detect when a moving-bed condition exists. Bed movement can vary substantially in a river cross-section with different flows. These measurements are important because they are indicators of substrate stability. Light detection and ranging (lidar) was collected simultaneously with bathymetry data to provide topographic data for the shorelines in order to relate the riverbank to the adjacent uplands and floodplain functions.

The development of three-dimensional (3D) models and 2D images using hydroacoustic and lidar data in a digital environment facilitates interpretation of benthic habitat characteristics. The multibeam derivatives from the St. Croix River were combined with the lidar, ADCP, and ground-truthing data in a geographic information system (GIS) to enable visualization and interpretation. Further modeling efforts with additional biological and chemical data could result in a full habitat suitability analysis. The ability to characterize preferred habitat variables could lead to a better understanding of the complex benthic habitat corridors where freshwater mussels reside and can provide resource managers with more information to accurately assess environmental variables that influence mussel distributions.

Methods

The goal of this project was to provide high-resolution topographic and bathymetric datasets to the NPS. A suite of hydroacoustic surveys were completed October 16–17, 2019, by the U.S. Geological Survey (USGS) within the approved Osceola survey area (fig. 1) to develop requested datasets including high-resolution multibeam and backscatter, sidescan imagery, river current velocities (in other words ADCP), and underwater videos (to be used as ground truthing). The project was water-level and weather dependent. Higher than normal water levels were desired to capture the shallower areas within the survey area in order to cover as much of the survey area closer to shore. Detailed maps of the river bedform and surficial bottom-substrate were developed for the NPS using a combination of acoustic data obtained during the hydroacoustic surveys of the Osceola study area. The riverbed geomorphology refers to the physical features of the bed surface created by hydraulic forces of the river, including bedforms like ripples and dunes. Surficial bottom-substrate is the bottom type, which can be composed of exposed bedrock, gravel, sand, mud, vegetation, or woody debris that is found at the surface of the bed floor.

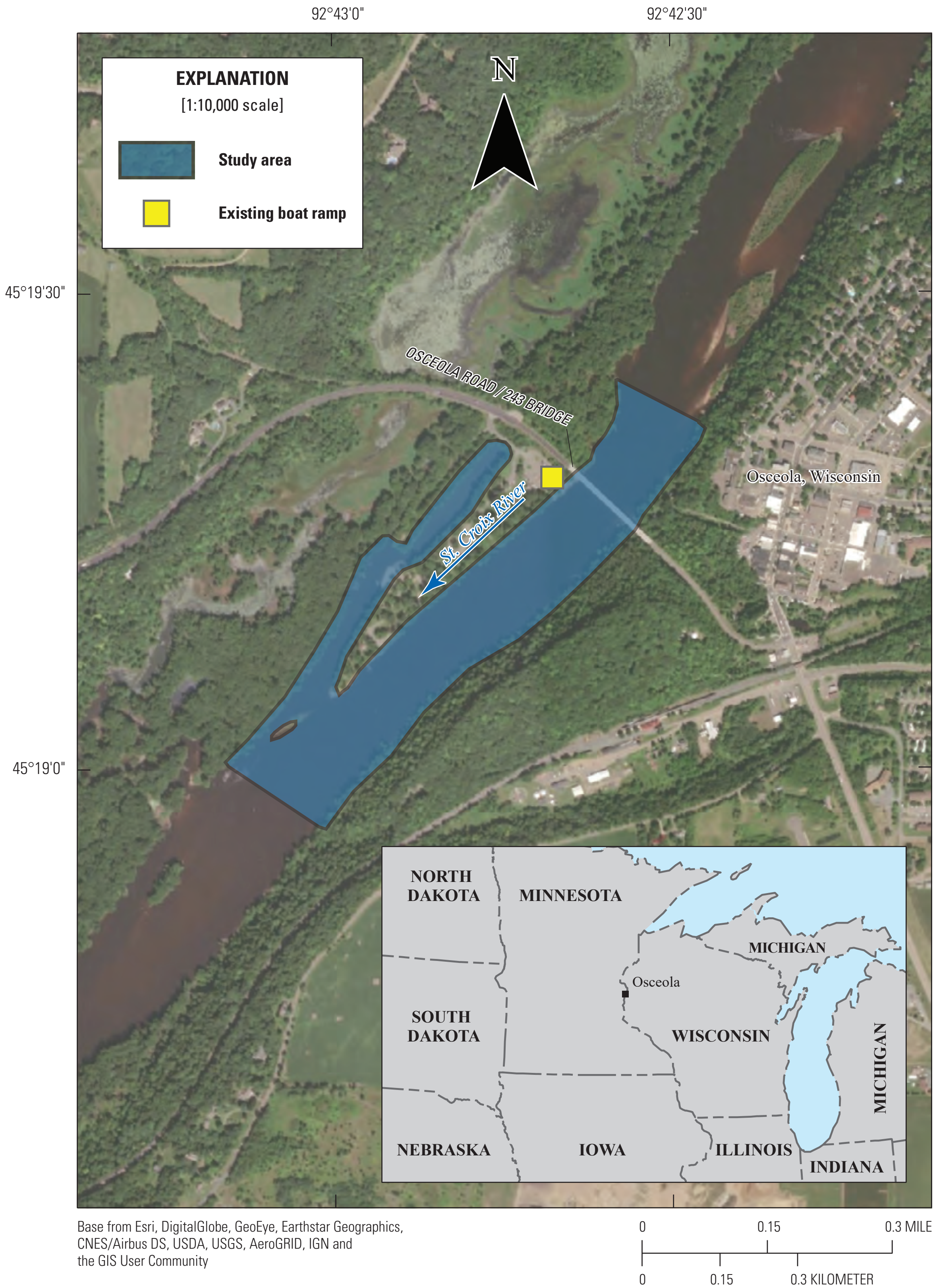


Figure 1. Hydrographic and topographic survey area (approximately 19 hectares) of the St. Croix River at the landing adjacent to Osceola, Wisconsin.

Data Acquisition

Bathymetric, topographic, and sidescan surveys were completed on October 16, 2019. These surveys included multibeam swath with backscatter, lidar, and sidescan for approximately 17.5 hectares adjacent to the Osceola landing. Survey conditions recorded include air temperature of approximately 1.7 degrees Celsius; calm, north-west winds around 5 miles per hour; and mostly cloudy skies. The water temperature of the St. Croix River was 7.2 degrees Celsius at the start of the survey.

Initially, a sidescan survey was completed using a Humminbird Helix 10 side imaging/down imaging sonar to determine whether underwater objects (in other words woody debris) were present, and therefore, hazardous to the MBES. For this initial sidescan survey, data were recorded at 800 kilohertz. This imagery is available at Hanson and Strange (2020). The sidescan data are high-resolution, but do not have the spatial accuracy of a MBES; it was used for navigation purposes during the survey, and as ancillary data during interpretation.

The USGS survey boat is an 18-foot (ft) flat-bottom Waterman that was used to complete all hydroacoustic and ground-truthing surveys. Survey lines were spaced approximately 15 meters apart in a shore-parallel orientation (fig. 2). The acquisition equipment consists of a Norbit integrated wideband multibeam system compact (iWBMSc) sonar, a tightly integrated bathymetric system, complete with a NovAtel Marine Synchronized Position Attitude Navigation Global Navigation Satellite System/Inertial Navigation System (GNSS/INS) system. The MBES is optimized to transmit a frequency modulated sound wave centered at 400 kilohertz (Norbit, 2018). From the returning signal, 512 beams are formed with a 160° fan-shaped swath by utilizing the integrated sound speed probe (Norbit, 2018). The swath can be electronically rotated to either side of the boat nadir, enabling data to be captured along sloping banks up to a depth just below the water surface. The curved receiver array of the Norbit system allows for narrow beams with a wide swath, reduced beam spreading, and corrections for surface sound speed variations on-the-fly (Norbit, 2018). All processing and export of time-stamped bottom detection occurs within the sonar head during data collection. The INS is a NovAtel MarineSPAN system that provides position in 3D space and measures the heave, pitch, roll, and heading of the vessel to accurately position the data received by the MBES (NovAtel, 2018).

Before the bathymetric survey, a Sound Velocity Profiler (SVP) was cast to measure the speed of sound throughout the water column. Next, a patch test was completed to correct multibeam data for roll, pitch, and yaw. The MBES collected swath data (multibeam and backscatter) at 400 kilohertz for the bathymetric survey. A swath width of 160 was used, and ranges were recorded at 75° on both sides of nadir using the hydrographic software HYPACK® and HYSWEEP® (HYPACK, Inc. 2019). Simultaneously, the MBES recorded sidescan using the following parameters: 400-kilohertz frequency, 80-kilohertz bandwidth, and a sweep time of 500 microseconds. Once the main channel of the survey area (working from thalweg to shore) had complete coverage of swath data (with overlap), the multibeam direction and swath angles were oriented to 90° to capture the shallow area along the shoreline. After a successful pass of both shorelines, the lidar unit (Velodyne VLP–16) was added to survey the terrestrial banks adjacent to the river. The lidar has 16 beams, allowing for up to 300,000 points per second to be collected along with multibeam data. Additional transects were completed along the shoreline to ensure complete coverage of the angled shoreline transects and lidar. The raw data were logged using the reference system World Geodetic System 1984—Universal Transverse Mercator zone 15 north (WGS84_UTM_Zone_15N). An additional SVP cast was measured at the end of the survey, providing two SVP measures: the first at the top and the second at the bottom of the survey.

On October 17, 2019, the remaining surveys of ADCP and underwater video ground truthing were completed. The SonTek M9 ADCP was used with a Differential Global Positioning System to capture river velocities. After initial instrument calibration, a stationary moving-bed assessment (SMBA) was completed. A total of five SMBAs were measured, and although there was very small movement detected (0.001 meters per second (m/s), no adjustments were required to calculate flow. ADCP transects were completed using methods similar to the moving boat method (Mueller and others 2013). A total of 12 cross sections were surveyed, spaced 100 meters apart (fig. 3).

Once the ADCP survey was complete, a random sampling strategy was used to sample 48 site locations using an Aqua-Vu underwater video camera. The camera was mounted to a 20-ft telescoping pole and lowered to the riverbed to record a short video of the surficial substrate present. A white board was used to record the sample number in accordance to the random site location. A Global Positioning System waypoint was also recorded using a handheld Garmin Oregon to pinpoint the location of the video recording. Due to river current, capturing the precise locations of the video recordings was difficult due to the drifting of the boat in the current.

Data Processing

Several types of data processing are required to derive datasets needed for benthic mapping. Each type of data (multibeam, backscatter, sidescan sonar, river current velocities) requires different methods to process the raw data. Different data types require individualized software and expertise to produce the suite of datasets needed for analysis.

