Understanding the Hydrologic Landscape to Assess Trajectories of Sediment Sources and Stream Condition in the Grass and Rapid River Watersheds

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Introduction

The Lower Elk River Chain of Lakes (LERCOL) system from Lake Bellaire to Elk Lake has been on a trajectory of change spanning back almost 150 years to when Elk Lake was first dammed, turning what was chain of smaller lakes connected via likely moderate gradient streams into a nearly flat, navigable waterway with deep enough connecting channels for moderate draft steam-powered riverboats. This artificially-created situation has now become a reference point for over a century of service and recreational use. Today, this chain of lakes is a jewel of northern Lower Michigan recreation, hosting tens of thousands of annual users, and perhaps billions of dollars of real estate predicated on continued recreational use.

Yet over the last several decades, residents and visitors alike have noticed significant changes along connecting channels, or links to this chain, specifically the Grass, Lower Rapid, and Torch Rivers in Northwest Lower Michigan. Channels that had been 6-9 feet deep had become 3-4 feet shallower, filled with sandy-textured sediment. Additionally, banks steadily widened, creating erosion issues that together with channel shallowing have forced dock reconfigurations and created navigational hazards.

This study, initiated and funded by the Elk-Skegemog and Three Lakes Associations, aims to better understand the scope and hydrologic context of sand sediment being deposited in the grass, Rapid, and Torch River channels, quantify its impacts, make implementable recommendations for management, and target further research efforts in the region.

Team Members

The project team consisted of researchers, technicians, and students at Michigan State University, and the State University of New York Brockport, along with employees of the Natural Resources Department of the Grand Traverse Band of Ottawa and Chippewa Indians, and Tip of the Mitt Watershed Council.

Team members from the Michigan State University Hydrogeology Lab were: Anthony Kendall, PhD in Environmental Geosciences and project lead; Lon Cooper, PhD candidate in Environmental Geosciences and long-time environmental consultant; Blaze Budd, MSU Hydrogeology Lab Research Technician; and Jordan Hein, an undergraduate student in Geological Sciences.

The MSU team conducted the bulk of the field work and analysis contained in this report, but were assisted very significantly in design, conduct, and evaluation of fieldwork results by Brett Fessel and Frank Dituri from the Grand Traverse Band of Ottawa and Chippewa Indians and Kevin Cronk from the Tip of the Mitt Watershed Council.

Field efforts, later analysis, and consideration of recommendations were greatly aided by the volunteer efforts of Dean Branson and Fred Sittel from the Three Lakes Association and Bob Kingon from the Elk-Skegemog Lake Association.

Activities

Project activities were divided into three phases: 1) a three-day field campaign, 2) archival aerial imagery collection, 3) computer simulation, and 4) analysis and reporting.

Field Activities

A three-day field campaign was conducted from September 24th through 26th, 2012, which resulted in the collection of the following data:

- GPS elevation and stream discharge measurements at numerous road crossings along tributaries to the Grass River and the Rapid River systems.
- Bathymetry data collection of the Torch, Lower Rapid, and Grass Rivers, along with detailed surveys of bathymetry at the outlets of the Torch and Grass Rivers.
- GPS-tagged photography of the banks, bottom, channel, signs of erosion and other relevant hydrologic features along the Torch, Rapid, and Grass Rivers and their tributaries.
- Survey-grade GPS elevation data was collected and survey control points were established along the Grass River, along with Lake Bellaire and Clam Lake.
- Photo, elevation, and bathymetry survey of Rugg Pond and its dam.

GPS and Stream Discharge Measurements of the Grass River Tributaries and Rapid River

Three teams were mobilized to collect GPS, stream geometry, and stream discharge measurements at road crossings of the Rapid River and Grass Creek tributaries (Shanty Creek, Cold Creek, and Finch Creek). The teams worked separately, as the GPS team could work more quickly than the two discharge teams. Even with two teams, more road crossings were visited for elevation measurements than for stream discharge.

The first team, consisting of Bob Kingon and Dean Branson, used a Trimble GeoXH mapping GPS instrument (see FIgure 1). The Trimble GeoXH has an accuracy of around 60 cm, thus the lat/lon/elevation of a point can be determined to somewhere around 2 feet. The instrument was placed at the water line of each road crossing, if accessible. Otherwise, a fixed point on a bridge or culvert was used for measurement, and the distance to the water surface was measured and input as an elevation offset in the instrument.

The second team, Anthony Kendall and Lon Cooper, measured stream discharge using a Sontek RiverSurveyor S5 Acoustic Current Doppler Profiler (ADCP) (see Figure 2). The Sontek S5 is a state-of-the-art instrument that measures the depth of the water column beneath it along with the velocity of water in several vertical intervals (called bins). Mounted on a boat, such as the small Hydroboard in Figure 2, or alongside a boat as in Figure 5, the instrument tracks its motion along the river channel and will build a complete picture of the stream channel velocity and discharge (Figure 3).

Team three consisted of Blaze Budd and Kevin Cronk using two different instruments to measure stream discharge: a Marsh McBirnie FlowMate2000 and an OTT Acoustic Doppler Current Meter (ADCM). These two instruments function differently, but essentially are both used to measure stream velocity at a discrete number of points (15-20) across a channel while being held by a wading operator. The "wading method" is traditionally the most common means of measuring stream discharge, and can be used in streams shallower than the ADCP can float.

Bathymetry and Cross Section Geometry Surveys of the Torch, Lower Rapid, and Grass Rivers

The next field objective consisted of conducting a bathymetry (depth) and geometry survey of the Torch River, lower Rapid River (navigable section only) and Grass River. For this objective, the MSU team used GPS attachment for the ADCP with a ~3 foot accuracy. The ADCP instrument was then mounted to the side of a 14' shallow draft Boston Whaler using a custom mount (Figure 5). Mounted in this configuration, the ADCP measures points every 1 second along the path of the boat as it moves down the channel.

The boat was then driven in three separate survey patterns: 1) a zig-zag longitudinal (down-channel) transect, interrupted every so often by a 2) perpendicular cross-section, and followed ultimately by 3) a detailed weave pattern survey of key targeted areas. The first set of surveys was conducted along the Torch River and the lower Rapid River (Figure 6). We conducted a weave survey at the mouth of the Torch River where it empties into Skegemog Lake. The following day, we conducted the same set of surveys along the Grass River, culminating with a weave survey of the outlet into Clam Lake at the Grass River Natural Area dock. This set of surveys was timed to coincide with survey-grade GPS surveys conducted by Brett Fessel and Frank Dituri (see the section below).

Extensive post-processing was done to the raw ADCP data to create a set of GIS bathymetry products. First, using a Geographic Information System (GIS), a channel mid-point line was drawn for each of the Grass, lower Rapid, and Torch Rivers (Figure 7a). This mid-point line was then used to calculate down-channel distance, which can differ significantly from the distance traveled by a boat on a zig-zag path. Then, the GPS boath track locations are then combined with the path-tracking data from the ADCP instrument itself to produce a location track more accurate than either method alone. Next, the deepest point along every 50 meters of channel distance (approximately the wavelength of the boat's zig-zag path) was extracted (Figure 7b). This point represented the thalweg depth, or the deepest point in the river channel. The average depth along the zig-zag track for each 50 meter increment was also determined.

The GIS datasets created for the bathymetric surveys are made available as digital Appendix A.

GPS-located Photographic Survey of the Torch, Lower Rapid, and Grass Rivers

During all project activities, photographs were taken with two cameras that also collect GPS information and "tag" each photo. In total, over 500 photographs were taken, including: team photos, instruments, road crossings, erosional features (Figure 8), channel features, sediment and stream bed, and other relevant hydrologic details. These photographs, combined with GPS tags and dates, provide a snapshot of the rivers in their current state, and can be used to conduct repeat photographic surveys years or even decades in the future. Additionally, they provide information to help guide recommendations and remedial actions, ground-truth aerial imagery data, and context and analysis for processing field-collected data.

All project GPS-corrected photographs are provided as digital Appendix B to this document.

Survey-Grade GPS Measurements of the Grass River, Lake Bellaire, and Clam Lake

Because the entire system downstream of Intermediate Lake has a very low gradient, higher accuracy GPS measurements were necessary in order to provide estimates of water surface slope, and to set survey control points for repeat measurement. Frank Dituri and Brett Fessell joined the MSU team during their Grass River surveys and used their Trimble R8 GNSS system, capable of accuracies on the order of tenths to hundredths of a foot , to install benchmarked cross sections and survey control and generate a longitudinal profile of bed and water surface elevations for accurate slope calculations and hydraulics.

Additionally, the MSU completed an elevation survey of Elk, Skegemog, Torch, Clam, Bellaire, and Intermediate Lakes, as well as Blair Pond (Figure 9). However, the expected accuracy of this instrument was insufficient to accurately determine the gradient from Bellaire to Elk Lake.

Photo, Elevation, and Bathymetry Survey of Rugg Pond

The MSU team collected detailed measurements of the Rugg Pond Dam, including GPS elevations of the dam's hydraulic features (Figure 10) and a bathymetric survey of the pond itself (Figure 42).

Historical Aerial Imagery

The historical aerial imagery archive located at Michigan State University's Center for Remote Sensing and Geographic Information Systems (RS&GIS) stores hard-copy photographic prints of all major aerial imagery campaigns in Michigan prior to 1998. These images are provided free-of-charge, but require scanning and georeferencing (the process of assigning spatial coordinates to an image for overlay of other mapping data). Aerial imagery was available for 1938, 1950s, 1960s, 1970s, 1980s, and the early 1990s.

Jordan Hein scanned each image and then georeferenced those images. The process for georeferencing consisted of locating features such as road intersections or lake shorelines in the aerial imagery and on existing GIS road and hydrology datasets. Approximately 4-10 such "control points" are located on each image, and then the image is stretched such that the total distance between control points on the image and on the GIS data is minimized. Then, the overlapping images are then mosaiced to create a "seamless" product covering the entire study area (Figure 11). In total, 989 photographs were digitized and georeferenced, and "stitched" into 6 seamless mosaics.

All digitized aerial imagery and mosaics are provided as digital Appendix C.

After the image stitching process was complete, Jordan extracted shoreline and stream bank positions for each of the mosaics, along with locations of all houses along the Torch and lower Rapid Rivers and what mosaic image those houses first appeared. From these products, the total width of river channels was extracted in order to analyze bank narrowing or widening over time, and distance each house was setback from the stream at the time of its first appearance. To determine total width of the river channels, a series of lines was drawn perpendicular to the channel at approximately a 650 foot spacing. These lines were then intersected a stream channel polygon digitized from each aerial imagery mosaic. The length of each line then gave a measure of the total channel width, and changes in width can be thus compared over time.

These aerial imagery products are provided as digital Appendix D.

Findings

Grass and Rapid River Tributaries

The GPS and flow survey of the Grass and Rapid River watersheds yielded two key datasets: stream gradients and how flow changes along the stream channel. Plotted in Figure 12 are elevations along Shanty, Cold, and Finch Creek, the three primary tributaries to Grass River. Shanty Creek and Finch Creek are significantly steeper than Cold Creek, which all things considered lead to greater sand transport potential. This confirms earlier modeling work in SWAT that suggested these basins are more significant contributors of sediment to the Grass River than is Cold Creek. Overall, the Rapid River has a relatively uniform gradient along its length, with a slope similar to Cold Creek, though with some higher and lower gradient shorter reaches.

In terms of stream flow (Figure 14), Cold and Finch are more larger tributaries to the Grass River providing in excess 1 cubic meter per second (cms; ~35 cubic feet per second, cfs) while flow on Shanty Creek peaked at less than 0.3 cms. Note that the discharge measured on Finch Creek decreases from a peak of 1.44 to 0.70 cms due to a distributary channel near the confluence with Grass River.

Rapid River discharge increases significantly near the confluence of Rapid and Little Rapid River, increasing from a total of approximately 1.3 cms to over 4 cms just downstream of Rugg Pond. Flow conditions at the time of measurement were likely influenced by recent rainfall, thus do not represent just groundwater inputs. Downstream of Rugg Pond, flow peaks at 6.17 cms before decreasing slightly prior to its confluence with Torch River. This flow peak likely represents the crest of the “flood wave” from the previous rains. Rapid River, due to its intimate connection with local groundwater tables, is likely a gaining stream along virtually its entire length.

Visual surveys and GPS-tagged photographs indicated numerous examples of poorly-designed culverts throughout the two river systems. This is particularly true in the upper reaches of the Rapid River, above Rugg Pond (see photos in digital Appendix B).

Grass River Longitudinal Transects and GPS Elevations

Post-processed boat track depths for the Grass River are plotted in Figure 15. This plot displays all collected data points along the zig-zag survey track. In general, the pattern is that the edge of the track has the shallowest depths, while the center is deeper. The shallowest depths were selected in order to reduce the necessity for trimming the motor during data collection. This occurred at approximately 2.25 feet of water depth in our boat, but would vary depending on boat draft.

To compare bulk trends in the overall channel depth, the average navigable depth and thalweg (maximum) depth was calculated for each 50 meter channel segment (Figures 16 and 19). Plotted in Figure 16 are the average navigable depth and thalweg depth (diagrammed in

Figure 7) along the ~12,000 channel feet between lakes Bellaire and Clam. Highlighted on the plot are the confluence locations with Shanty, Cold, and Finch Creeks. Clearly visible at each confluence is a decrease in both average navigable and thalweg depths. These are not, however, remarkable decreases relative to others in the channel. Nevertheless, each confluence was accompanied by a distinct plume of sediment, visible on the water (Figure 17) and in the raw satellite imagery (Figure 18). The river responds to these sediment plumes by shifting the thalweg and widening the channel, and also by pushing that sediment downstream. The smoothed data do not show this effect as clearly as the raw data.