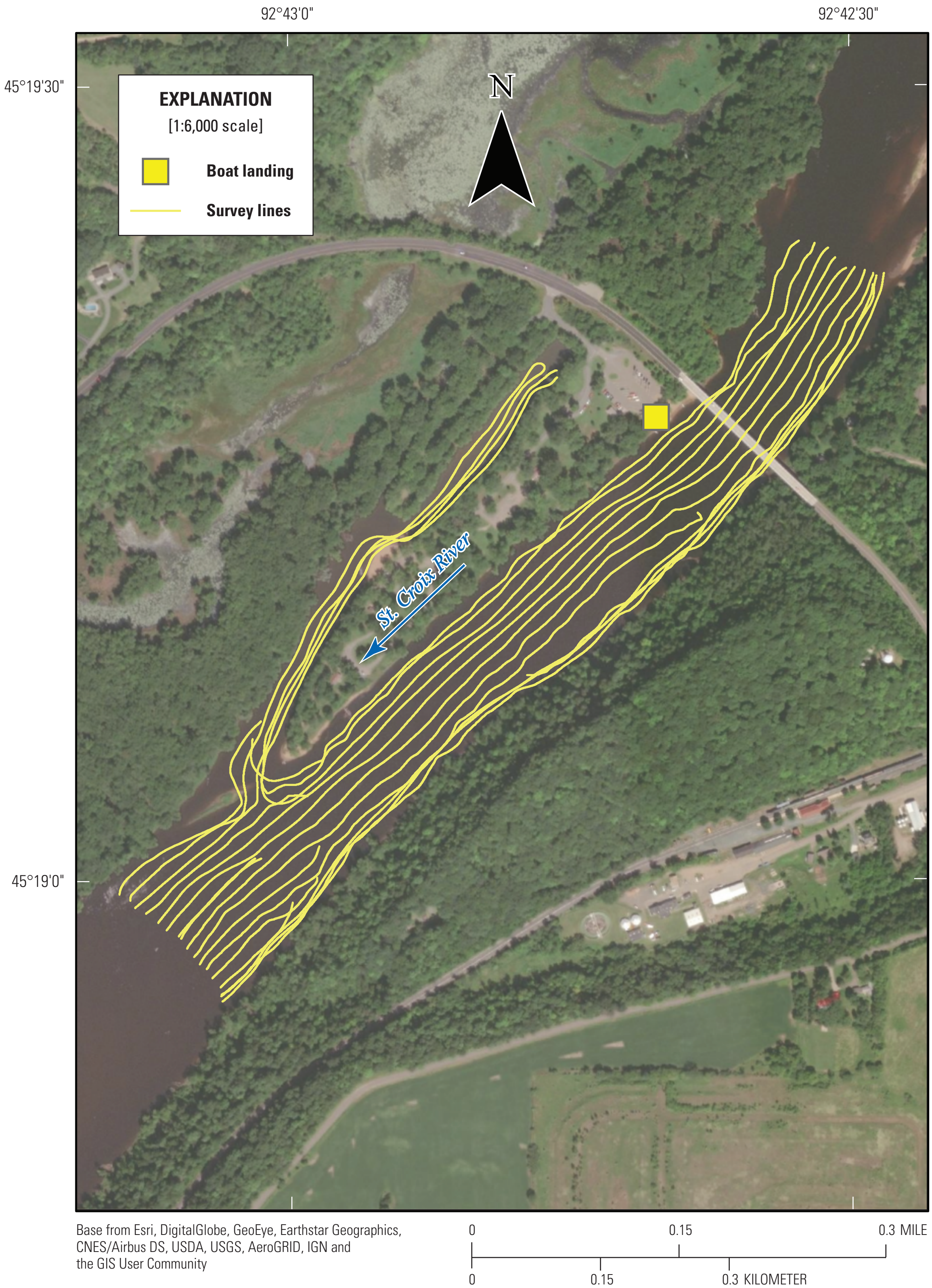


Figure 2. Track lines from the October 16, 2019, bathymetric and topographic survey on the St. Croix River near Osceola, Wisconsin.

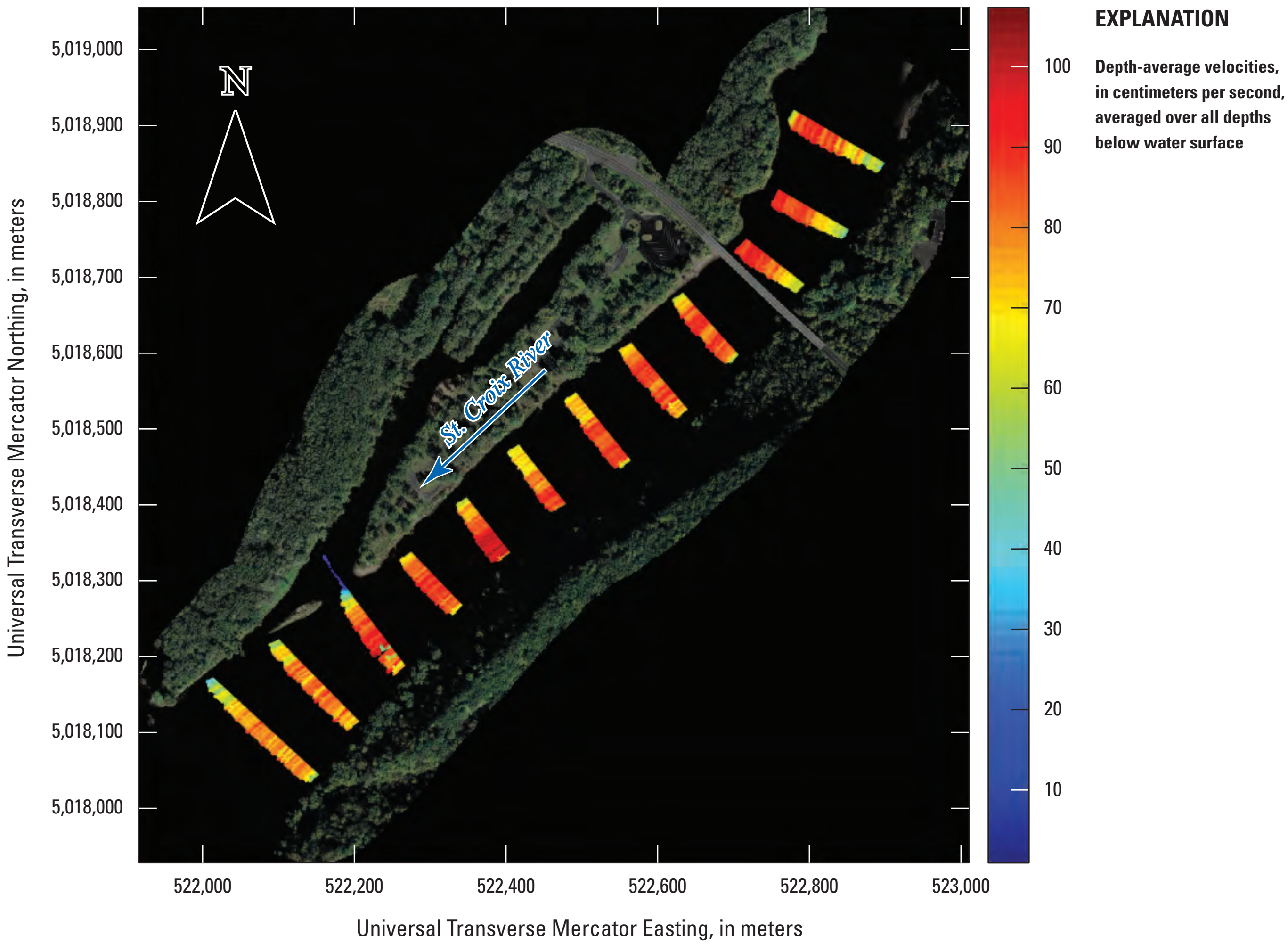


Figure 3. Depth-averaged velocities, in centimeters per second, along the surveyed transect lines of the main channel of the St. Croix River near Osceola, Wisconsin.

Global Navigation Satellite System/Inertial Navigation System Positioning Data

The first data to be processed were the positioning data measured with the NovAtel MarineSPAN. The raw GNSS/INS file was added to Waypoint Inertial Explorer (8.70). Base stations for the National Oceanic and Atmospheric Administration Continuously Operating Reference Station program were added in the software to help correct the 3D positioning location. The data were then processed, tightly coupled, using the precise point kinematic method. Once the GNSS/INS data completed postprocessed kinematic processing, it was exported as a smooth best estimated trajectory file to correct all sounding data in HYPACK.

Swath Multibeam and Lidar Data

Raw multibeam and lidar track lines (HSX files) were imported into the HYSWEEP Editor—MBMAX64 tool. In HYSWEEP Editor, corrections such as sound velocity, patch test, and tide were applied to get the most accurate values from the survey, and the uncertainty was estimated.

Sound Velocity Profiler

Some factors degrade the precision and accuracy of bathymetry. One of these factors is the sound velocity in the water column. The residual errors from sound velocity changes can be controlled using precise measurement equipment such as an SVP (Zhao and others, 2014). The SVP points measured during the Osceola survey were added to

HYSWEEP to correct the speed of sound in the raw multibeam data. Table 1 shows the two SVP samples that were measured during the Osceola survey.

Patch Tests/Boresight

A boresight calibration was performed with the MBES at the beginning of the 2019 field season using the NovAtel SPAN marine logging and system setup files. A boresight calibration is required to eliminate systemic errors due to misalignment between the MBES antennas and the inertial measurement unit corrections (Seube and Keyetieu, 2017; Norbit, 2018). Since the 1990s, the sole practical method to calibrate boresight angles has been the patch test (Wheaton, 1988).

Patch tests are a series of dynamic calibration tests that are used to check for subtle variations in the orientation and timing of the MBES with respect to the INS and real-world coordinates. Patch tests are important to measure because they determine timing offsets caused by latency between the MBES and INS: the angular offsets to roll, pitch, and yaw caused by the alignment of the transducer head (Huizinga, 2017). Although a boresight is completed at the beginning of each field season, a patch test is still performed before every survey to ensure values are staying consistent. The patch test values used for correction of Osceola survey data were the following:

- Pitch:−1.50
- Yaw:−1.50
- Roll:−0.18

Gage Data

River gages with water-level stages and discharge levels are maintained by many different State, Federal, Tribal, and local agencies. River gages near survey study areas are important tools for estimating water surface elevation and safe discharge rates while in the field. For the Osceola, Wisconsin survey, the river gage USGS 05340500 St. Croix River at St. Croix Falls, Wisconsin, was used to correct for the multibeam tide value (table 2). Tide was extrapolated and corrected using the distance from study area.

Vessel Configuration

As with all equipment that contains GNSS/INS and antennas, offsets must be measured to get an accurate and precise location of the equipment phase center. The multibeam was set up on the port side of the vessel with a carbon-fiber mount (Portus Pole). The mount used a 0.3-meter antenna mast with two antennas: primary placed forward and secondary placed aft. The carbon-fiber mount was built specifically for Norbit's integrated multibeam systems and allows for consistent offset measurements. Each time the Portus Pole is mounted to the vessel, the only offset required for measurement is the Z-value: sonar draft in water. Table 3 shows the offset measures that are automatically applied with every NovAtel logging file (while surveying) and do not change from survey to survey.

The second set of offsets change for each survey and were applied during postprocessing. When the POSPac adjustment file smooth best estimated trajectory was imported to HYSWEEP, there are device offsets that change with multibeam draft and location of lidar puck. Table 4 shows the values measured for the Osceola survey.

Uncertainty Estimation

Quality-assurance measures were assessed in real time during the MBES survey within the HYPACK survey software. The total propagated uncertainty (TPU) for each cell is computed using the combined uncertainty and bathymetric estimator (CUBE) in HYPACK. The cell size for the Osceola project was 0.5 meter. CUBE is considered "algorithmic hydrography" and is used to determine the uncertainty of a depth estimate (Calder and Wells, 2007). The error estimated is defined as the difference between the true value and the estimate values. The exact true value can never be determined, so the actual error can never be computed. Thus, uncertainty

Table 1. Sound Velocity Profiler samples taken during the Osceola survey on October 16, 2019.

[UTC, Coordinated Universal Time; m/s, meter per second]

Sample time (UTC)	Average velocity (m/s)	Latitude	Longitude
	Sample 1		
17:46	1435.12	45.3162	−92.7178
	Sample 2		
22:33	1439.06	45.3235	−92.7086

Table 2. U.S. Geological Survey 05340500 gage information utilized during the Osceola survey.

[USGS, U.S. Geological Survey; °, degree; ', minute; ," second; ft, foot; ft³/s, cubic foot per second; NAVD 88, North American Vertical Datum of 1988]

Gage information		
Name	USGS 05340500	
Location	Latitude 45°24'25," longitude 92°38'49," in Southwest 1/4 Northwest 1/4 sec.30, Township 34 North, Range18 West, Polk County, Hydrologic Unit 07030005, St. Croix National Scenic Riverway, on left bank, 1,500 ft downstream from powerplant of Northern States Power Company, in St. Croix Falls, and at mile 52.2.	
Operated by	U.S. Geological Survey, Northwest Wisconsin Field Office, Rice Lake, Wisconsin.	
Gage height, ft	October 16, 2019-7.38 ft	October 17, 2019-7.05 ft
Discharge, ft³/s	October 16, 2019-13,300 ft³/s	October 17, 2019-12,300 ft³/s
Datum of gage	690.04 ft above NAVD 88	
Temperature, degrees Celsius	October 16, 2019-7.6 °Celsius	October 17, 2019-7.7 °Celsius
Distance from study area	6.5 miles	

Table 3. Portus Pole offsets that were added to NovAtel software before the survey began.

[m, meter; +, plus; iWBMSc, integrated wideband multibeam system compact; IMU, inertial measurement unit]

Lever arms using standard 1.881 m sonar pole	+Forward (m)	+Starboard (m)	+Down 0.3 Antenna Mast (m)
iWBMSc IMU to bottom forward antenna	1.099	0	−2.159
iWBMSc IMU to bottom aft antenna	−0.899	0	−2.159
Aft edge top sonar pole inserts to bottom center sonar flange	0.089	0	1.881
Bottom center sonar flange to iWBMSc sonar reference	−0.117	0	0.023

Table 4. Device offsets that were input to HYPACK before postprocessing began.

[m, meter]

Device offsets	Starboard (m)	Forward (m)	Vertical (m)
Default for all surveys	0.000	−0.061	0.102
Multibeam	0.000	−0.061	0.342
Lidar puck	0.230	−0.281	0.502

is the estimate of this error's magnitude (Calder and Wells, 2007). The gridded bathymetry has uncertainty due to positioning errors, depth sounding errors, sound velocity errors, and grid processing errors; and the estimated Inertial Explorer errors provide the Global Positioning System position error of each individual measurement.

Several steps are required before generating surfaces for the bathymetric datasets. Depth data were edited using filter algorithms in HYPACK HYSWEEP Editor (MBMAX64). These filtering algorithms remove noise such as water column turbulence or fish. Following these routine filter applications, the data are exported as laser format, to be further cleaned (edited) for noise using ArcGIS and GeoCue LP360.

Swath Backscatter Data

The HSX files were imported into Caris HIPS and SIPS (v.11.2). The data were georeferenced, and a gridded surface was constructed. A backscatter mosaic was generated using the SIPS BACKSCATTER option.

Sidescan Data (Multibeam)

The HSX were imported into the Hypack 2019 targeting and mosaicking program. Each file was manually edited for spikes and anomalies in "scan view," and a smoothing algorithm was applied to each range line. Once all files were viewed, the mode was switched to "mosaic mode." A mosaic was generated, and individual transects were generated in case additional editing was needed. The sidescan mosaic was imported into Esri's ArcGIS v.10.7, where some of the individual transect lines were clipped to cover anomalies. This process provided a "clean" mosaic that is often desired because it provides a "picture" of the physical bed characteristics based on differences in acoustic reflectance.

Acoustic Current Doppler Profiler

The raw ADCP files (.rivr) created by RiverSurveyor Live (during the survey) were imported into the USGS-Velocity Mapping Toolbox (VMT) (Engel and Jackson, 2017). The Velocity Mapping Toolbox allows for rapid processing, visualization, and analysis of ADCP transect data (fig. 3). The imported raw files were batch processed and the GIS table creation utility was used to export transects as a comma-separated values table. The comma-separated values tables were loaded into a GIS for further analysis and mapping. Diffusion interpolation with barriers was used to generate an average stream velocity surface model (fig. 4).

Ground-Truth Data

On October 17, 2019, 48 sites were sampled at random locations to provide ground-truth information for acoustic interpretations (fig. 5). Videos using an underwater camera (Aqua-Vu) were recorded at each site. The videos were interpreted and "still images" (fig. 6) were captured to use as representations of the sediment type at each sample location. Descriptions of the videos were provided within the attributes of a shapefile dataset, which also reports the still image identification (appendix 1).

The still images of the St. Croix riverbed mostly indicate a homogenous sandy bottom, except in a few instances where gravel, cobble, or gravel and cobble were present. There was a large amount of woody debris present in the study area, mostly near shorelines, which often prevented site sampling closer to the shoreline. In some underwater videos, presence of mussels was noted and this information was captured within the shapefile (appendix 1) that corresponds to the underwater video interpretation.

The riverbed along the northern shore of the peninsula showed a different bottom (fig. 6, image b). It was quite hard to determine the substrate because much of the bed was covered by a layer of soft mud and detritus (leaves), which was characterized as organic. The still images were also used to help make inferences of intensity values for interpretation of the geophysical data from the multibeam backscatter.

Ground-truth locations and descriptions were recorded in a geospatial dataset with point features showing the site name and location of each ground-truth sample (appendix 1). Image descriptions are included in the metadata that define and describe all attribute names and class code names. Still images were provided in standard image file format (.jpeg), and each image is associated with the sample location (appendix 1). Often, multiple data types were identified at the same location; therefore, multiple images were clipped and labeled by adding a letter (in other words b, c, d, and so forth).

Derived Datasets and Benthic Analysis from Sonar Data

Effective benthic mapping analysis and visualization required the following data products: digital elevation models (bathymetry and topobathy; [DEM]), slope, ruggedness, geomorphic landforms, backscatter, sidescan, current velocities, and surficial sediment classification. Additionally, metadata are a component for all data deliverables. Metadata are compliant with the Federal Geographic Data Committee specifications, attached to each dataset and in XML format.

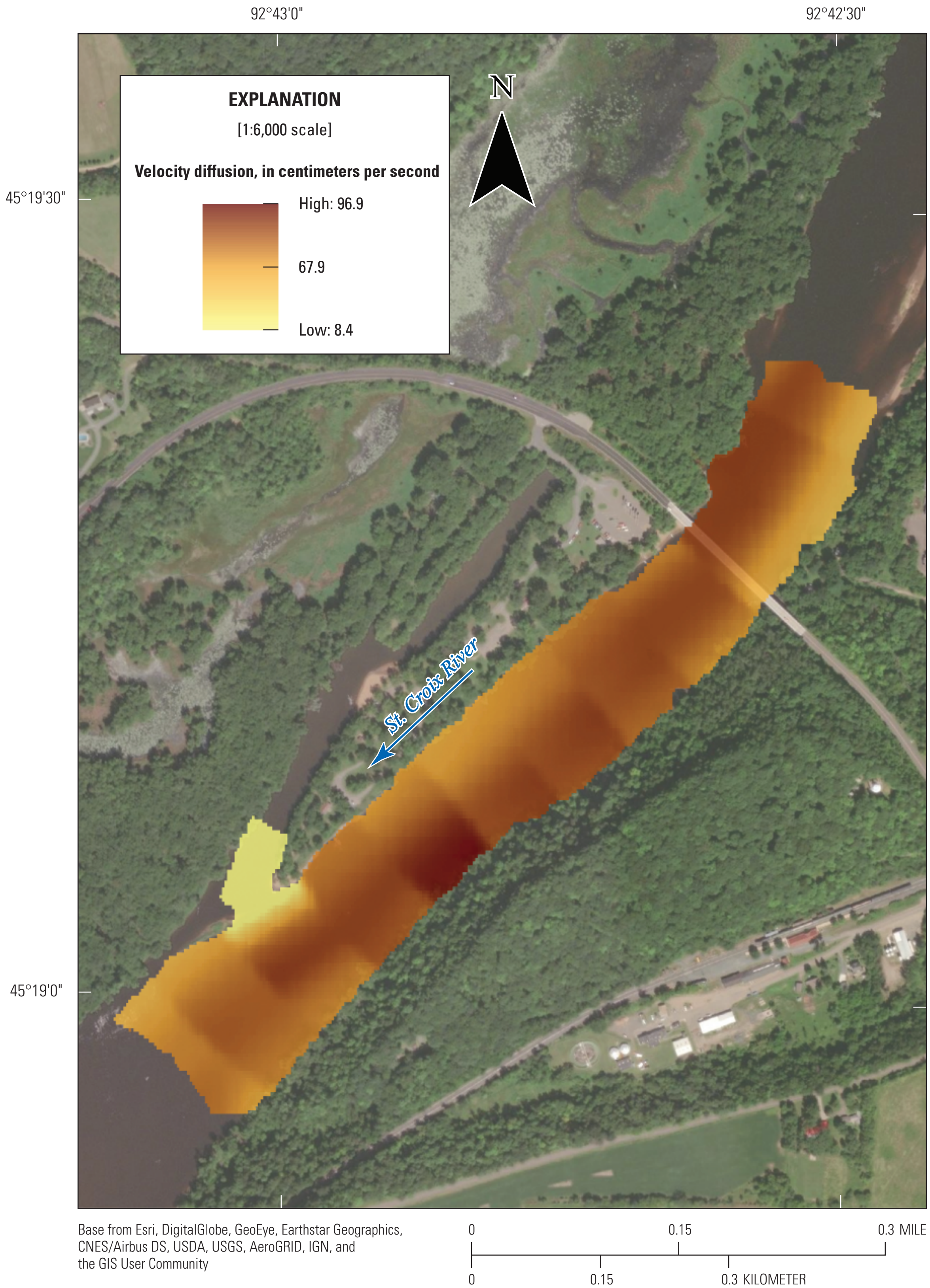


Figure 4. Averaged flow or diffusion surface model of channel velocity, in centimeters per second, of the St. Croix River near Osceola, Wisconsin. The general direction of flow moves from north to south for the St. Croix River.