Navigation of the Grass River was relatively trouble free, though trimming the motor and hugging one edge of the channel was necessary at times. These navigation issues depend on the type of watercraft, but likely begin when average depth across the navigable width falls below 3 feet. Six or seven instances of this occurred along the Grass River, in particular downstream of the Shanty Creek confluence and 1-2,000 feet downstream of the confluence of Cold Creek.

Survey-grade GPS data of water surface elevations are plotted in Figure 20. Note the points between 6,000 and 8,000 feet down channel likely represent either a mislabeling of river bottom measurements as water surface, or errors in data resulting from postprocessing. To minimize the effects of these disturbances, and to assign an elevation to all points on the channel, a second-order polynomial was fit to the entire channel data series. The fit was reasonably good for this function, though it likely over-represents the gradient early in the channel, and under-represents later gradients.

In general, the elevation gradient is very shallow, no more than 1/10,000, or 0.01%. By contrast the gradient along Rapid River is approximately 0.5%, and sections of Shanty and Finch Creek closer to 1.5%. Gradient drives flow, and flow drives sediment transport. This discrepancy in gradient results in significant deposition of sediment bed load from tributaries into the main channel of Grass River, with little capability for the river to then move this sediment downstream.

As a result of the shallow gradient, flow along the entire Grass River channel is limited by the level of Torch Lake. To visualize this, a smooth second-order polynomial derived from the elevation data in Figure 20 was applied to each of the 50-meter average navigable depth and thalweg depth points, allowing those to be transformed from simple depths to absolute elevations. These are plotted in Figure 21. This makes clear that the bottom of the river bed at the Lake Bellaire outlet (the start of Grass River) is well below the water surface at the Grass River outlet into Clam Lake. The hydraulic resistance caused by the low gradient can be simply visualized by imagining that the water entering at the Lake Bellaire outlet is essentially directly pushing against the water in Clam Lake, rather than flowing unrestricted downslope.

The detailed weave survey of the Grass River mouth is mapped in Figure 22. Clearly visible in this map are the Grass River Natural Area dock and adjacent tongue of sandy sediment being deposited by one of the distributary channels of Finch Creek. This tongue, shown as orange and red (shallow) depth points persists downstream for approximately 300 feet and merges with another from a second channel, which then continues for another 500 feet before it is no longer distinctly visible at the furthest downstream extent of this survey. A semi-permanent GPS-located benchmark was established at the Grass River Natural Area dock at the time of this survey, allowing for a repeat survey to be conducted. This repeat survey will allow for very accurate determination of sediment volume changes over time.

Rapid and Torch River Longitudinal Profiles

Torch and Rapid river boat tracks are plotted in Figure 23. These tracks show acute navigational issues along the entire lower Rapid River segment (see Figure 24). Indeed, the navigable section proved shorter than anticipated prior to the field data collection. Visible in the satellite imagery basemap are very long docks reaching out to the boat track. The navigable width was very short narrow, and our zig-zag pattern was limited by channel depths along much of this segment.

Broadly, Torch River started out 5-6 feet deep, became shallower until just downstream of the confluence with Rapid River, and then stayed 4-5 feet deep until approximately 5,700 feet down channel from the Torch Lake outlet. At that point, the river deepened significantly, stabilizing near 9-10 feet, until becoming somewhat shallower just upstream of its confluence with Skegemog Lake. The marked disparity in depths in the upper and lower Torch River reaches is clearly visible in Figure 26 and is examined in further detail in the next section.

Similarly to the weave survey conducted at the outlet of Grass River, we conducted another at the outlet of Torch River into Skegemog Lake (Figure 27). We did not establish the same accuracy benchmark for this survey, however, because the water level on Elk Lake is very tightly controlled this serves as a reasonably accurate vertical datum, allowing for repeat surveys of the same point and sediment volume comparisons to be made in the future.

Rugg Pond Bathymetric Survey

Based on our bathymetric survey, Rugg Pond continues to function as a sediment sink for coarse-grained bed-load sediments from the upper watershed. Water exiting the spillway pipes downstream is then “sediment starved”, meaning it has the potential to further erode sediment downstream. There is visible evidence of some bank erosion at the dam outlet, however the relatively armored channel bed prevents significant scour at that location. From the dam, the swift current of the Rapid River maintains the potential to transport sand, but given the coarse texture of much of the stream bed along this length, the stream appears to be supply-limited (meaning less sediment is available to the water than it could theoretically transport) until the current begins to slow downstream of Freedom Park in Rapid City. At this point, the system becomes transport limited, and sediment deposition begins.

We conducted a Bathymetric Survey of Rugg Pond on November 4, 2012, but experienced technical difficulties with the ADCP instrument that limited the survey. We were able to collect one good transect around most of the perimeter of the pond, though the exact locations of each point were somewhat uncertain because the GPS receiver was not able to lock on to sufficient satellites, and boat track position was calculated solely using the instrument's bottom track capabilities. Nevertheless, we collected sufficient data (Figure 42) to demonstrate the Pond is still deep enough to retain bed load sediments, and to likely allow all but the finest suspended sediments to settle out of the water column prior to leaving the dam pond.

Historical Aerial Imagery

Simple visual comparisons (Figure 28) showed dramatic changes over the 80 year project scope. Visible are changes in stream width, mid-channel bars, stream depth, and other sedimentation features. Also visible are dramatic land use changes, which can be both indicators and drivers of changes in stream morphology.

To more accurately quantify the changes in the stream channel, the banks of the Grass, lower Rapid, and Torch rivers were hand digitized from each aerial imagery mosaic. These features are illustrated in Figures 29 and 31. While the positions of the stream channels appear to shift year to year this is mostly an artifact of uncertainties in georeferencing. Changes in stream channel geometry within a given single-time mosaic are much more robust, meaning that broad changes to river shape (i.e. new meanders) and river width can be confidently interpreted.

Following digitization of the historical stream channel geometries, the width of the channel was measured. The method described above for determining river width was specifically designed to be insensitive to small shifts in channel position from georeferencing inaccuracies. Changes in stream width are displayed graphically in Figures 30 and 32.

Changes in channel width were significant in all three river systems. Across the Grass River, the channel has widened on average approximately 25 feet between 1938 and the early 1990s. Only two sections showed little widening. Changes to the lower Rapid and Torch rivers were much more dramatic, however, in some cases exceeding 175 feet of widening. Also unlike the Grass River, where there is no systematic spatial pattern to widening, much of mid-lower Torch River experienced little to no widening, while areas in both the Torch and Rapid near their confluence widened significantly.

This spatial pattern is striking because it closely mirrors a dramatic difference in bank condition and stream depth observed during our Torch and Rapid River longitudinal surveys. Figure 33 was taken just below the Rapid River confluence with Torch River and shows massive recent bank erosion, leaving only the stumps and root structures of dead trees and a small island with younger trees still persisting. This stands in stark contrast to Figure 34 where no such in-channel vegetation was visible, instead replaced by long stretches of armored banks and characterized by much deeper channel depths (Figure 26).

These observations led us to compare the channel depths with the widths obtained from aerial imagery analysis (Figures 30 and 32) to produce Figures 36 and 37. Figure 36 shows little correlation between widening and depth along the Grass River. However the Rapid and Torch Rivers should a strong inverse correlation: deep areas of the channel have experienced little widening (Figure 37). This would be expected if the channel were initially close to uniform depth and bank erosion led to the infill of the channel thalweg in some areas but not others. The photos in Figures 33 and 34 illustrate this effect well.

Closer examination of field-collected GPS-tagged photos indicated further differences in the built infrastructure along the river banks. Houses in shallower sections of the lower Rapid and Torch rivers tended to be newer and set back further from the river, in some cases not visible at all. Contrast Figure 34 showing an older-style cabin with Figure 35 of a larger A-frame home with more modern (post 1970s) architecture.

To quantify the differences in home age and setback, aerial imagery mosaics were used. Figure 38 shows the years that each house positively identified from aerial imagery first appeared in our mosaics, overlain with channel widening. This figure illustrates that areas with more significant channel widening were in general built up later than sections that have remained narrow. Figure 39 shows those home ages with their distance from the river at the time of construction. The more modern homes were built with significant setbacks from the river. The lower section of Torch River that has resisted bank erosion was built earlier, homes were built closer to the river, and because of this seawalls were often constructed to protect the properties.

A visual comparison of Rugg Pond in 1938 vs. 2011 imagery (Figure 43) shows that the pond has filled significantly with sediment over the last ~75 years. This sediment fill rate suggests that the useful lifetime of the Pond as a sediment retention structure may be on the order of several more decades without any actions to deepen the pond, such as dredging.

Conclusions

This project has resulted in a nearly 20 GB database of field data, photography, aerial imagery, and GIS products. This database provides the foundation for the findings and conclusions in this report, and will serve as a critical snapshot of the state of the Grass/Rapid/Torch river system in 2012 that will serve as a reference point for decades to come. These records can also elucidate gaps in the existing and expanding dataset to be filled in order to prepare a comprehensive understanding of the process, prediction accuracy and more informed feasibility study and associated applicable action plans.

Our field data collection and combined aerial imagery analysis demonstrate that several key areas in the Grass River, all of the lower Rapid River, and portions of upper Torch River are affected by shallow channel depths. These depths lead to restrictions in two-way motorized watercraft traffic, even potentially impeding upstream navigation completely. Our data clearly locate these areas, and link them to bank erosion over the last 80 years inferred from aerial photographs.

Certain areas of the Torch River that have not experienced changes have been spared from widening and shallowing due to bank armoring put in place before restrictions on seawalls took effect, and at a time when houses could be built on low-lying areas with little setback from streams. These engineered banks have preserved recreational use of the water, but often compromise the benefits of natural stream function from an ecological and geomorphic perspective and leave little to no value for wildlife habitat or aesthetic value.

The watershed of the Grass River provides a significant source of sediment to the navigable channel, yet efforts to reduce these inputs may be less effective than desired. Because of the high gradients and significant baseflow discharge of Shanty, Cold, and Finch Creeks, these tributaries have likely always been contributors of sand to the Grass River. Bedload sand can be seen moving in the creeks even at low baseflow levels.

In the following section, we present a series of recommendations for dealing with the navigational problems. These recommendations should be taken as a means to solve that particular problem, with full awareness that any engineered modification of a system can result in myriad impacts on all uses, recreational, aesthetic, and ecological. Understanding the path by which this system has arrived at its current state is critical to putting into context any proposed changes to it.

Recommendations and Additional Data Needs

The trajectories of change presented in this report have been in place for more than a century, and result from a fundamental imbalance of sediment input and output from the three rivers. To reverse this trend, there are three broad categories of options: 1) reduce inputs, 2) remove stored sediment, and 3) increase sediment movement out of the rivers and into Clam and Skegemog Lakes. Recommendations to reduce inputs are discussed further in the

Based on our data collection and analysis, and informal discussions with stakeholders, we recommend:

1. establish a GIS database of the system;
2. preliminary installations of large woody debris (LWD) bank armoring at select locations along the Grass River;
3. continue to improve road crossings and identify acute sediment sources in tributaries;
4. a detailed shoreline character analysis of areas affected by erosion;
5. a feasibility study of large-scale LWD armoring and dredging of acute navigational hazards;
6. a stakeholder and property owner survey to gauge the support for active intervention options;
7. continued regular monitoring of channel bed sediment elevation, and establishment of uniform and rigorous methods for data collection; and
8. studying new management options for the Elk Lake Dam to increase the hydraulic gradient at key times of the year.

1. Establish a GIS Database

Because these recommended, and any other, actions to be undertaken toward reducing the sediment problem on the Grass, Rapid, and Torch Rivers will be led by a cadre of volunteers spanning a large region over many years to decades, it is important to establish a permanent GIS repository. This database will store the data generated during this project, related efforts, and any follow-on actions. It will provide the means by which any contracted or volunteer efforts can then return data to the partner organizations, which can be used to monitor long term changes and provide independent verifiability of any remedial actions, and to help validate simulations or models developed.

Developing the infrastructure and expertise for this database should not be expensive, and there are numerous organizations and individuals with the skills and expertise to accomplish it already within umbrella of existing partnerships.

2. Preliminary Large Woody Debris (LWD) Bank Armoring Installations

Armoring banks to protect them from erosion, but also to help confine flow to a more limited section of a stream channel, is a method that has been widely applied across northern lower Michigan. Sometimes referred to as tree revetments, these installations typically consist of several mid-sized trees anchored to the bank aligned such that their crowns face downstream. Installations of this type can be seen extensively across the Au Sable River, Pine River, and Pere Marquette, among others.

The Grass River differs from these rivers in that motorized two-way watercraft traffic is the predominant use of the waterway. Furthermore, the installation of such LWD armoring is intended not simply to prevent further erosion, but also to modify the current in the channel, potentially deepening the thalweg and narrowing the banks over time.

Efforts are currently underway to install two initial sites. These efforts have focused on permitting, gathering public opinion, siting, and securing funding. In addition to those efforts, we recommend that re-surveying channel depths up- and down-stream of the two installations take place in late Spring of 2014. Also, prominent signage should be installed at the sites to inform recreational users of the structures, and to direct them to a website with more information. Further meetings and feedback opportunities should be presented to gauge support and perception of these first installations.

In addition to the two sites selected for initial installation, which will be in critical shallow depth areas downstream of Cold Creek, an additional site downstream of Shanty Creek is recommended. Selection of this additional site would depend on availability of material for the installations, and other issues related to shoreline character and site access.

3. Road Crossing and Erosion Feature Improvement

Efforts undertaken to evaluate acute sediment sources should continue, including:

- maintaining an inventory of road crossings, noting conditions, storing photographs, and identifying problematic culverts;
- regularly updating this inventory via volunteer assessments on a rolling, biennial basis;
- walking tributaries during late summer low-flow periods, photographing and describing any acute erosional features; and
- taking remedial actions to repair erosional features and problematic culverts.