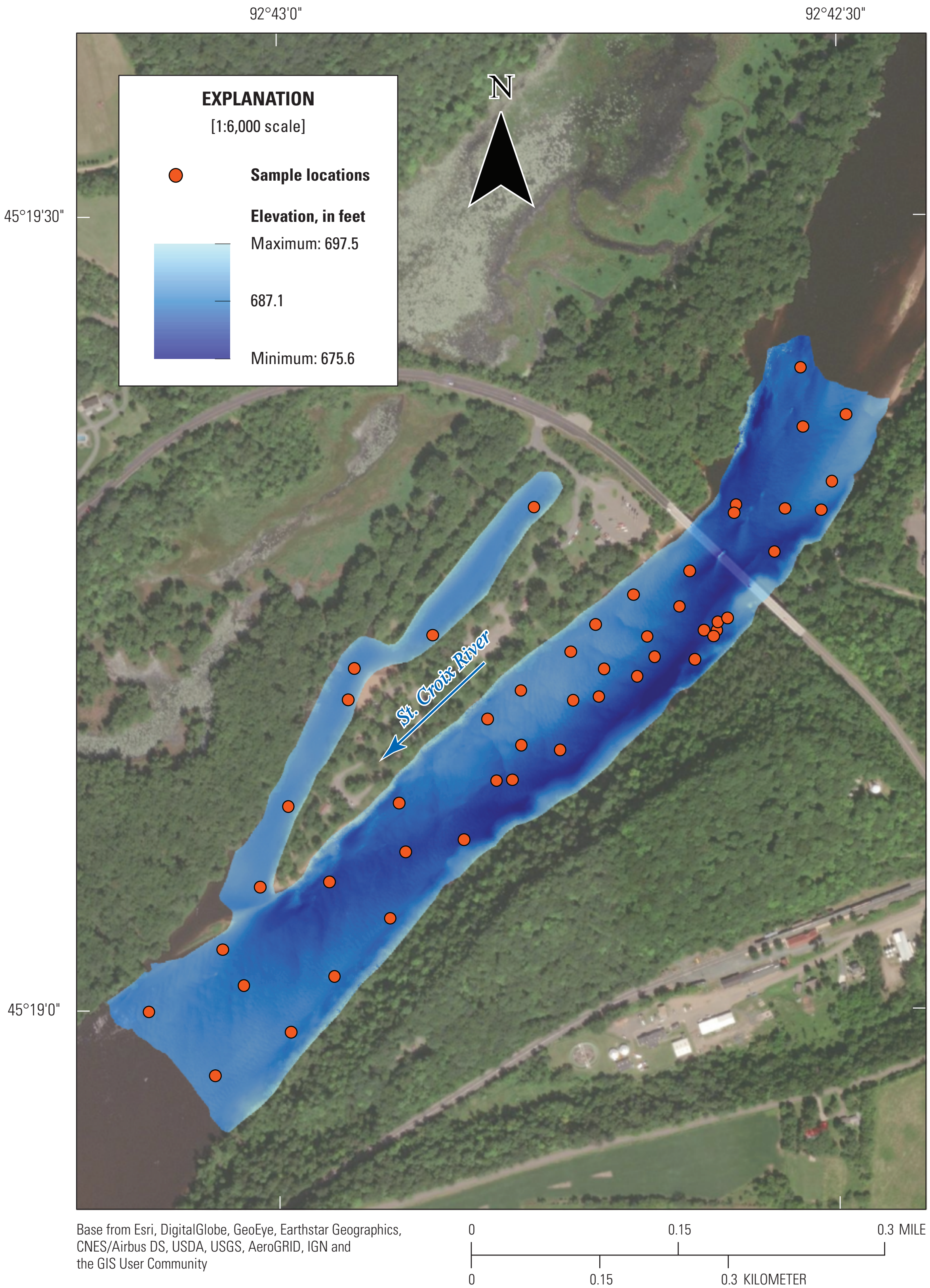


Figure 5. Bed observations captured on the St. Croix River near Osceola, Wisconsin. The random samples (48 total) were collected using an underwater video at random locations.

Figure 6. Still images captured from underwater videos sampled at random locations on the St. Croix River near Osceola, Wisconsin. The following classes were interpreted from these bed materials: *A*, sand; *B*, organic (detritus and [or] mud); *C*, gravel; *D*, woody debris; and *E*, cobbles. Note, the white object in each image is a polyvinyl chloride pipe extension mounted on the camera pole that is used for bottom detection and keeping the camera resolution consistent.

Digital Elevation Models—Bathymetry and Topobathy

The DEMs were generated in elevation and depth for both bathymetry (fig. 7) and topobathy (fig. 8). For all elevation product deliverables, including the DEM derived hillshade (fig. 8), the World Geodetic System 1984 reference system was used with a spatial resolution of 1 ft (per NPS specifications). Contours (fig. 9) were also generated from the elevation data, for both bathymetry and topobathy. The minimum elevation value at the North American Vertical Datum of 1988 was measured at 675.59 ft, and the maximum elevation value was 715.36 ft. A total of 19.99 hectares of bathymetry were surveyed, and a total of 2.58 hectares of terrestrial lidar were surveyed.

Using CUBE, the uncertainty value for the bathymetry and its products were calculated. The average uncertainty value was estimated at 0.018 meters. Most of the values were less than 0.3 meters, which is within the specification for an International Hydrologic Organization “special order” survey, the most demanding survey standard of the International Hydrographic Organization (International Hydrographic Organization, 2008). All TPU values that fell outside of the 95 percent confidence interval were located on the shoreline and removed from the dataset. The final TPU confidence level error was calculated as 0.00020 meters.

The positional uncertainty for the bathymetry and lidar data were estimated from Waypoint’s Inertial Explorer (version 8.70). Horizontal positional uncertainty was estimated with a standard deviation of 0.08 meters. Vertical positional uncertainty was estimated with a standard deviation of 0.18 meters.

From the bathymetry, other informative measures were derived such as slope and terrain ruggedness, which can be used to model river bedforms.

Backscatter and Sidescan

High-resolution backscatter and sidescan mosaics were generated at 0.05 meters to provide as much detail as possible. Though images were mosaicked to a set raster resolution, true resolution is limited to the data collection parameters. The backscatter mosaic (fig. 10) had an intensity range from 2.92 to 85.93 values. The higher values coincided with harder surfaces (in other words gravel, cobble, and rock), and the lower values coincided with softer surfaces (in other words mud).

Sidescan is the acoustic reflection of the riverbed and is displayed as a raster dataset with a range from 0 to 255-pixel values (fig. 11). The “range” of acoustic reflectance is a typical grayscale image, where the pixel value is a single number that represents the brightness of the pixel. The most commonly used format is an 8-bit grayscale image, where the brightness values of the pixels range from 0 to 255, where 0 is black and 255 is white.

Acoustic Doppler Current Profiler—Current Velocities

In an attempt to follow the USGS standards for measuring discharge from a moving boat (Mueller and others 2013), a total of 46 ADCP track lines were measured in the study area. On average, four overlapping track lines were measured at each planned line, spaced 100 meters apart (fig. 3). Table 5 shows the average velocities measured for all track lines. The average area surveyed was 452.303 square meters. The mean vessel speed during the transect lines was 0.593 m/s. The total discharge measured was 269.931 cubic meters per second.

A total of five SMBA locations were measured during the survey with a Differential Global Positioning System. Typically, the presence of sand dunes indicates a moving bed. However, none required a moving-bed correction for the ADCP transect lines. Likely, the sand dunes might be the result of a recent high-water event. Table 6 shows the mean moving-bed values and mean water velocity measured at each SMBA point.

Geomorphic Bedforms

Advances in remote sensing have allowed scientists to create novel methods for classification and mapping of landforms, or river bedforms, from DEM based images (Jasiewicz and Stepinski, 2013). Specifically, geomorphons are a qualitatively new way to classify geomorphic landforms, or river bedforms, by using local patterns and differential geometry modeled on an image analysis concept called local binary patterns (Stepinski and Jasiewicz, 2011). When observing the river bedforms, it should be noted that the morphology of a riverbed is not static. The observed conditions for this study will change with river current flow conditions. Geographic Resources Analysis Support System GIS (ver. 7.8) was used with the r.geomorphon package to calculate geomorphons and associated geometry using the DEM surveyed on October 16, 2019.

The geomorphic landforms (fig. 12) were generated as a raster dataset. Table 7 shows the distribution of landforms that were calculated from the r.geomorphon algorithm in the Geographic Resources Analysis Support System GIS (ver. 7.8). To classify the geomorphons of the DEM, using differential geometry, an outer search radius of 20

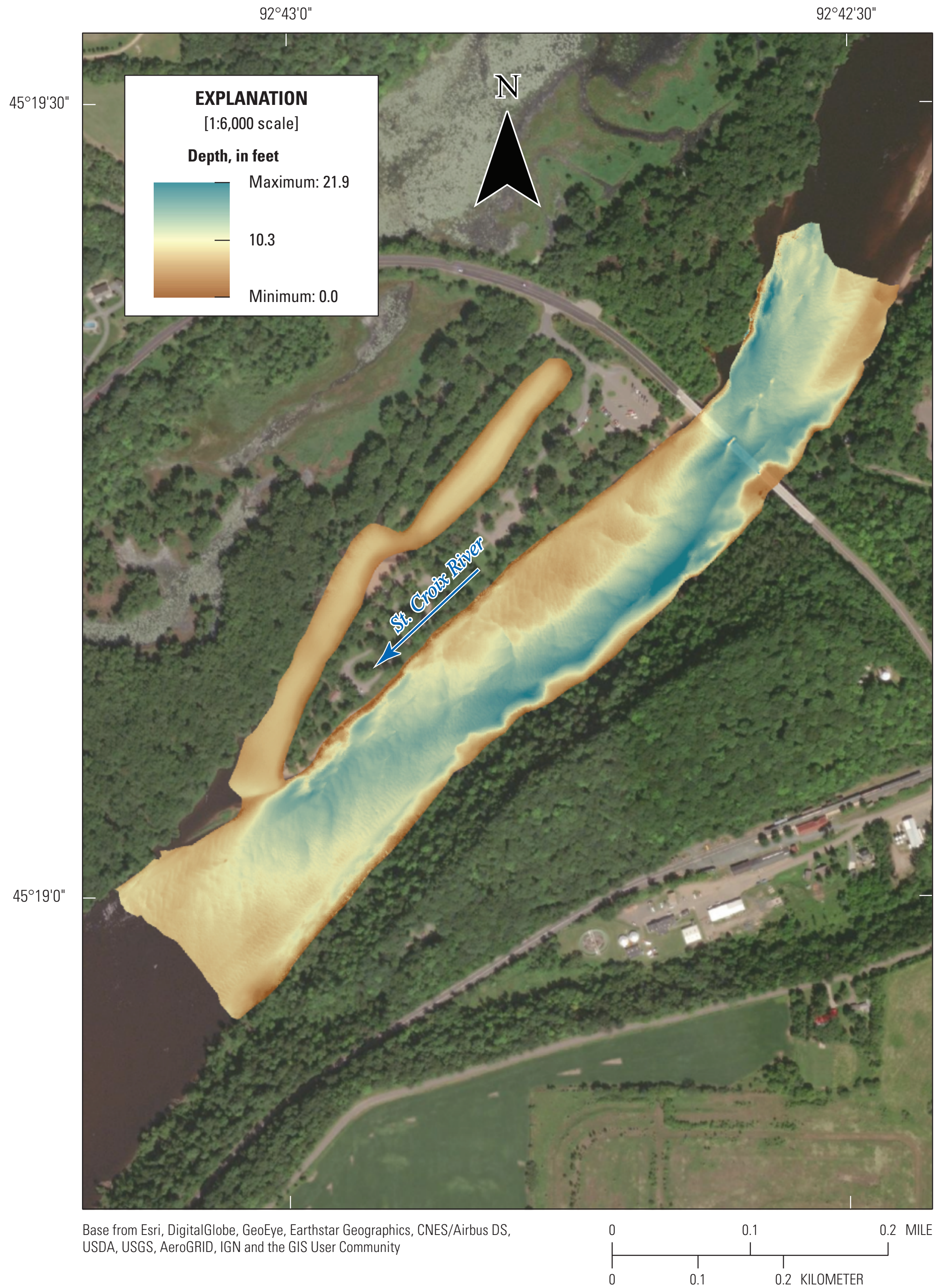


Figure 7. Bathymetry derived from the hydrographic survey of the St. Croix River near Osceola, Wisconsin. Depths ranged from 0 to almost 22 feet.

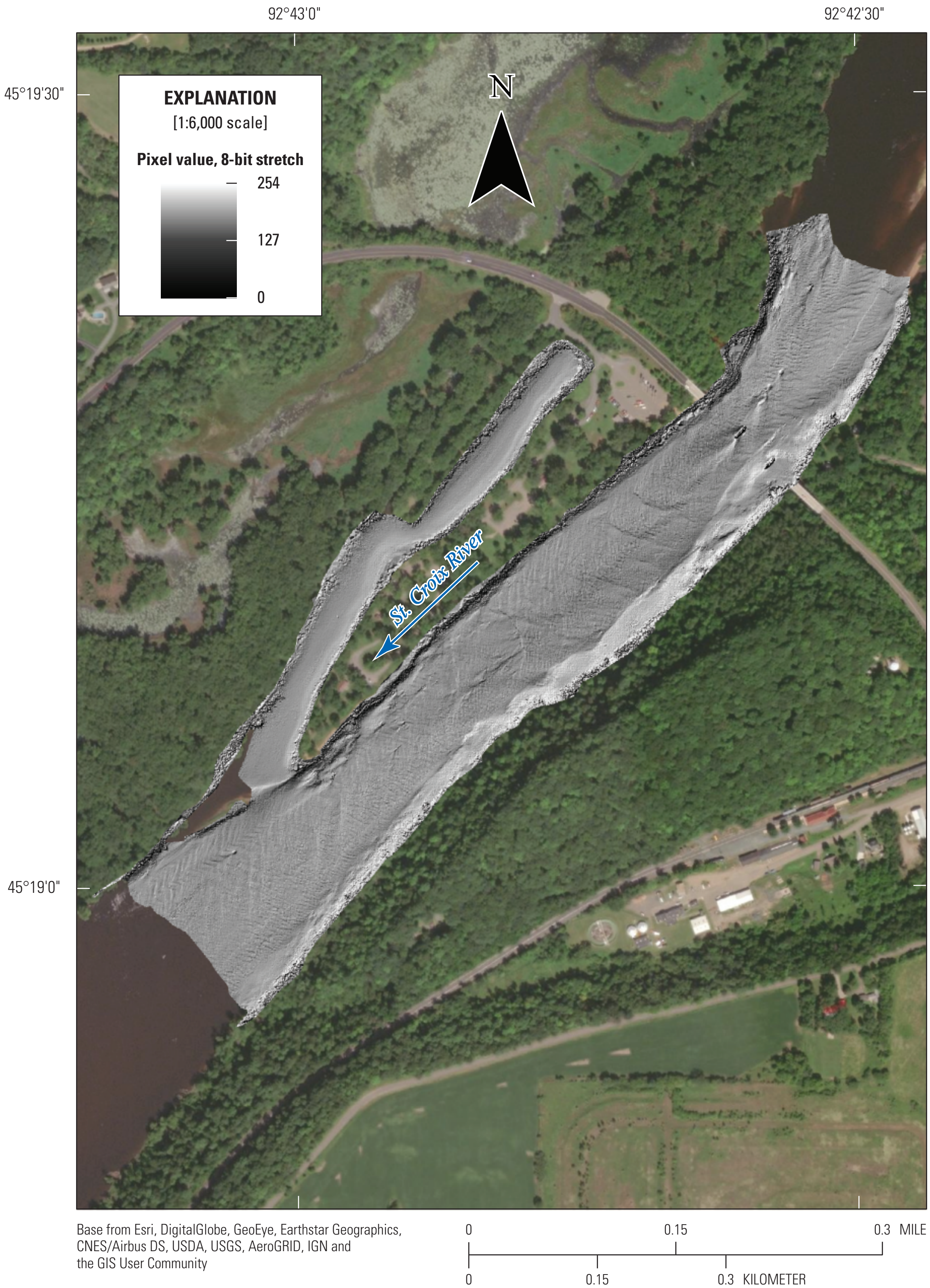


Figure 8. Hillshade surface showing the topographic relief derived from the bathymetric survey of the St. Croix River near Osceola, Wisconsin.

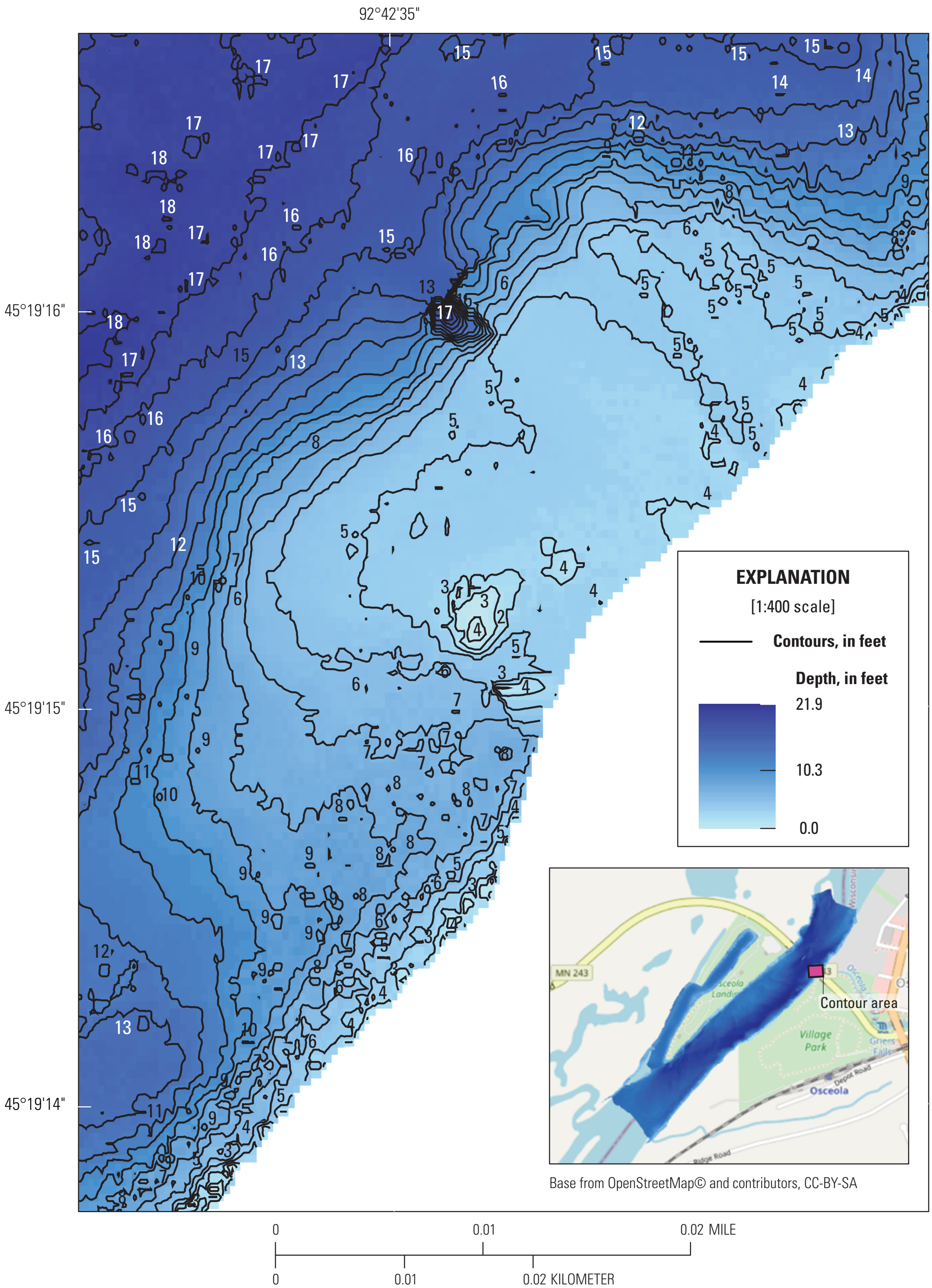


Figure 9. Example area of 1-foot contours of the St. Croix River near Osceola, Wisconsin.