4. Detailed Shoreline Character Analysis

Any efforts to fix a perceived problem must not lead to further, perhaps unintended, negative consequences. In particular, the Grass River and portions of the Rapid and Torch have stretches of pristine shoreline vegetation (Figure 40), and present wildlife (Figure 41). The general character of the shoreline needs to be fully characterized to determine the suitability for shoreline modification at that location. Shoreline can provide aesthetic, ecological, economic, and erosion protective value.

Volunteers equipped with GPS-tagging cameras (for example most smartphones) can gather the necessary photographic data, which can then be classified inexpensively. Consultation with ecologists will help to determine a classification scheme that will eventually lead to a suitability ranking for shoreline remedial action. These classifications should then be entered into a GIS shoreline inventory.

5. Feasibility Study of Large-Scale LWD Armoring and Dredging

We recommend that areas or reaches identified as limiting navigation , based on channel aggradation or other morphological changes, be investigated further for detailed hydraulic analyis for channel modifications and feasibility to address navigation issues while fully considering other salient issues such as costs and details on planning, engineering, designing, construction, maintenance and monitoring., tech capacity, permitting, armoring and dredging. This feasibility study should consider the costs, technical suitability, ecological and aesthetic concerns, availability of materials for installations, site access and permitting, and other factors.

Areas with significant shoreline erosion and considerable flow, such as along much of the Grass River and the Torch River, will likely need only some form of shoreline armoring to reduce active stream width. After this, sand-sized sediment should be transported further downstream.

The Lower Rapid River presents opportunities to selectively target LWD armoring projects, though doing so will require a different permitting process along the largely privately-owned shoreline as opposed to the mostly publicly-owned shoreline on the Grass River. Furthermore, because the Lower Rapid has widened so dramatically, the requisite water velocities needed to deepen the thalweg after LWD installation are likely to be found in fewer locations. However, because of navigation issues, we were unable to collect any depth-velocity transects during our longitudinal survey. We recommend performing cross-section velocity surveys with an ADCP as done in this study at numerous locations along the Lower Rapid River, both above and below the Aarwood Road bridge, that can be accessed via canoe or kayak.

In addition to shoreline restoration efforts, LWD installations may potentially be used at the upstream-most location where erosion has caused the river to widen in order to help stabilize and maintain shoreline and river depth. According to the historical shoreline delineation conducted here (see Figure 31), significant bank widening begins upstream of the Aarwood Road bridge. This bank widening appears to continue in the most recent imagery analyzed, and halting this further erosion can likely help reduce sediment sources further downstream.

However, to maintain the desired hydraulic cross sectional area to accommodate navigation, the lower Rapid River in particular may require dredging in order to deepen the channel in key areas. This dredging can also provide sediment to reconstruct eroded banks behind LWD installations. These actions are likely to occur primarily on private property, and thus buy-in from landowners will be key to implementing any active intervention approaches (see Recommendation #6).

Dredging is invasive and expensive, and is by no means a cure-all to navigation issues. It can, however, effectively deepen areas that even with LWD reinforcement may have difficulty moving sediment on their own. Even then, there are many issues associated with dredging including maintenance, cost, and liability. Any decisions to pursue this course should be taken with extensive evaluating of the ramifications and feasible alternatives.

6. Stakeholder Survey of Support for Active Intervention

Prior to implementing projects beyond the initial LWD installations, a survey of stakeholder support for such actions should be undertaken. This survey should:

- determine perceptions the current state and desired end-point of the system;
- ask opinions on the performance and appeal of initial LWD installations;
- rank the desirability of potential remediation solutions;
- gauge support for adaptation to changes, as opposed to active mitigation;
- provide education about related issues;
- be a feedback mechanism for additional suggestions; and
- inquire about uses of the rivers.

The survey will offer engagement and provide legitimacy for efforts to improve the state of the system, and facilitate the permitting process through (presumably) clear stakeholder support.

7. Continued Regular Monitoring

Efforts to reverse the widening and shallowing trajectory of the Grass, Rapid, and Torch Rivers will take years to decades before they bear full fruit. During this process, regular monitoring will provide the best basis for assessing efficacy and function of actions taken while considering stability trends and. The data and methods in this report can serve as a background and template for anyone wishing to conduct follow-on studies. Monitoring should consist of: before-and-after surveys near installations or where impacts are expected, and biennial full-system surveys to gauge the broader scale trajectory of all three rivers. Of particular interest are changes that could occur following large rain events, or sudden pulses of water due to releases from upstream or downstream dams.

8. Studying Management Options for the Elk Lake Dam

By increasing the hydraulic gradients from Lake Bellaire to Clam Lake, and then from Torch Lake to Skegemog Lake, the sediment carrying capacity of the system will increase, and channel thalwegs may deepen. One means of achieving this would be to simultaneously lower the levels of Intermediate Lake and Elk/Skegemog Lakes by releasing water from their respective dams. Under the current legal structure, Elk Lake is maintained to within a few inches of a court-ordered level. To minimize impacts on recreation, a release could be made during the fall and winter months, an action which courts throughout the state have allowed for similar reasons (erosion or ecological concerns).

This type of management action would need to be evaluated to determine if:

- releases can accomplish desired gradients within a several month timeframe;
- the system can recover to required summer levels as mandated; and
- existing engineered infrastructure can handle these changes.

This option may provide the greatest lever to affect the trajectory of the system upstream of Elk Lake, however this study has not collected sufficient data to definitively answer that question. A comprehensive study should be undertaken to better define the role of the dam and its management on sediment deposition upstream. The study should be undertaken by a large group of stakeholders, and involve both academic researchers as well as consultants from private industry. Stakeholder groups across the region have extensive experience forming such teams, and in conducting large scale planning and feasibility studies.

We recognize as well that altering management of the dam would be a long-term effort, potentially requiring approval from the Federal Energy Regulatory Committee to modify the license of the dam. Furthermore, an analysis of the impact on hydroelectric energy production should be undertaken. Finally, extensive efforts should be undertaken to address community concerns, particular from riparian landowners that stand to be most affected by any active intervention strategy, particularly this one.

Figures

Figure 1. Bob Kingon of the Elk-Skegemog Lake Association collecting a GPS measurement on the Cut River. In the background, Lon Cooper (in yellow) and Anthony Kendall (in black) prepare for a stream discharge measurement using the ADCP (white and blue boat).

Figure 2. Lon Cooper and Anthony Kendall pulling the ADCP across Shanty Creek, a tributary of the Grass River, the measure stream discharge and channel geometry.

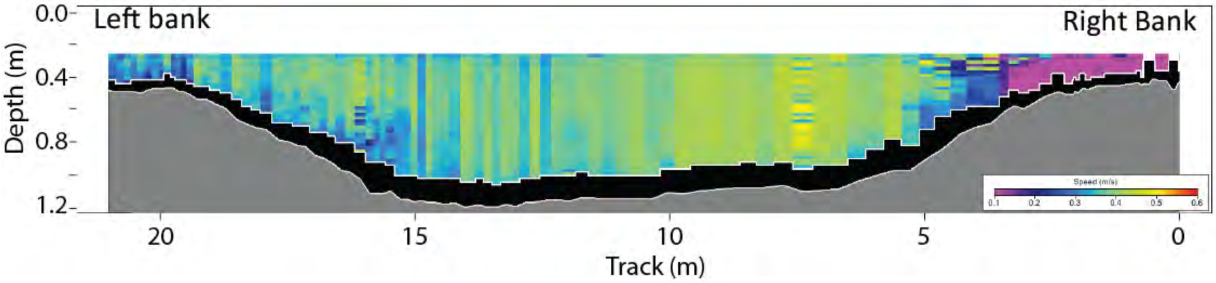

Figure 3. Sample ADCP cross-section showing the depth, geometry, and water velocity in the channel. Colors in purple and blue are slower water (potentially even flowing backwards), while yellow and red indicate more swiftly moving current.

Figure 4. Blaze Budd measuring discharge using the wading method (with the OTT ADCM) along the upper Rapid River near sunset.

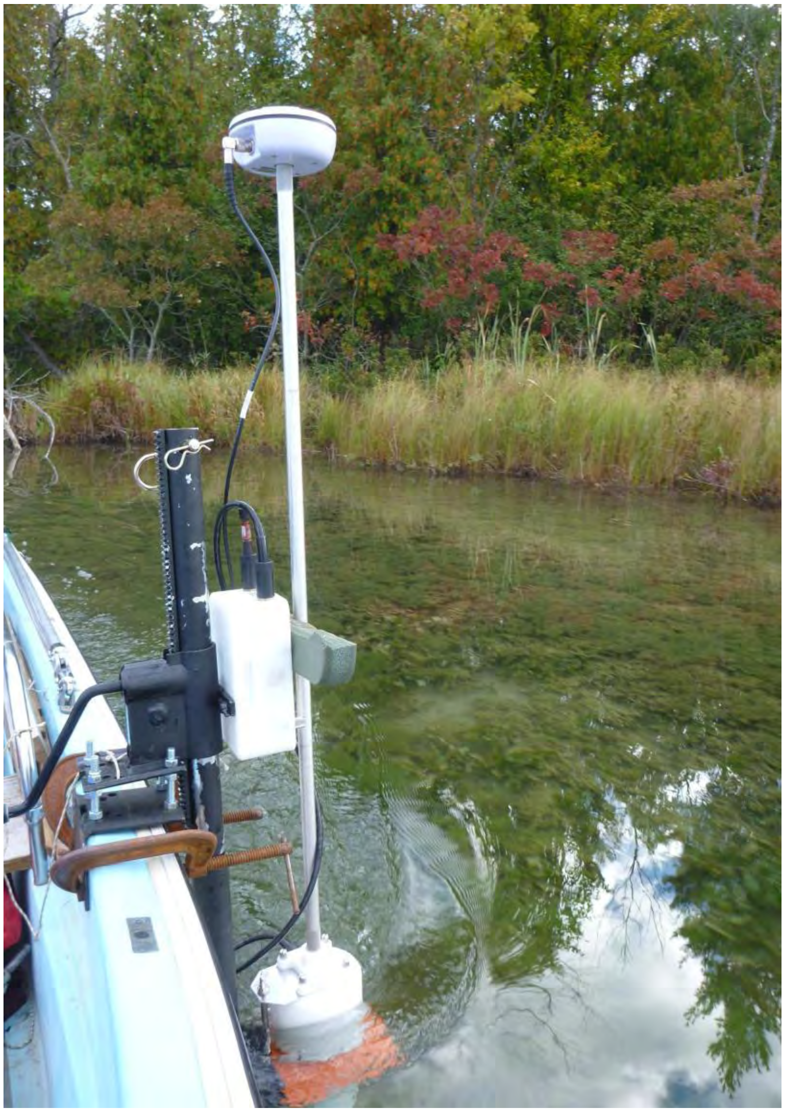

Figure 5. ADCP mounted to the side of MSU’s boat collecting simultaneous GPS and depth measurements along the Grass River.

Figure 6. Anthony Kendall driving MSU’s boat on the Torch River. The zig-zag pattern of navigation along the channel is visible in the wake trail behind the boat.

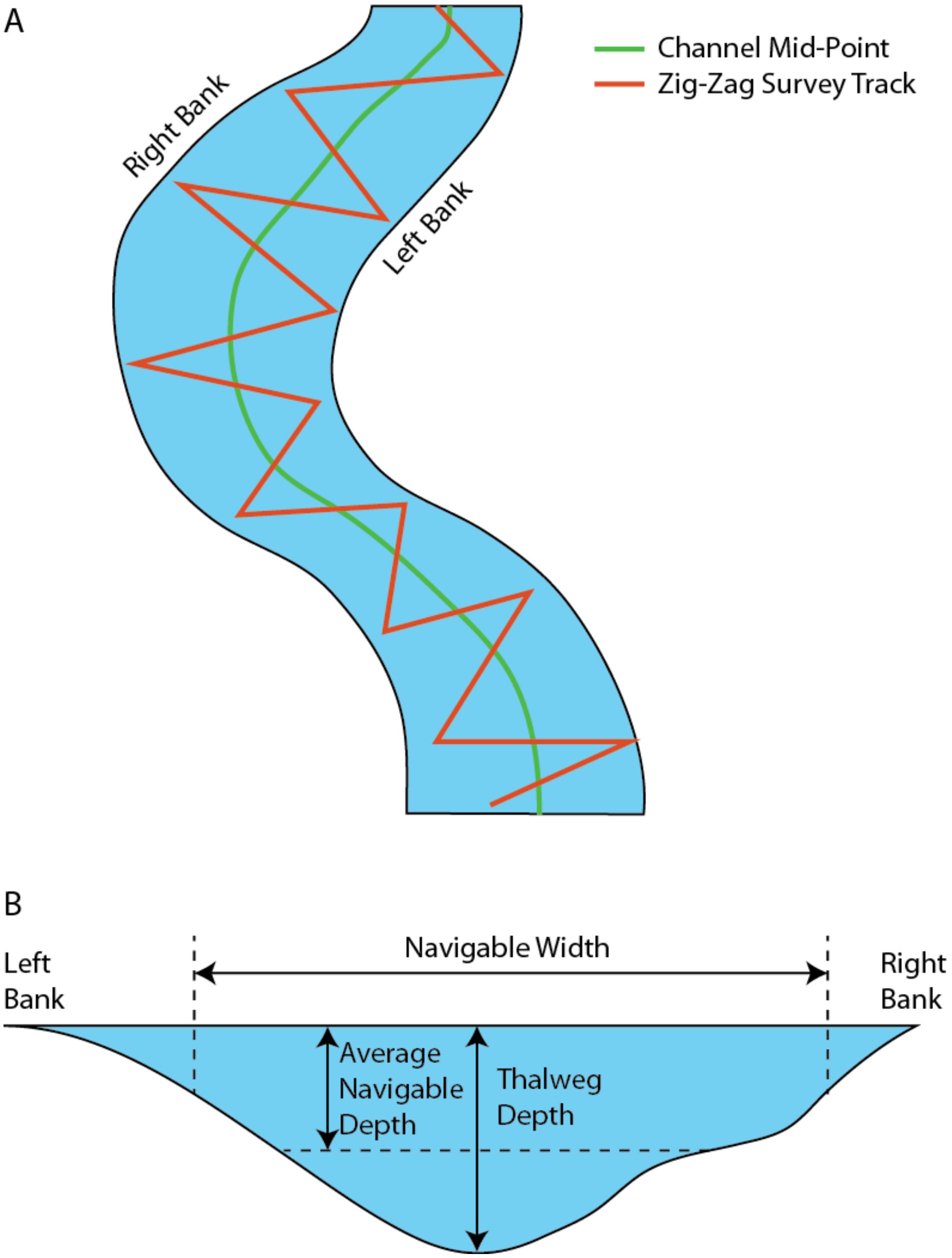

Figure 7. Schematic diagram of key post-processed channel data concepts. Part A shows a map view, illustrating the channel mid-point line and conceptual zig-zag survey track path. Part B is a cross-sectional view illustrating the navigable width of the stream, the average navigable depth, and the thalweg depth. By convention, the Right Bank is on the right while facing downstream.