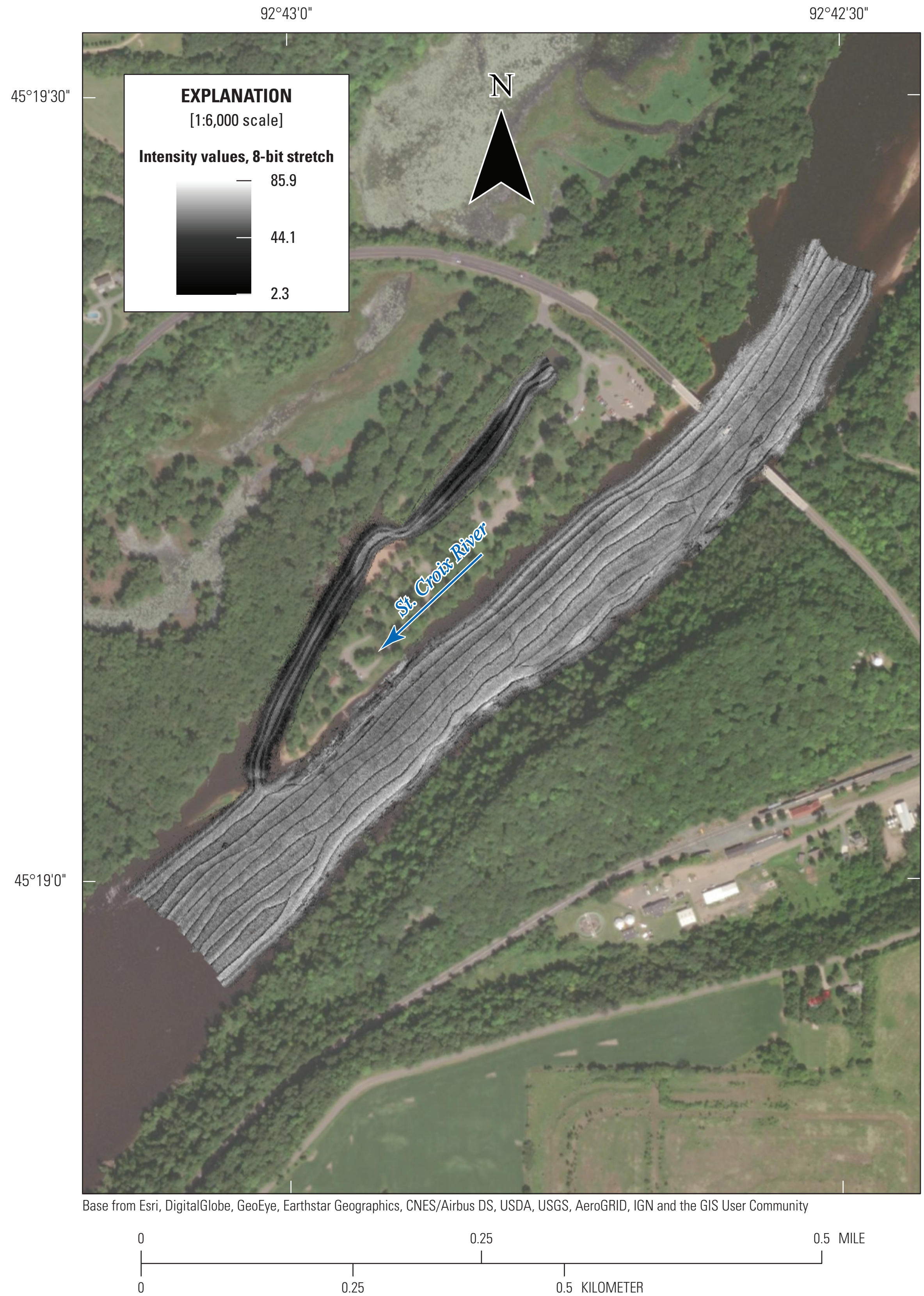


Figure 10. Backscatter (intensity) map of the St. Croix River near Osceola, Wisconsin. Backscatter strength is associated with bed type.

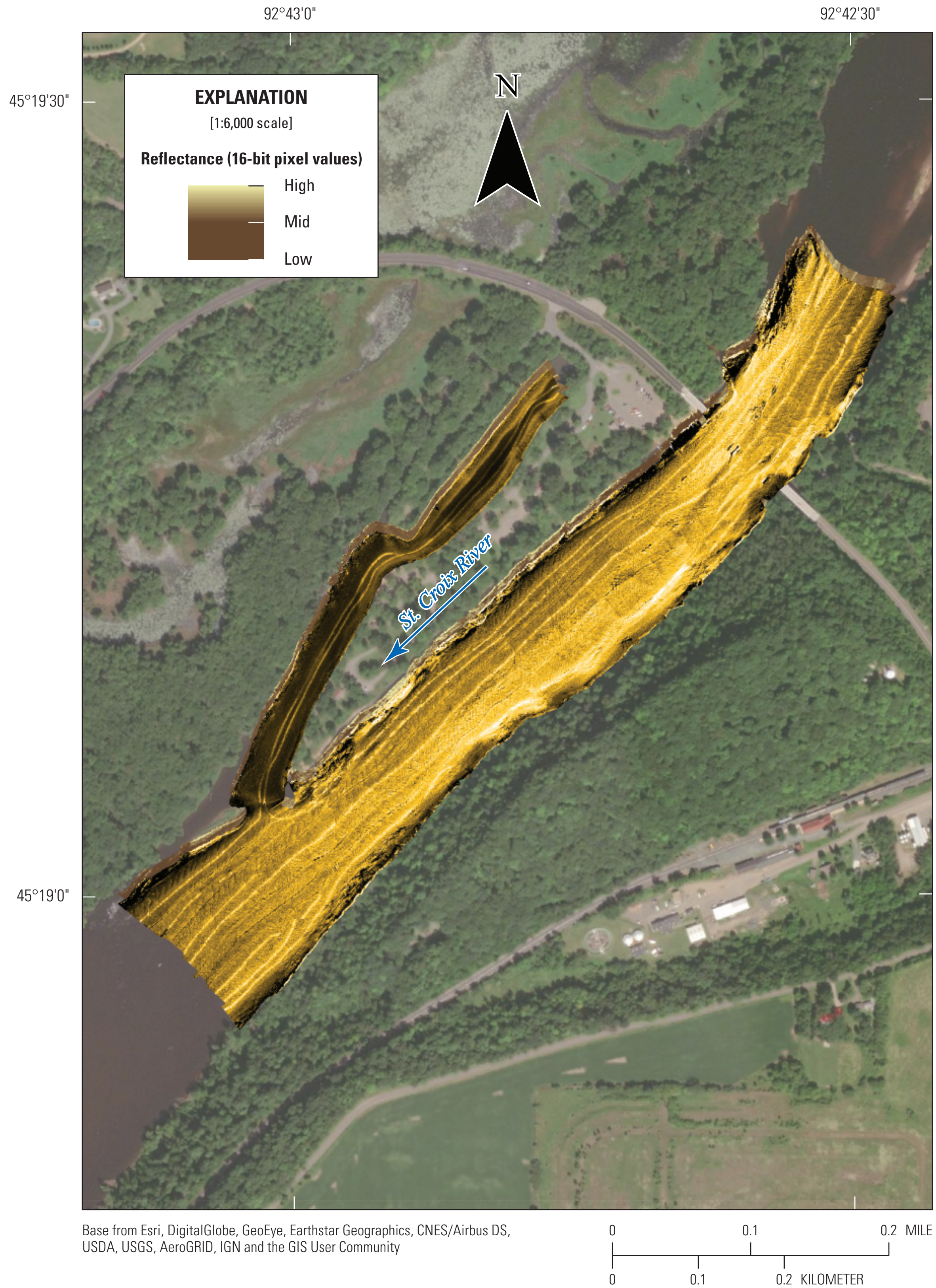
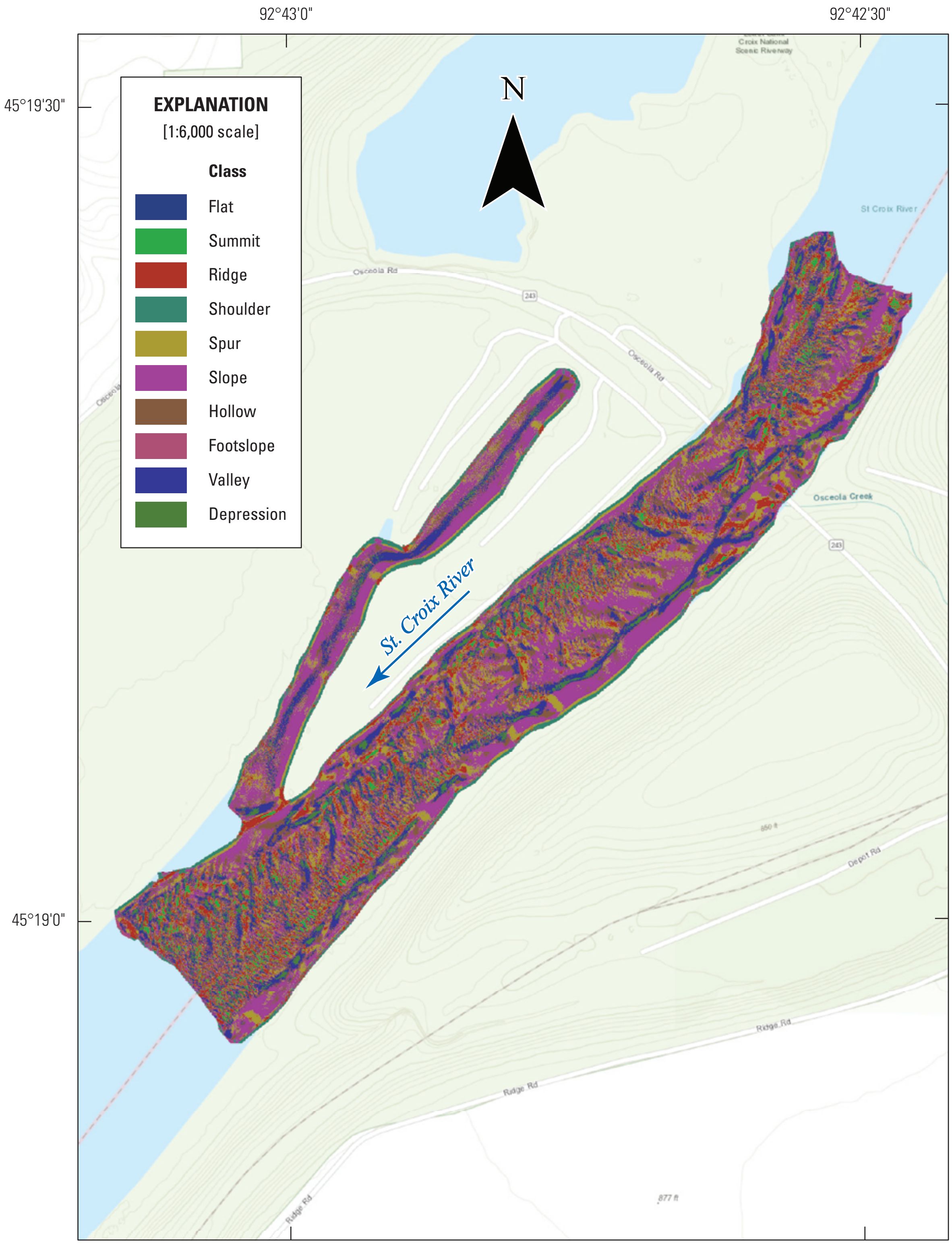