Figure 8. Image of severe bank erosion along the lower Rapid River. The stumps in the foreground were once on shore.

Figure 9. Lon Cooper surveying the water line at the outlet of Craven Pond (Blair Lake).


Figure 10. Lon Cooper collecting a GPS elevation measurement below the secondary spillway of Rugg Dam.

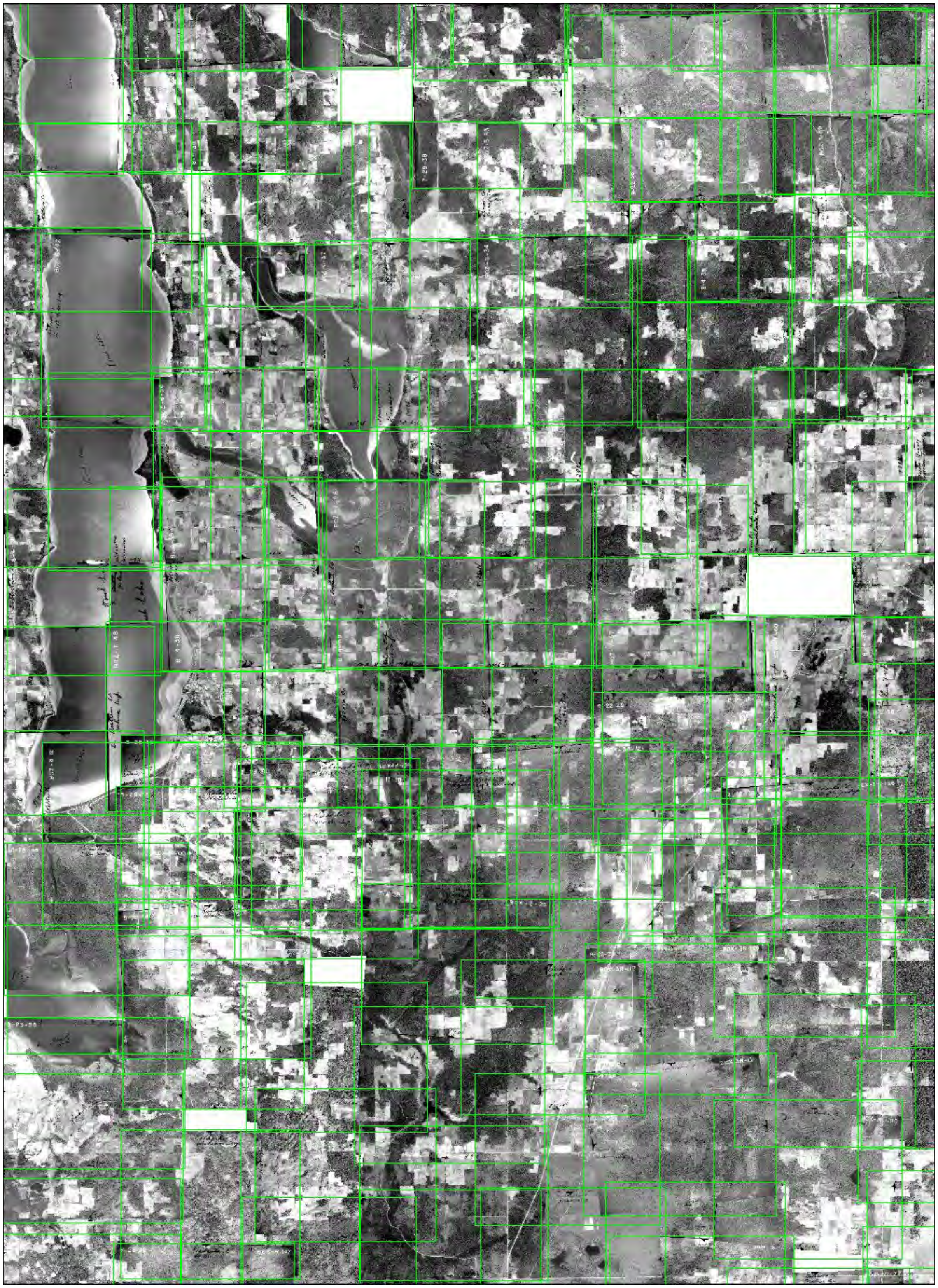

Figure 11. Portion of the image mosaic for 1938 showing green outlines for the footprints of individual images within the mosaic.

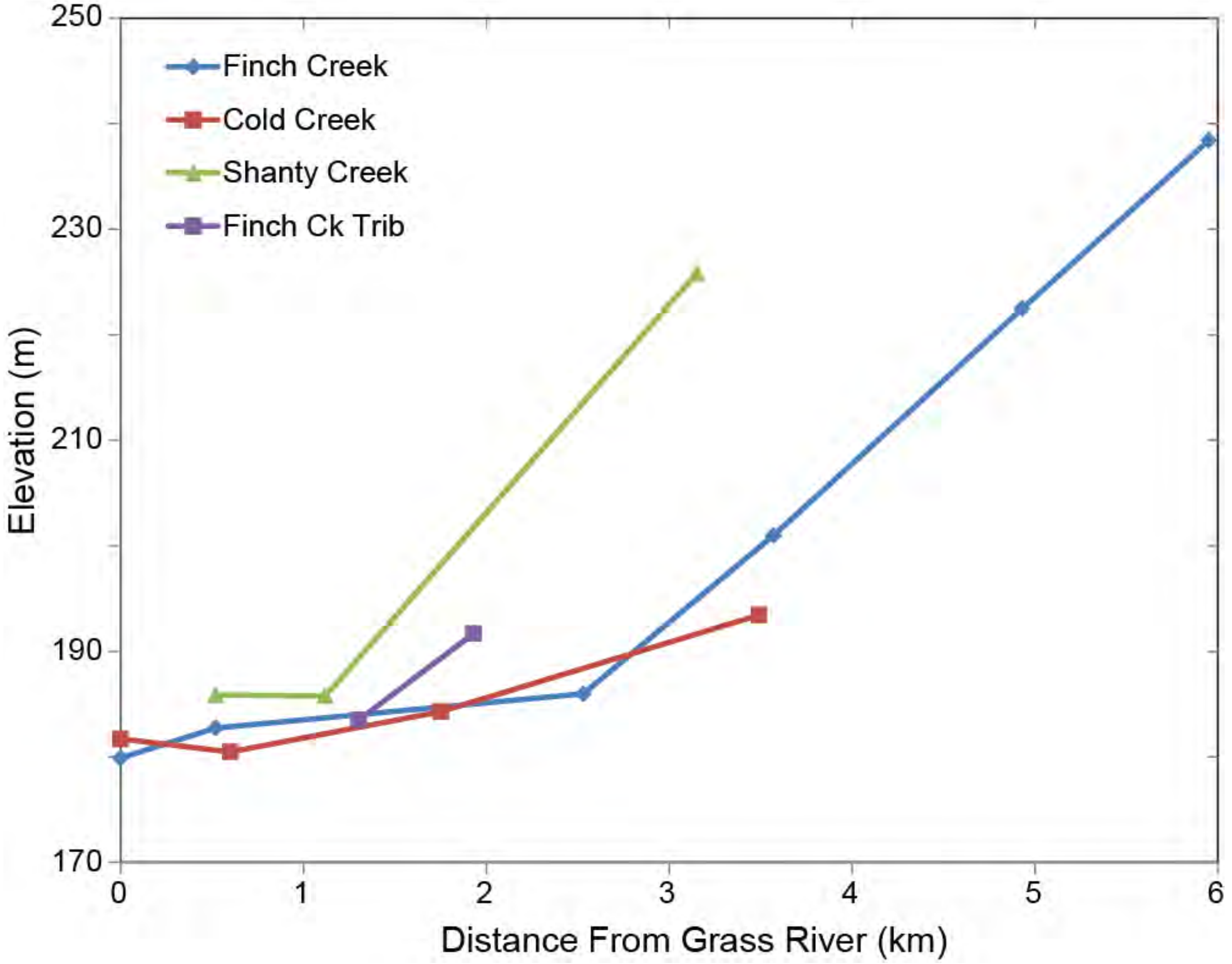

Figure 12. Plot of GPS-surveyed elevations along tributaries to the Grass River

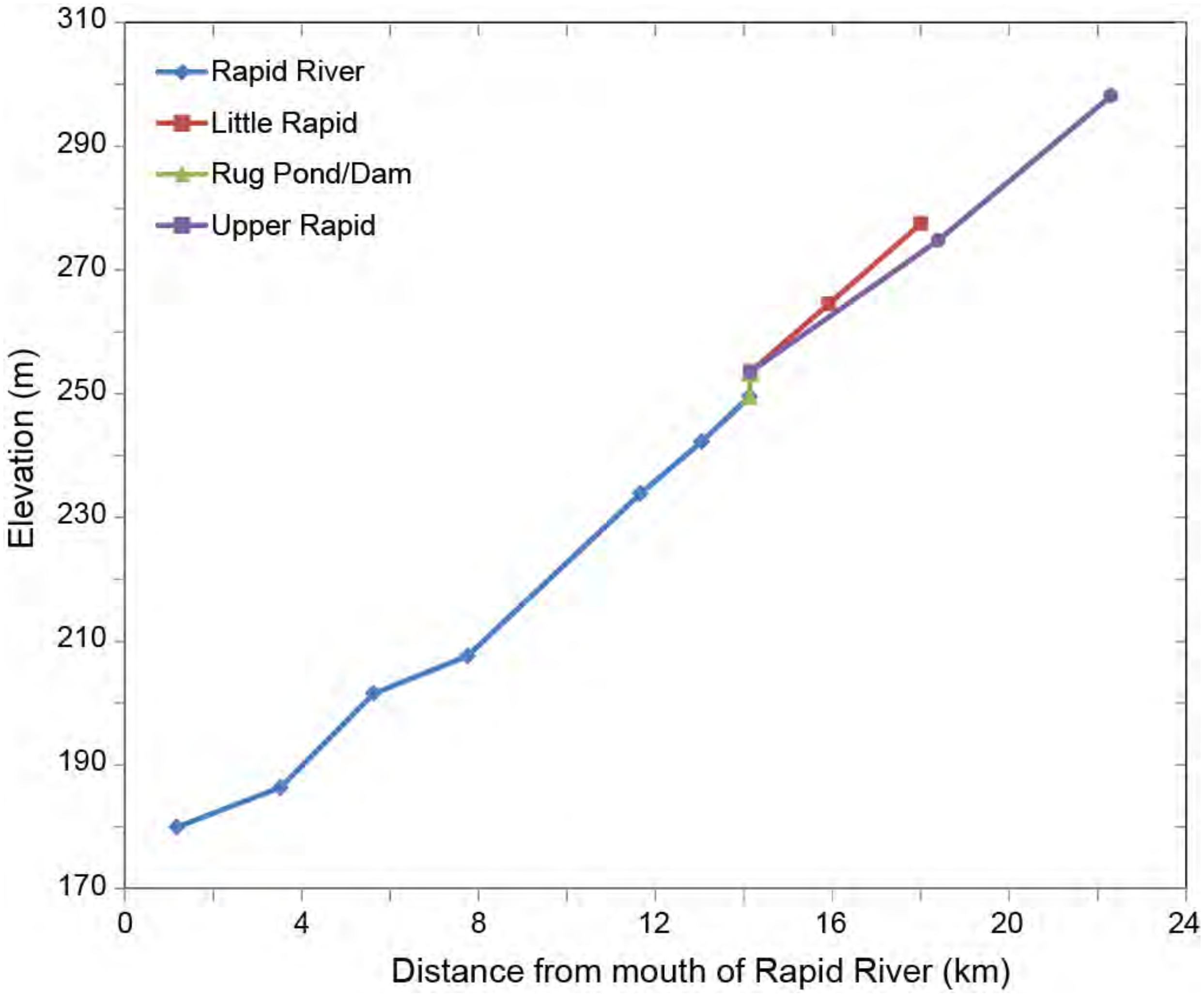

Figure 13. Plot of GPS-surveyed elevations at road crossings along Rapid River, including Rugg Pond Dam.

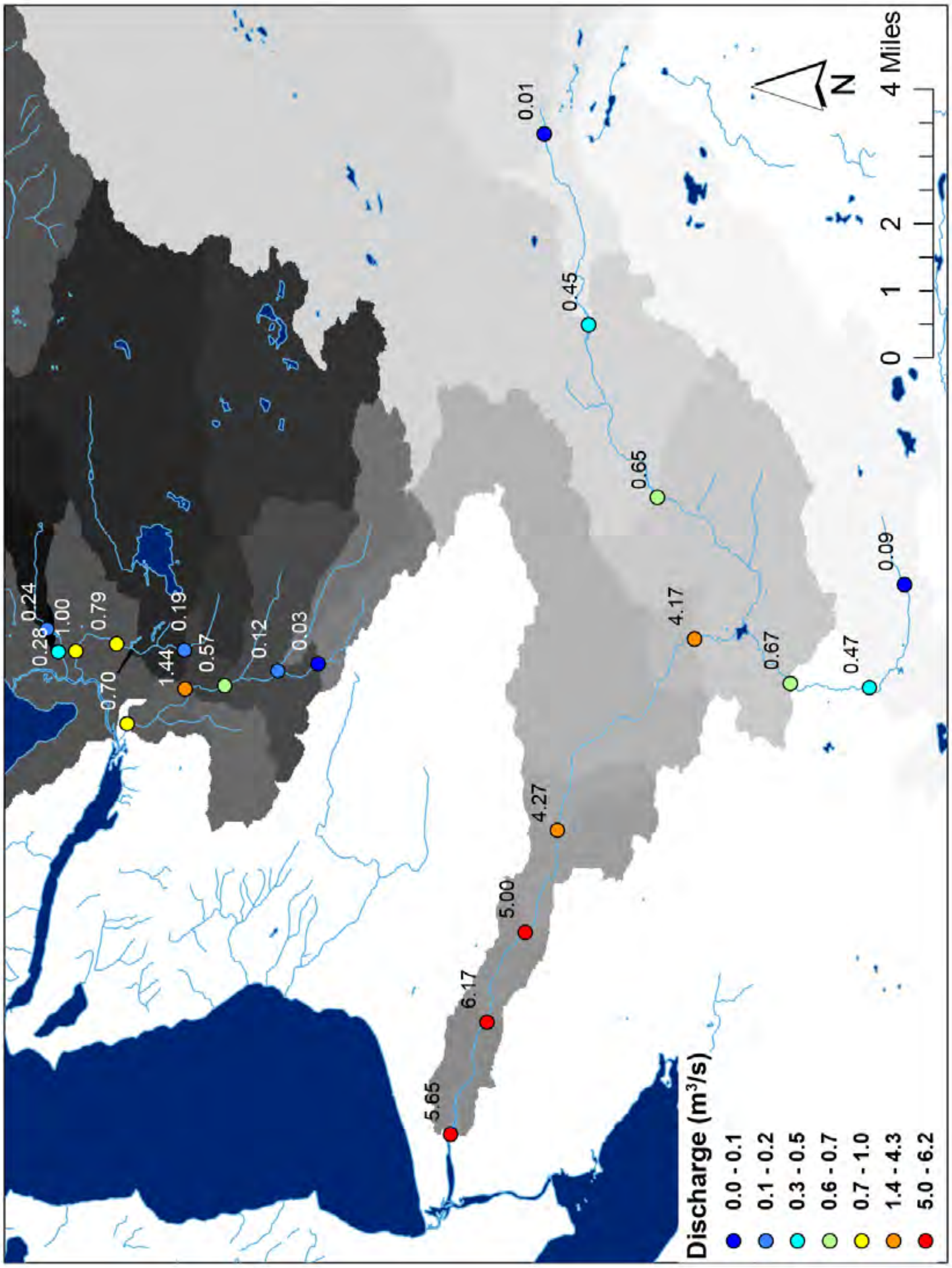

Figure 14. Map of measured discharge values along the Grass River tributaries and Rapid River, including catchments for each point in shades of grey.

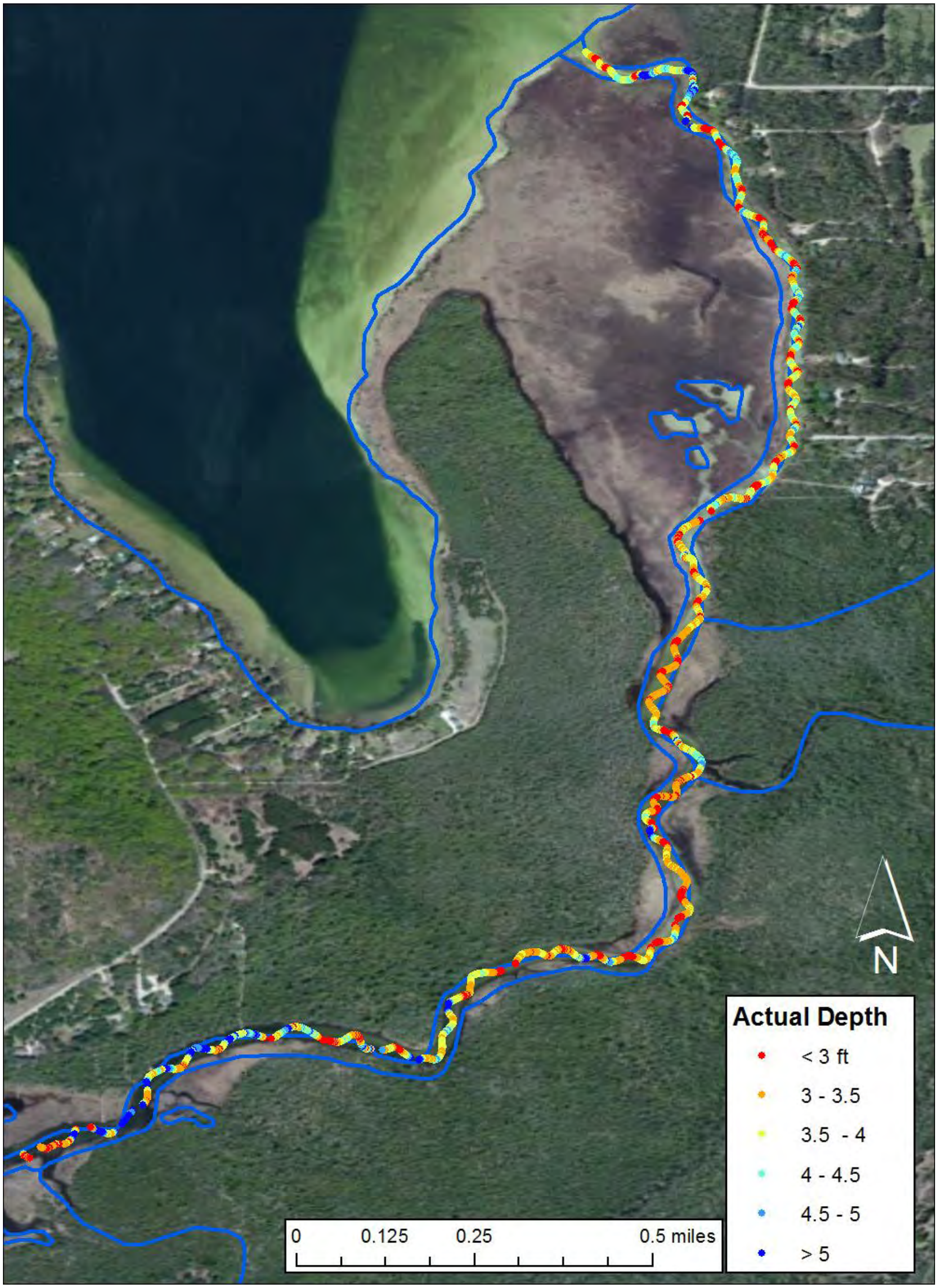

Figure 15. Map of the Grass River longitudinal transect depth measurements collected with the ADCP. Notice the zig-zag path of the boat, which was used to capture the depths of the entire navigable channel.

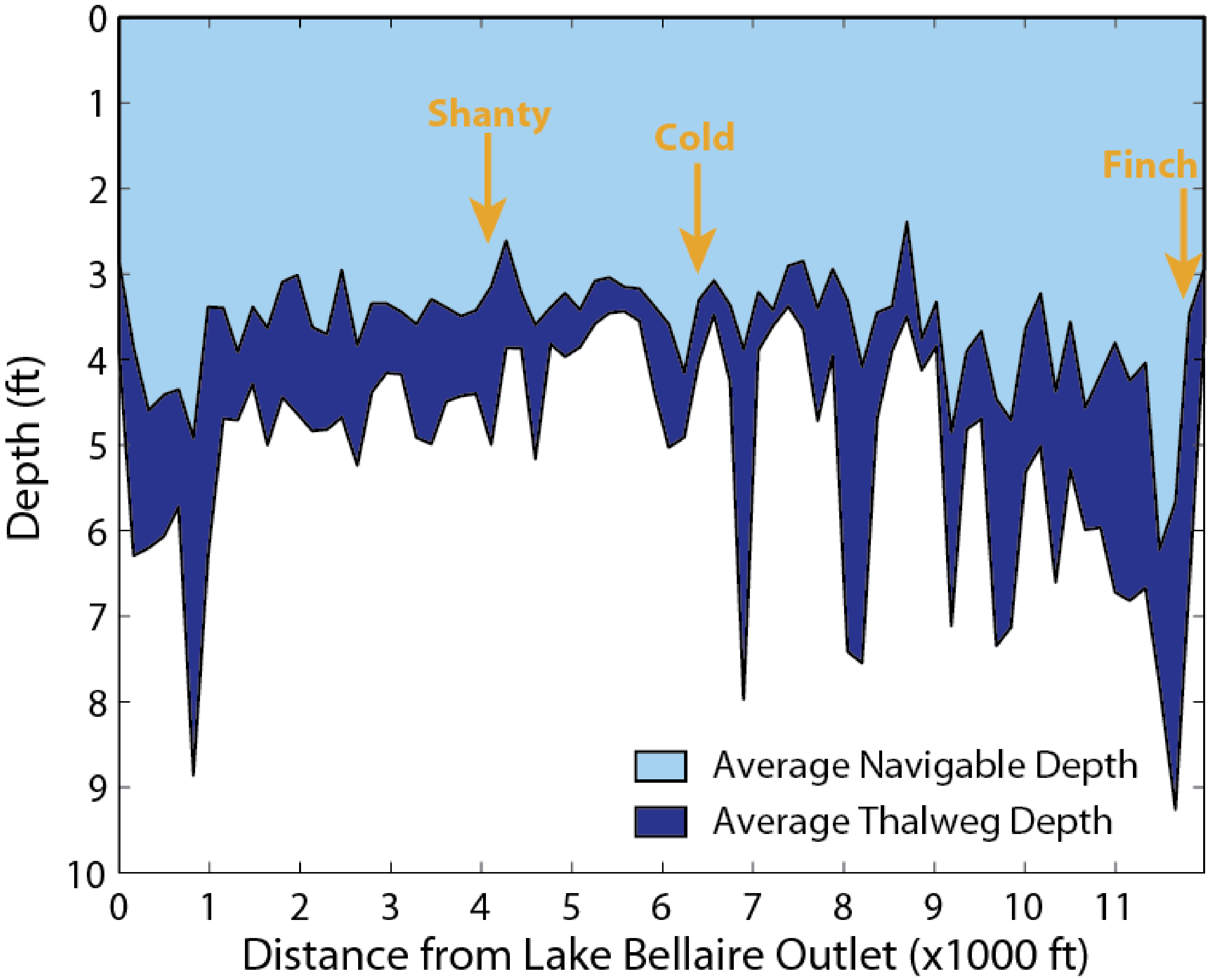

Figure 16. Plot of 50-meter average navigable channel depth along the Grass River, and average thalweg depth. The thalweg depth was calculated as the deepest point along each 50 meters of distance along the channel median.

Figure 17. Image of the confluence of Shanty Creek and Grass River. The perspective looks upstream at Shanty Creek. Note the active sand sediment plume from Shanty Creek on the right of the image. Note that this location differs from the Shanty Creek confluence on most maps, as shown in Figure 18 below.

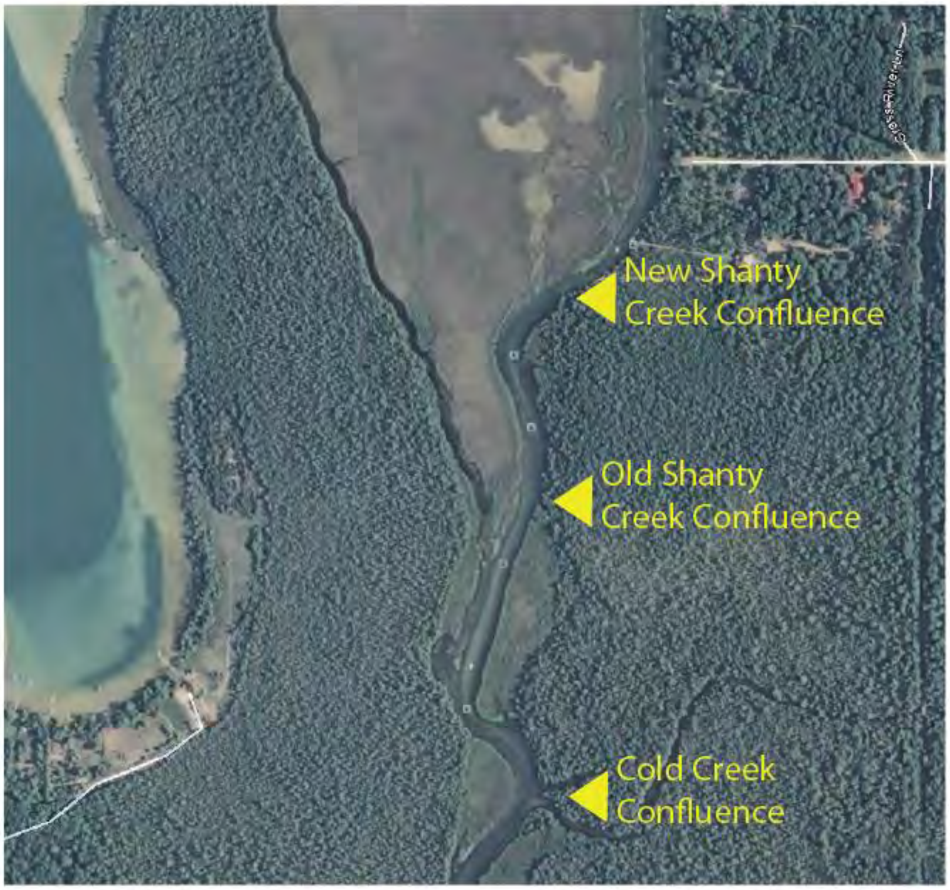

Figure 18. Plot of observed location of the Shanty Creek confluence on recent satellite imagery (Copyright Google), compared to the historical (mapped) confluence.