Figure 11. Sidescan image mosaic of the St. Croix River near Osceola, Wisconsin. Sidescan imagery provides a view of the underwater landscape.



Base from Esri, HERE, Garmin, Intermap, Increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, OpenStreetMap© contributors and the GIS User Community

0 0.1 0.2 MILE
0 0.1 0.2 KILOMETER

Figure 12. Landforms of the St. Croix River near Osceola, Wisconsin, calculated from the r.geomorphon algorithm in Grass GIS (Ver. 7.8).

Table 5. Average and standard deviation values of different measurements collected with the SonTek acoustic Doppler current profiler.

[ADCP, acoustic Doppler current profiler; °, degree; C, Celsius; m, meter; m/s, meter per second; m^3/s, cubic meter per second]

ADCP measurement	Mean	Standard deviation
Temperature (°C)	7.9	0.3
Track distance (m)	125.49	32.91
Average boat speed (m/s)	0.595	0.132
Average water velocity (m/s)	0.593	0.401
Average discharge (m^3/s)	269.931	173.014

Table 6. Stationary moving-bed assessment measurements measured between Acoustic Doppler transect to check for a moving-bed correction.

[m/s, meter per second]

File name	Mean moving-bed velocity (m/s)	Mean water velocity (m/s)
smba_20191017092213	0.008	0.817
smba_20191017103105	0	0.708
smba_20191017112827	0.005	0.810
smba_20191017123845	−0.017	0.854
smba_20191017133853	0.005	0.709

Table 7. Geomorphon distribution for the Osceola survey (fig. 12).

[%, percent]

Geomorphon classification	Percent coverage	Geomorphon classification	Percent coverage
Flat	0.0052%	Slope	31.37%
Summit	3.09%	Hollow	12.99%
Ridge	12.30%	Footslope	0.46%
Shoulder	4.78%	Valley	15.27%
Spur	15.53%	Depression	4.20%

meters was used with an inner search radius of 10 meters at a flatness threshold of 1°. This dataset was exported as a raster and served with the package of map data.

Surficial Sediment Classification

Images, including backscatter, slope, terrain ruggedness, and bathymetry were all loaded into Trimble's eCognition (v. 9.3) for object-based image analysis. Object-based image analysis uses parameters such as color, size, shape, texture, and form to classify objects. An initial segmentation was performed to extract image objects, which provide a framework for identifying relationships between objects (Trimble, 2017). Segmented polygons are based off reflectivity, texture, pattern, and context. Digital interpretation occurs by looking at the thresholds of segmented objects. Intensity values generally indicate soft versus hard substrate. Lower intensity values indicated darker/softer bottom and higher values indicated lighter/harder bottom. Terrain ruggedness values range from 0 to 1, with numbers closer to 0 indicating smoother terrain, and numbers closer to 1 indicating "rougher" terrain. Object classification was completed by determining threshold values for these values. The ground-truthing information (shapefile format) is applied to help infer feature values from the backscatter. Since the initial data used for this analysis came from the HSX, an additional spatial adjustment was applied using a GIS.

The geospatial dataset consists of polygon features that describe the surficial sediment characteristics of the study area (fig. 13). Attributes include calculated geometry of the area for each polygon. The class code indicates a dominant substrate type with a capital letter, and if there is a secondary or third,

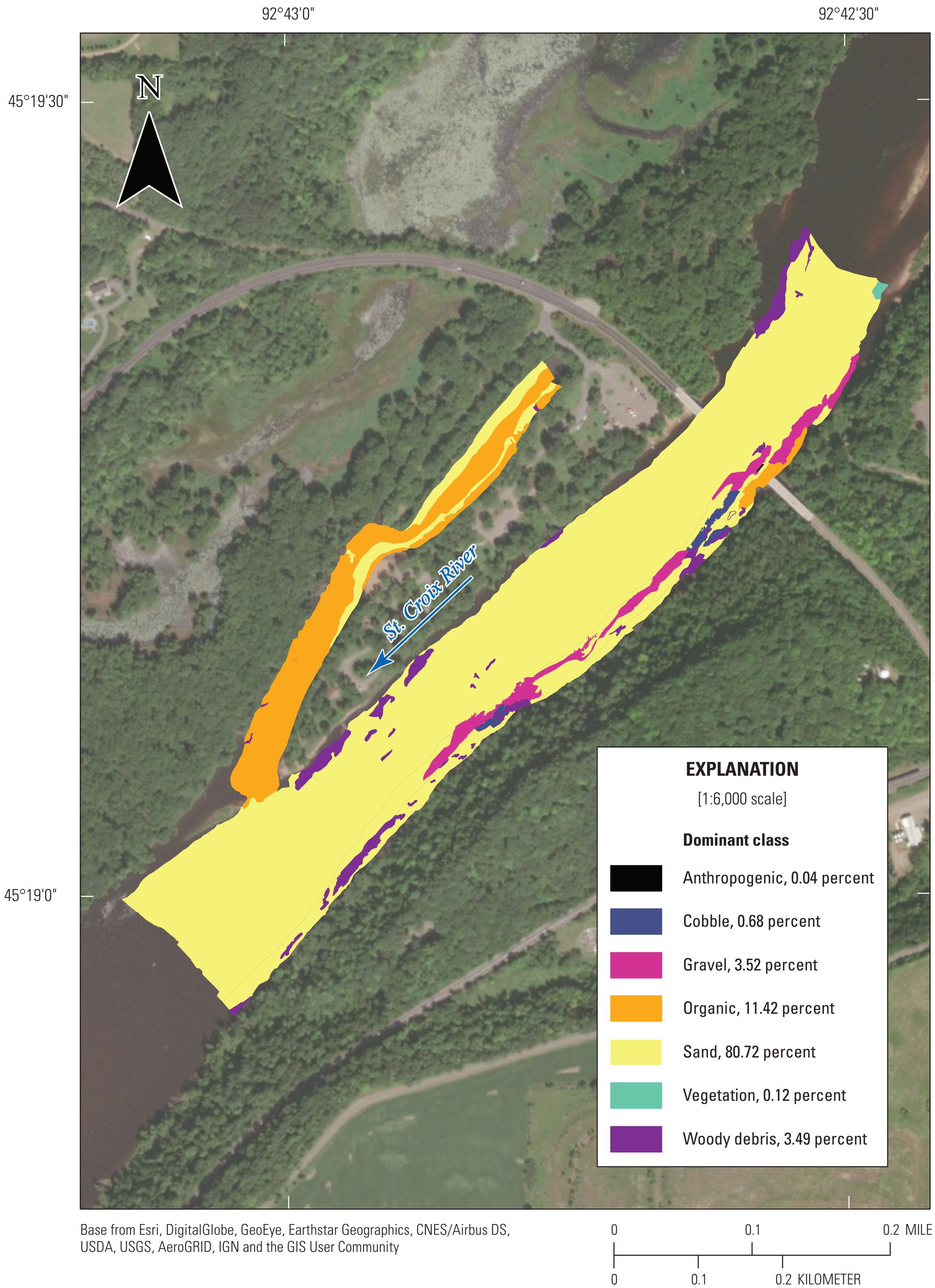


Figure 13. Predicted substrate or type of surficial sediment in the St. Croix River near Osceola, Wisconsin.

the type code follows in order of observed coverage quantity (in other words “Sg” is code for predominant sand with gravel). Topology of the final classification was made clean so that there was no overlap or gaps among polygon boundaries. Table 8 lists the percent coverage of each dominant substrate type (fig. 13), totaling 93 polygons and 17.36 hectares. Sand covered the largest amount of area (80.72 percent), followed by the organic class (11.42 percent). The anthropogenic class covered the smallest area (0.04 percent), representing the Osceola Road/243 Bridge piers.

It is important to know that boundaries between sediments are not actually precise polygons, but rather soft boundaries (gradual transitional). Although the data collected are considered high-resolution, and the products generated are fine scale resolution, it is still difficult to determine boundaries.

Physical Habitat Analysis

Physical aquatic habitat is generally defined as the combination of depth, velocity, and substrate where organisms live (Jacobson and others 2002). Physical habitat varies within a river spatially and with time because of changes in river hydraulics. In this study area, depth ranged from 0 to 21.89 ft (fig. 7). As expected, the deeper channel running through the study area corresponds to the faster river currents. These same areas are where the harder substrate types of cobble, gravel, and rock were found.

Analysis of the combined hydroacoustic datasets indicated the survey area was largely covered by sand. These areas were easily depicted by assessing the hillshade or shaded surface relief model and bathymetry. The sand dunes are quite evident in the topography (fig. 8), from the current boat landing on the Minnesota side and downward, to almost the end of the peninsula (fig. 7). The sand dunes were superimposed on a larger bar that extended through most of the study area on the right side of the channel and contained smaller ripples on top of dunes. The geomorphon classification showed five bedforms filling the majority of the study area: ridge, spur, slope, hollow, and valley (fig. 12).