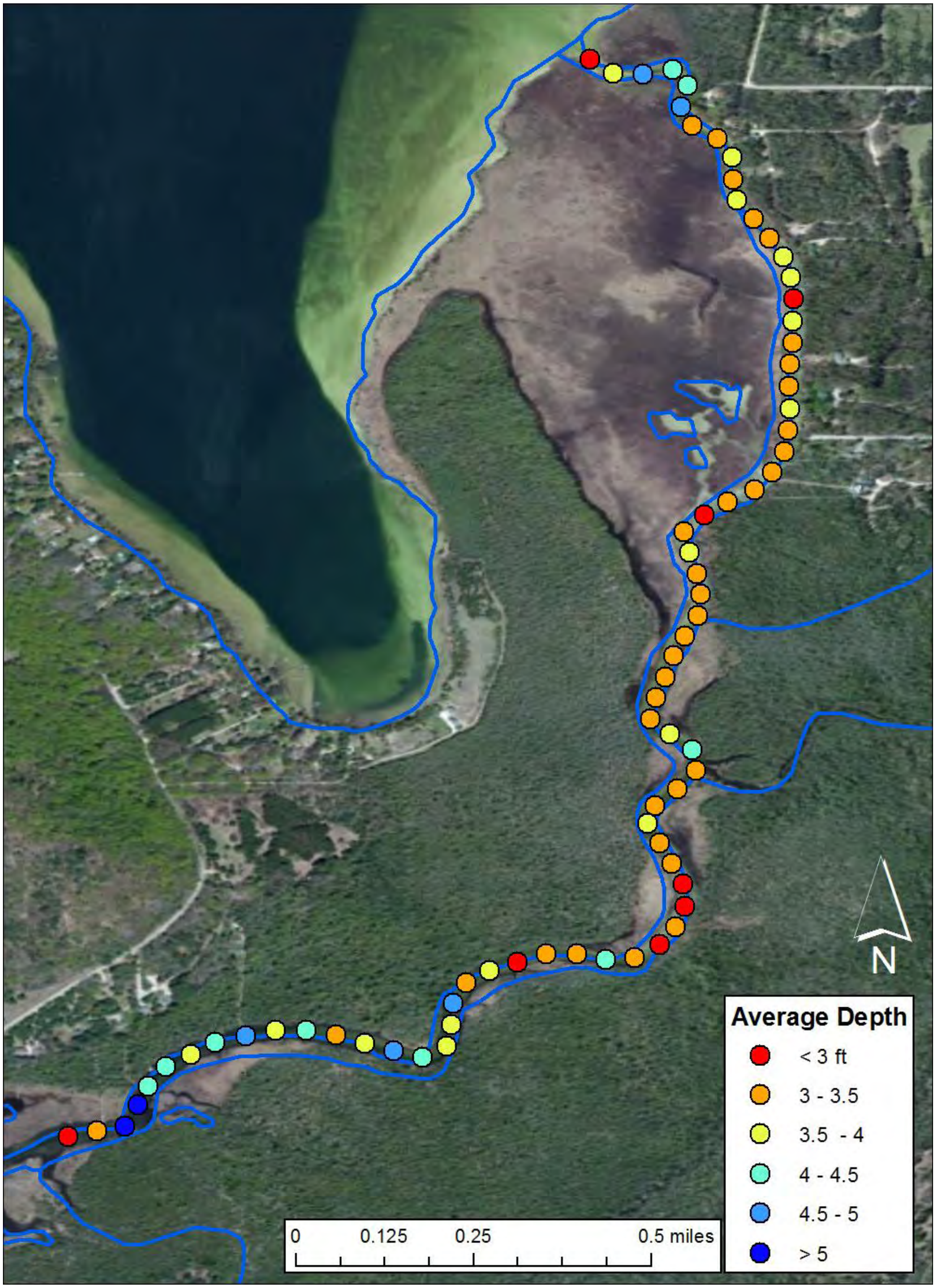

Figure 19. Map of average navigable depth along the Grass River, averaged in 50 meter increments along the channel.

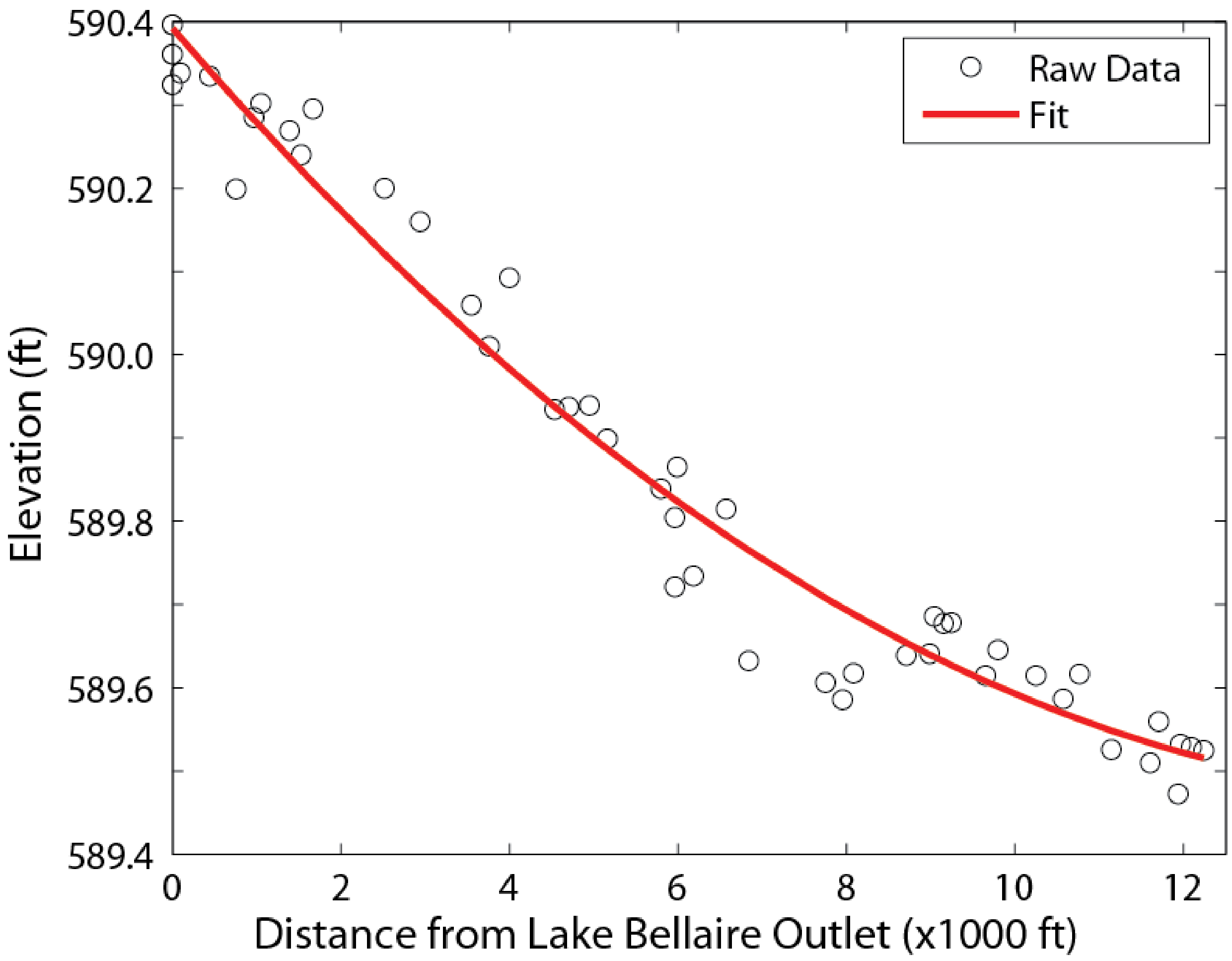

Figure 20. Plot of GPS elevations collected along the Grass River transect, including both raw data and a second-order polynomial fit.

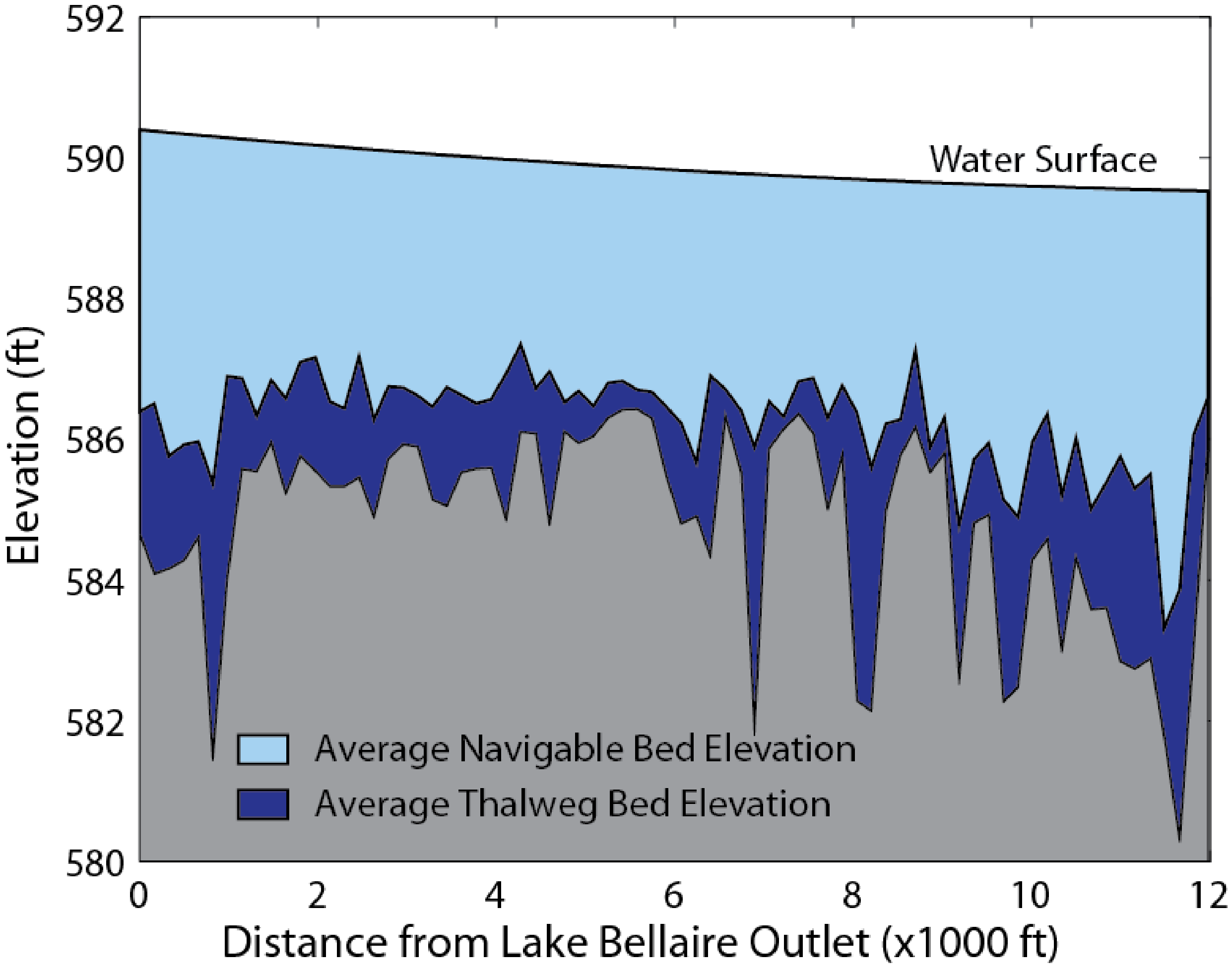

Figure 21. Plot of average navigable stream bed elevation and thalweg bed elevation, given by the polynomial fit in Figure 20. Similarly to Figure 16, the data are averaged for 50-meter lengths of channel.