Supporting evidence was provided by underwater video sampling, with 71 percent of the locations described as sand (appendix 1). Elevation ranged from 209 to 225 meters (appendix 1). During data collection, because of the large coverage of sand, initial assumptions included a moving bed. However, completion of five stationary moving-bed tests (table 6) using an ADCP throughout the study area implied there was no significant (0.001 meters per second) moving bed present.

The thalweg exists near the Wisconsin shoreline (starting just below Osceola Road/243 Bridge). This depression begins just above the bridge and extends about one-third the survey length downstream. The deep groove is continuous, and it is along this hydrogeomorphologic phenomenon where harder substrates of gravel and cobble are located. Six bed observations described cobbles, gravel, and rocks (appendix 1) captured within the short underwater videos. Only 4.2 percent of the coverage indicated hard substrate (fig. 13) as dominant bed material, but gravel and cobble are known as excellent indicators of substrate stability. Additionally, mussel presence was noted in three of the four underwater videos sampled in this cobble and gravel substrate area (appendix 1). The other location of mussel presence was recorded in sandy substrate.

Large amounts of woody debris (3.5 percent, or 0.6 hectares) (fig. 13) were located throughout the study area and represented greater area than vegetation, cobble, and anthropogenic classes and was roughly the same area as gravel. Coincidentally, there were a couple of large woody debris pileups located along the Wisconsin shoreline near the stable substrate locations identified with mussel presence. Further biological analysis should be conducted in this area because of the mussel presence and favorable habitat conditions.

Table 8. Calculated geometries of combined substrate classes mapped (fig. 13).

[%, percent]

Class	Description	Number	Acres	Hectares	% Cover
A	Anthropogenic	2	0.02	0.01	0.04%
C	Cobble	3	0.29	0.12	0.68%
G	Gravel	9	1.53	0.62	3.52%
O	Organic	16	4.95	1.97	11.42%
S	Sand	16	34.97	14.02	80.72%
V	Vegetation	1	0.05	0.02	0.12%
WD	Woody debris	46	1.51	0.61	3.49%

An area northwest of the peninsula was very dark on the sidescan (fig. 11) and backscatter (fig. 10), indicating a soft muddy substrate there. Bed observations (appendix 1) supported this analysis with all samples (six total, 12 percent), indicating some organic or detritus (leaves) descriptions.

Conclusions

This project was facilitated by the National Park Service to gather physical and benthic information to aid in planning the relocation of the boat landing adjacent to Osceola, Wisconsin. The physical parameters of a river; including water depth, velocity, and substrate type; can indicate the habitat types in the site location and thus, mussels, fish, and other species that use the site. Surficial sediment was important to characterize because it provides information about the physical character of the riverbed. For example, it is well known that certain species of freshwater mussels prefer bedforms that remain stationary, with little to no movement, and some species of fish prefer deeper pool-like habitats or woody debris. Geomorphological bedforms were important for landscape pattern recognition of the riverbed terrain because the bedforms are required to study the landscape, structure, and processes found in a study area. If future hydroacoustic surveys are measured in this area, geomorphic and bedform change studies could be completed. Post-reconstruction surveys might be needed in the future to determine whether habitat or geomorphic change has occurred.

Because the data were collected by mapping professionals, the links between data collection, analysis, visualization, and quality are maintained through the entire process from collection through analyses and final map products. But this project does not supply habitat analysis to identify biological communities (habitat mapping). For example, indepth mussel surveys could be done to document the locations of current mussel beds. Mussel surveys, by experienced divers, can provide a more robust assessment of habitat, including the different mussel species found, their size, and indications of live versus dead (Wisconsin Department of Natural Resources and others, 2004). Mussel surveys also provide records of substrate type and usually include water quality parameters. This additional information is necessary to adequately assess habitat for aquatic organisms.

Assessments of physical habitat are challenging because they require detailed mapping of physical characteristics at spatial scales relevant to an organism's use of habitat, whether that assessment is for fish, mussels, invertebrates, or other organisms. Assessment, after a boat landing is constructed, requires an understanding of baseline parameters for comparison.

To date, habitat classification standards exist for marine and estuarine habitats, but currently do not apply to freshwater habitats, with the exception of the Great Lakes (Federal Geographic Data Committee, 2012). Therefore, although the goal of this project was to provide habitat characteristics for the survey area, only physical characteristics can be predicted or determined by combining hydroacoustic data with ground-truthing videos. The products generated provide general sediment types found at the river bottom surface. The geomorphic bedforms, or landforms, are somewhat easier to predict with existing geomorphic models, such as the Geographic Resources Analysis Support System geomorphic model used.

In conclusion, the suite of datasets developed from U.S. Geological Survey hydrographic and topographic surveys provide a baseline benthic map, allowing scientists and managers to reference habitat features characteristic to native freshwater mussels or other desired benthic organisms. By combining these measured and interpreted data layers, the mapped underwater features could suggest relationships that drive the distribution and abundance of aquatic organisms and vegetation.

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Appendix 1. Attributes from the Bed Observations Shapefile

Table 1.1.

[ft, foot; m, meter; N/A, not applicable, S, sand; C, cobbles; Od, organic-detritus; Ods, organic-detritus-sand; D, detritus; Osd, organic-sand-detritus; Sg, sand-gravel; Gsr, gravel-sand-rock; Sr, sand-rock; Gc, gravel-cobble; Gcr, gravel-cobble-rock]

Site	Video	Description	Comment	Class	Longitude	Latitude	Elevation (ft)	Elevation (m)
O1	873	sand	N/A	S	−92.708201	45.322901	708.01	215.80
O2	874	grainy sand	N/A	S	−92.708873	45.323394	710.70	216.62
O3	875	grainy sand	N/A	S	−92.708845	45.322772	710.51	216.56
O4	876	grainy sand	N/A	S	−92.708415	45.322199	706.54	215.35
O5	877	grainy sand with tiny pebbles	N/A	S	−92.709111	45.321913	712.94	217.31
O6	878	N/A	too dark	N/A	−92.709839	45.321956	685.58	208.96
O6B	879	sand, gravel, and rock	dark	S	−92.70987	45.321869	713.69	217.53
O7	880	sand	N/A	S	−92.710535	45.321262	715.01	217.93
O8	881	cobbles	mussel present	C	−92.710135	45.320643	713.61	217.51
O9	882	cobbles	mussel present	C	−92.710117	45.320726	711.80	216.96
O10	883	sand	N/A	S	−92.710691	45.320889	690.13	210.35
O11	884	large grain sand	N/A	S	−92.711377	45.321013	700.15	213.41
O12	885	large grain sand	N/A	S	−92.71194	45.320704	691.66	210.82
O13	886	large grain sand	N/A	S	−92.711813	45.320239	714.22	217.69
O14	887	large grain sand	N/A	S	−92.712309	45.320417	710.10	216.44
O15	888	large grain sand with tiny pebbles	N/A	S	−92.712275	45.319912	712.57	217.19
O16	889	large grain sand	N/A	S	−92.713054	45.320015	712.60	217.20
O17	890	large grain sand	N/A	S	−92.713049	45.319443	711.94	217.00
O18	891	large grain sand	N/A	S	−92.713555	45.319718	713.74	217.55
O19	892	sand	very dark, mussel present	S	−92.713419	45.319068	713.44	217.46
O20	893	course grainy sand	N/A	S	−92.714871	45.318837	686.26	209.17
O21	894	organic layer with leaves	N/A	Od	−92.716945	45.31796	711.25	216.79
O22	895	organic layer with leaves, sandy	N/A	Ods	−92.71652	45.318805	706.19	215.25
O23	896	organic layer with leaves	N/A	Od	−92.715627	45.319922	712.45	217.15
O24	897	leaves	N/A	D	−92.714365	45.320596	688.36	209.81
O25	898	mud (organic), sand, leaves	N/A	Osd	−92.712845	45.321937	721.11	219.79
O26	899	organic/leaves	N/A	Od	−92.715536	45.32025	716.71	218.45
O27	900	sand	N/A	S	−92.715914	45.318012	731.68	223.02
O28	901	sand	N/A	S	−92.717503	45.317301	721.90	220.03
O29	902	large grain sand	N/A	S	−92.718604	45.316651	723.00	220.37
O30	903	sand	N/A	S	−92.717187	45.316928	706.24	215.26
O31	904	sand	N/A	S	−92.717622	45.315981	726.10	221.31
O32	905	sand	N/A	S	−92.716494	45.316435	723.74	220.60

Table 1.1.—Continued

[ft, foot; m, meter; N/A, not applicable, S, sand; C, cobbles; Od, organic-detritus; Ods, organic-detritus-sand; D, detritus; Osd, organic-sand-detritus; Sg, sand-gravel; Gsr, gravel-sand-rock; Sr, sand-rock; Gc, gravel-cobble; Gcr, gravel-cobble-rock]

Site	Video	Description	Comment	Class	Longitude	Latitude	Elevation (ft)	Elevation (m)
O33	906	large grain sand with tiny pebbles	N/A	S	−92.715843	45.317022	740.67	225.76
O34	907	large grain sand with gravel	N/A	Sg	−92.715009	45.317624	717.03	218.55
O35	908	large grain sand with pebbles or gravel	N/A	Sg	−92.71478	45.318324	717.71	218.76
O36	909	gravel with sand, rocks	N/A	Gsr	−92.713909	45.318449	719.75	219.38
O37	910	sand	N/A	S	−92.713185	45.319075	720.94	219.74
O38	911	sand	N/A	S	−92.712471	45.319389	716.32	218.33
O39	912	sand	N/A	S	−92.711894	45.319948	723.20	220.43
O40	913	sand with tiny gravel	N/A	Sg	−92.711318	45.32016	723.49	220.52
O41	914	sand with tiny pebbles	N/A	S	−92.711058	45.320365	722.01	220.07
O42	915	sand, rock	mussels present, woody debris	Sr	−92.710327	45.32064	721.45	219.90
O43	916	sand	N/A	S	−92.709269	45.321464	712.75	217.25
O44	917	sand	N/A	S	−92.708576	45.3219	722.29	220.15
O45	918	large gravel, small cobbles	N/A	Gc	−92.709976	45.32077	722.51	220.22
O46	919	large gravel, small cobbles	N/A	Gc	−92.710186	45.320579	720.96	219.75
O47	920	large gravel, cobble, rock, boulder	woody debris	Gcr	−92.710464	45.320337	721.75	219.99
O48	921	large grain sand with tiny pebbles	N/A	S	−92.711166	45.320577	721.59	219.94

For additional information contact:

Director, Upper Midwest Environmental Sciences Center
U.S. Geological Survey
2630 Fanta Reed Road
La Crosse, WI 54602
608–783–6451

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