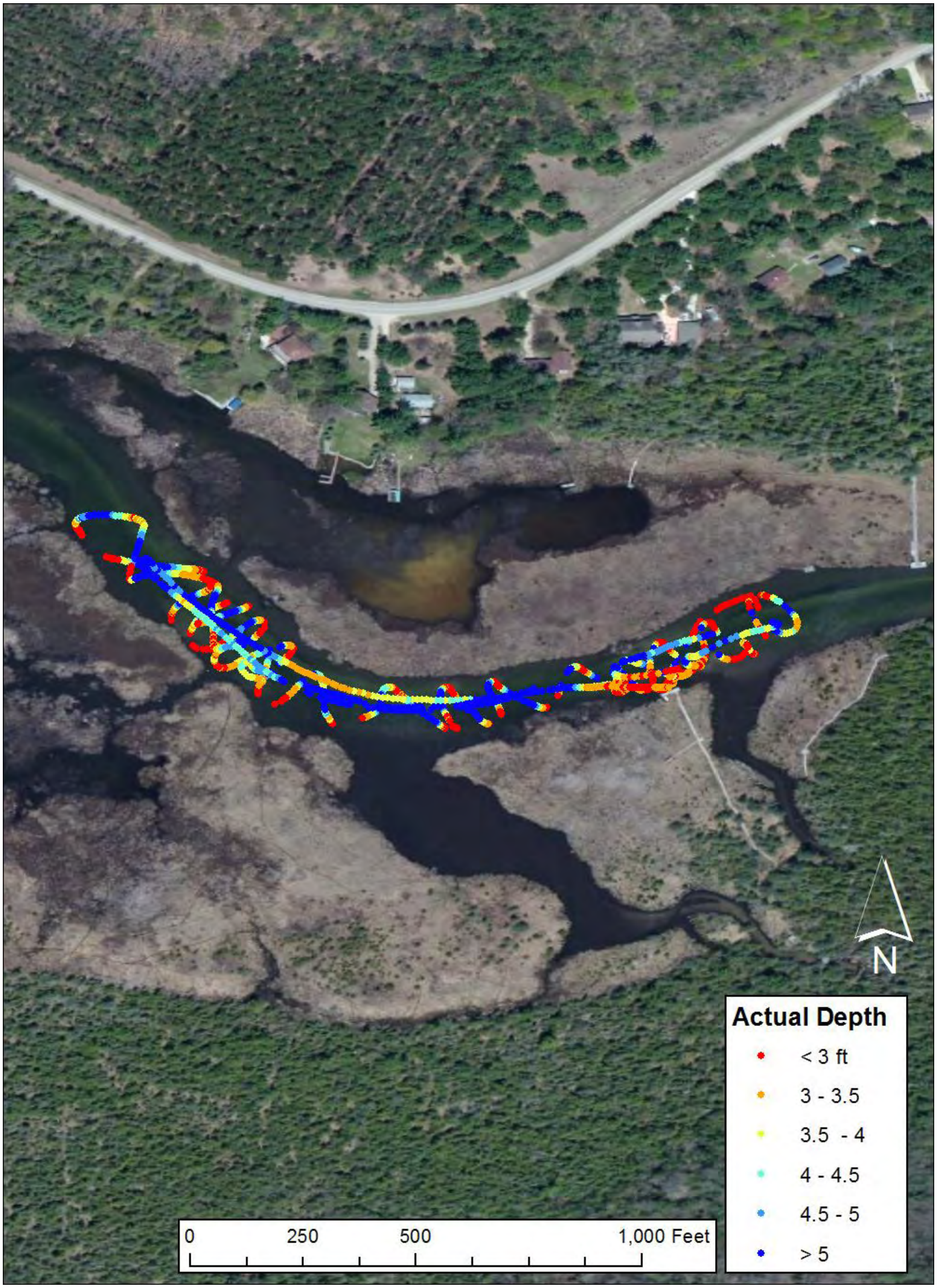

Figure 22. Map of detailed channel depths at the Grass River outlet into Clam Lake.

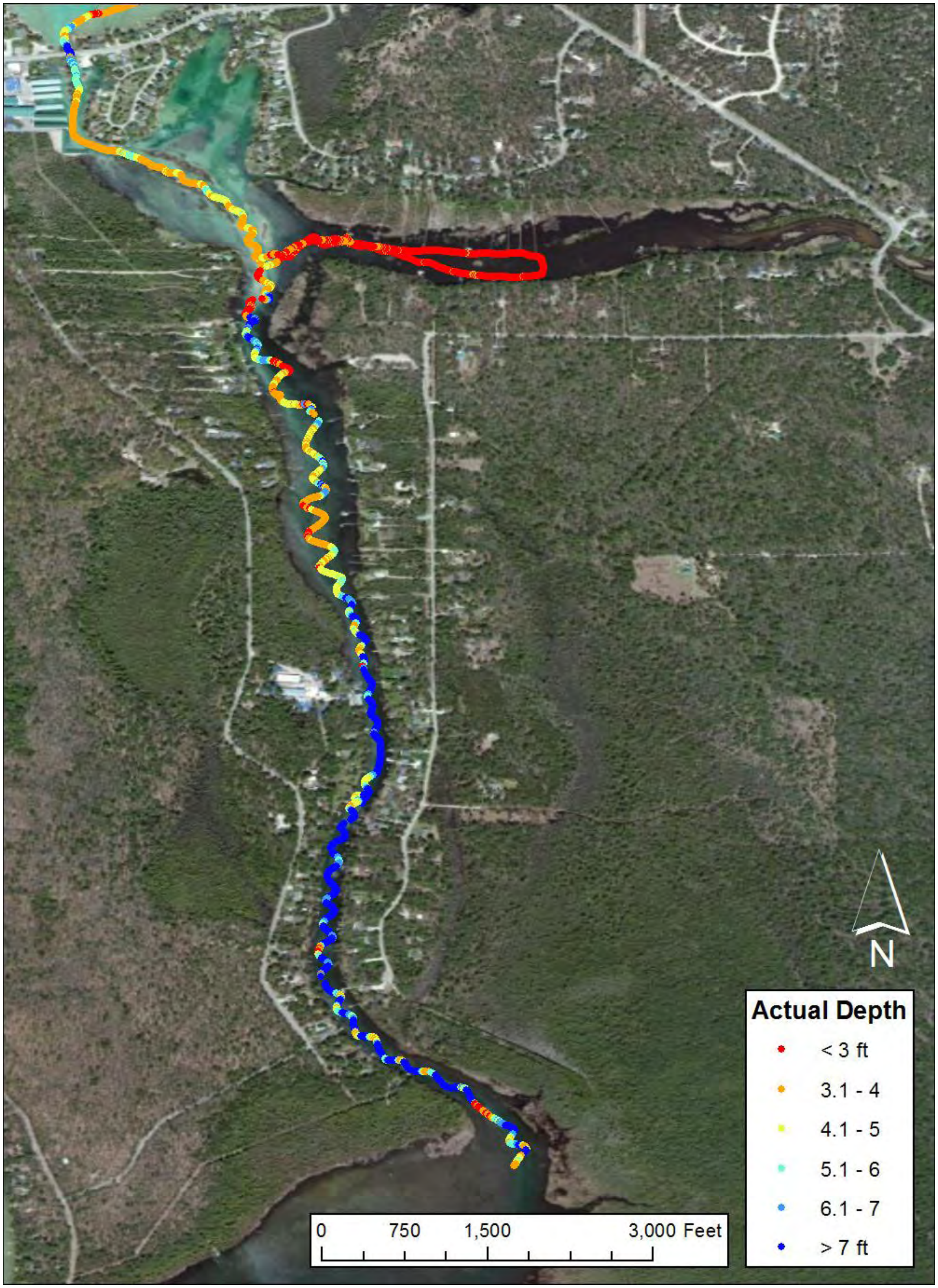

Figure 23. Map of measured depths of the Torch and lower Rapid Rivers along the boat track, which followed a zig-zag pattern throughout the navigable portion of the channel.

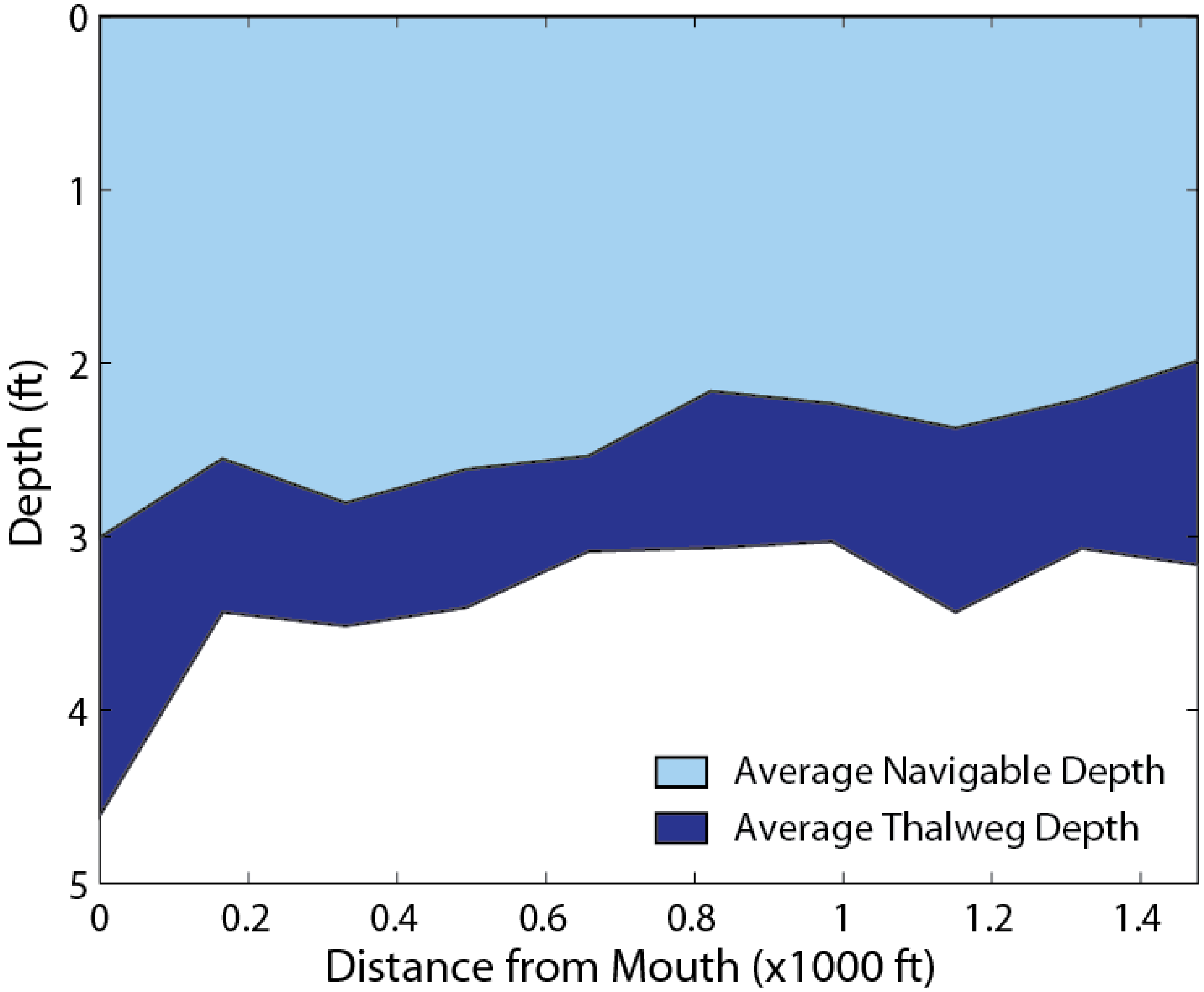

Figure 24. Plot of 50-meter average navigable channel depth along the lower Rapid River, and average thalweg depth.

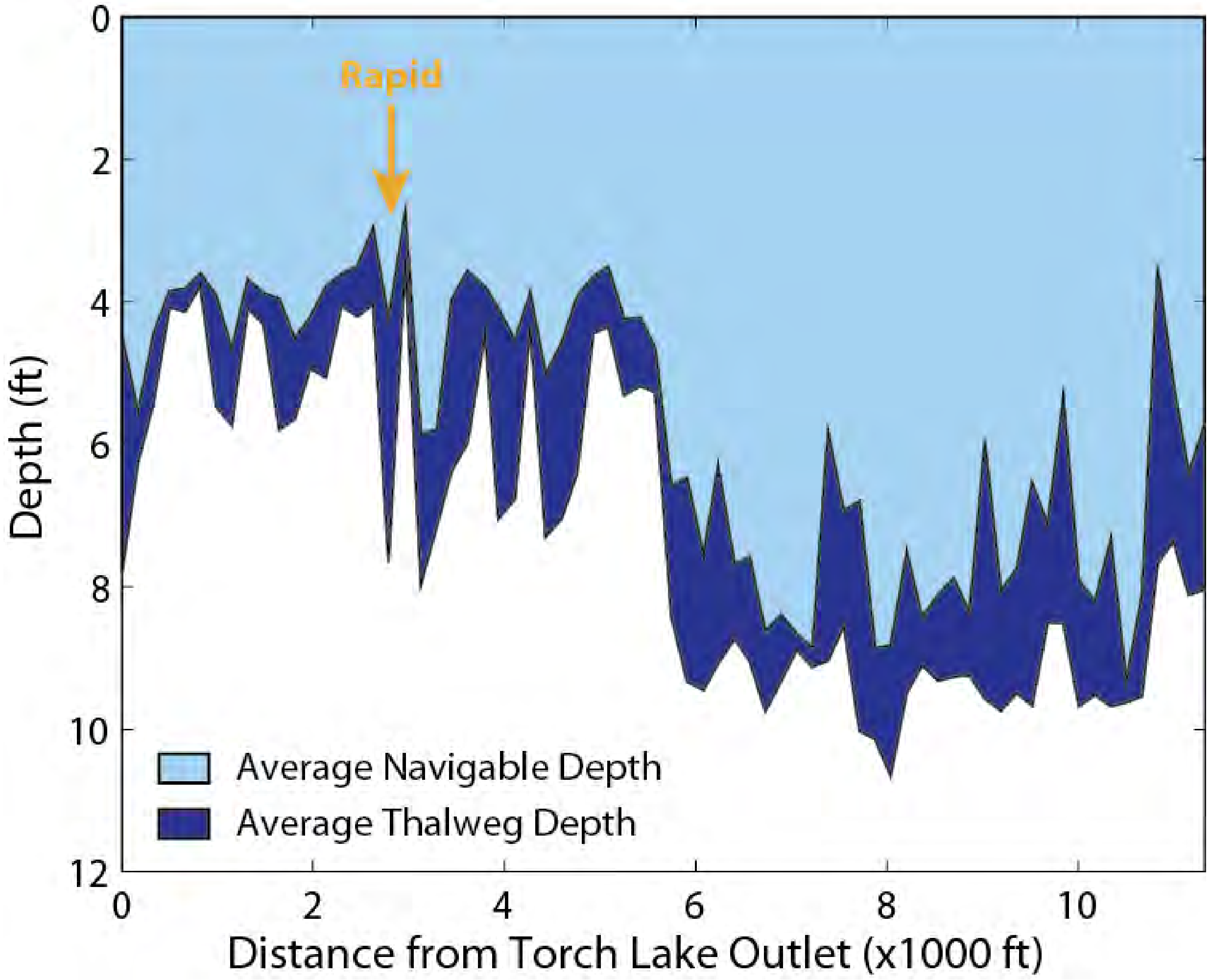

Figure 25. Plot of 50-meter average navigable channel depth along the Torch River, and average thalweg depth.

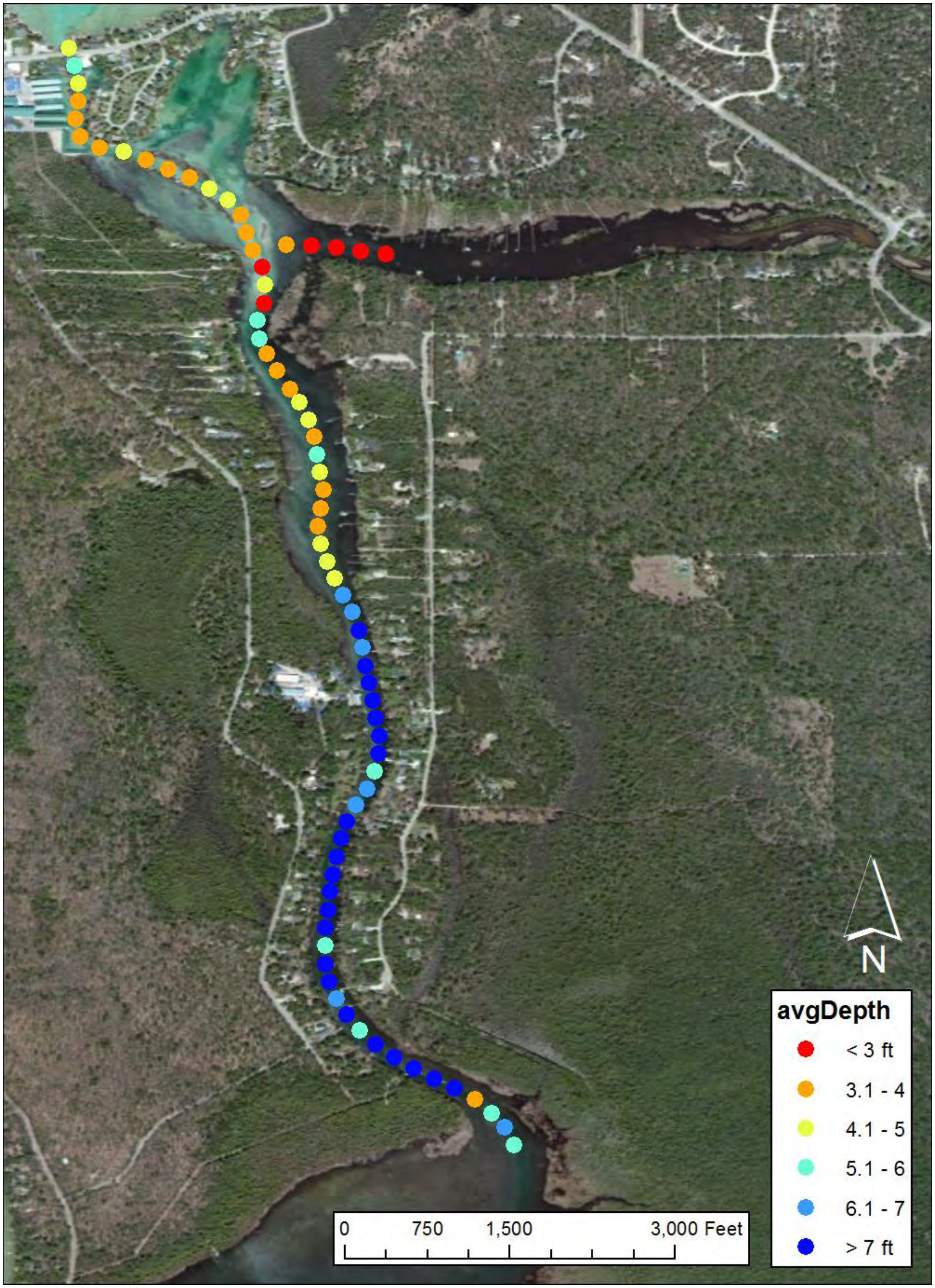

Figure 26. Map of average navigable depth along the Torch and lower Rapid Rivers, averaged in 50 meter increments along the channel.

Figure 27. Map of detailed channel depths at the Torch River outlet into Skegemog Lake.

Figure 28. Comparison of the same frame (Grass River at the mouth into Clam Lake) between 1938 and 2010. The 2010 channel is significantly wider, and new mid-channel sediment features have developed downstream of Cold Creek.

Figure 29. Map of the Grass River through time as digitized from historical aerial imagery. Note that the positions of the streams are not as accurate as the geometry. Thus the shifts in the channel should not be interpreted as genuine, but the shape of the channel and its dimensions are accurate.

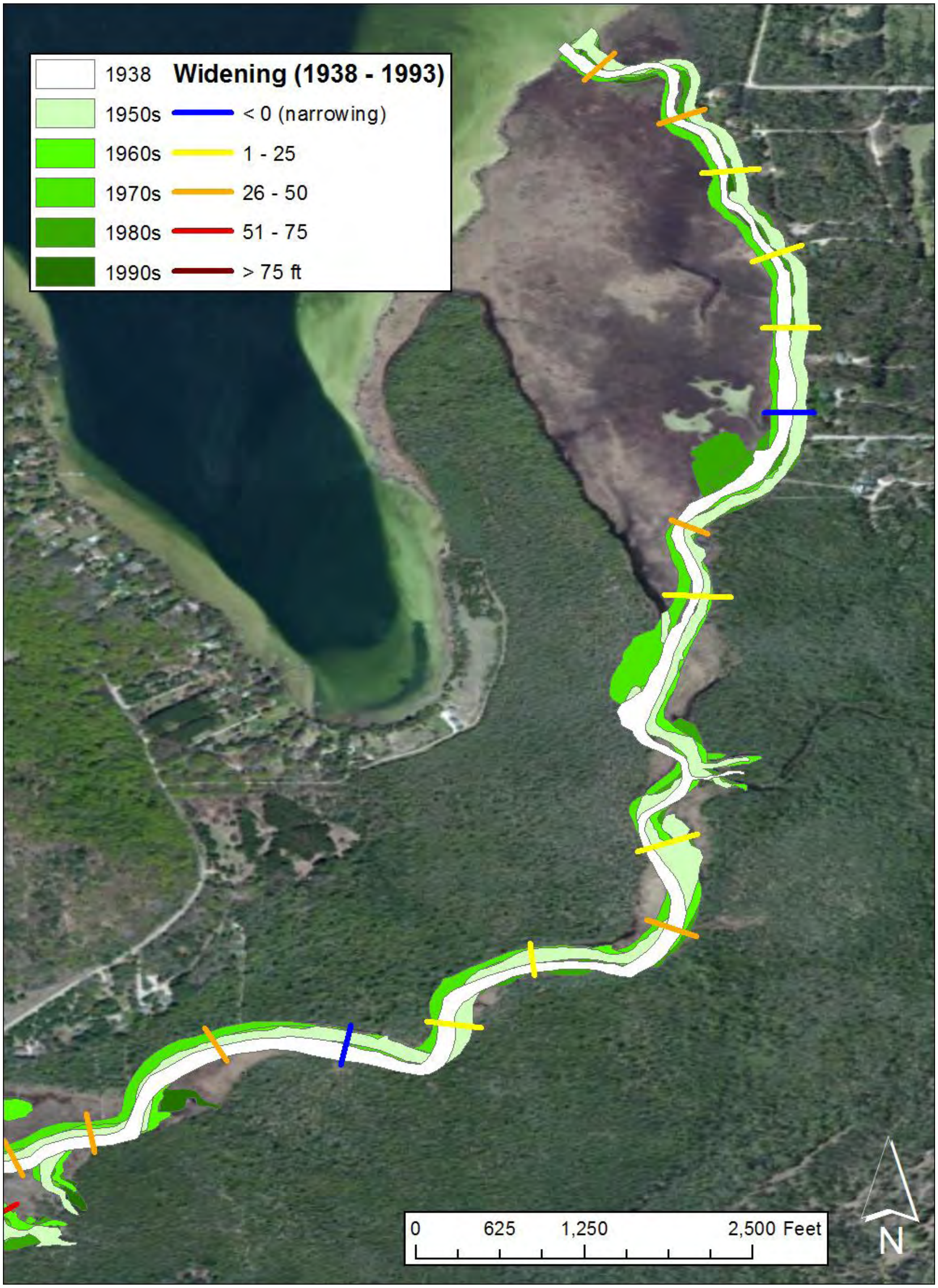

Figure 30. Same stream channel maps as in Figure 29, overlain with cross sections approximately every 200 meters. Those cross sections were intersected with the stream channel edges in order to determine change in stream width over time.

Figure 31. Map of Torch and lower Rapid Rivers showing channel changes through time as mapped with aerial imagery. Caveats about channel position discussed in Figure 29 apply here as well.

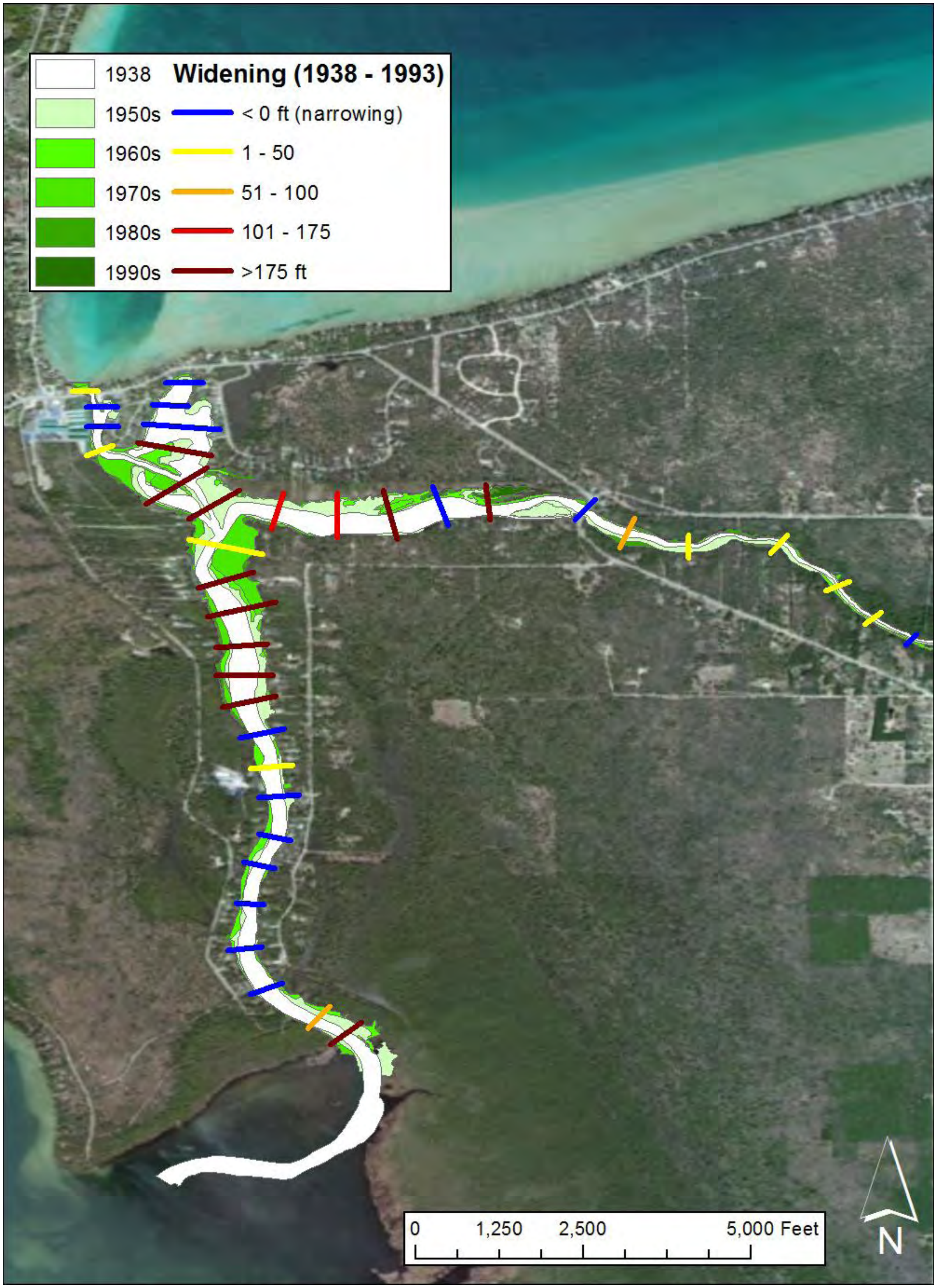

Figure 32. Map of channel cross section width changes between 1938 and 1993, overlain on historical channel geometry maps.

Figure 33. Image showing significant recent bank erosion just downstream of the Rapid River confluence with Torch River.

Figure 34. Image further downstream from Figure 33, in the middle Torch River. Visible is the completely armored bank of a wooden seawall.

Figure 35. Image of a house on the north bank of the lower Rapid River, formerly set significantly back from the river but experiencing significant modern erosion. Other docks are visible, with homes set back far enough that they lie beyond the tree line.

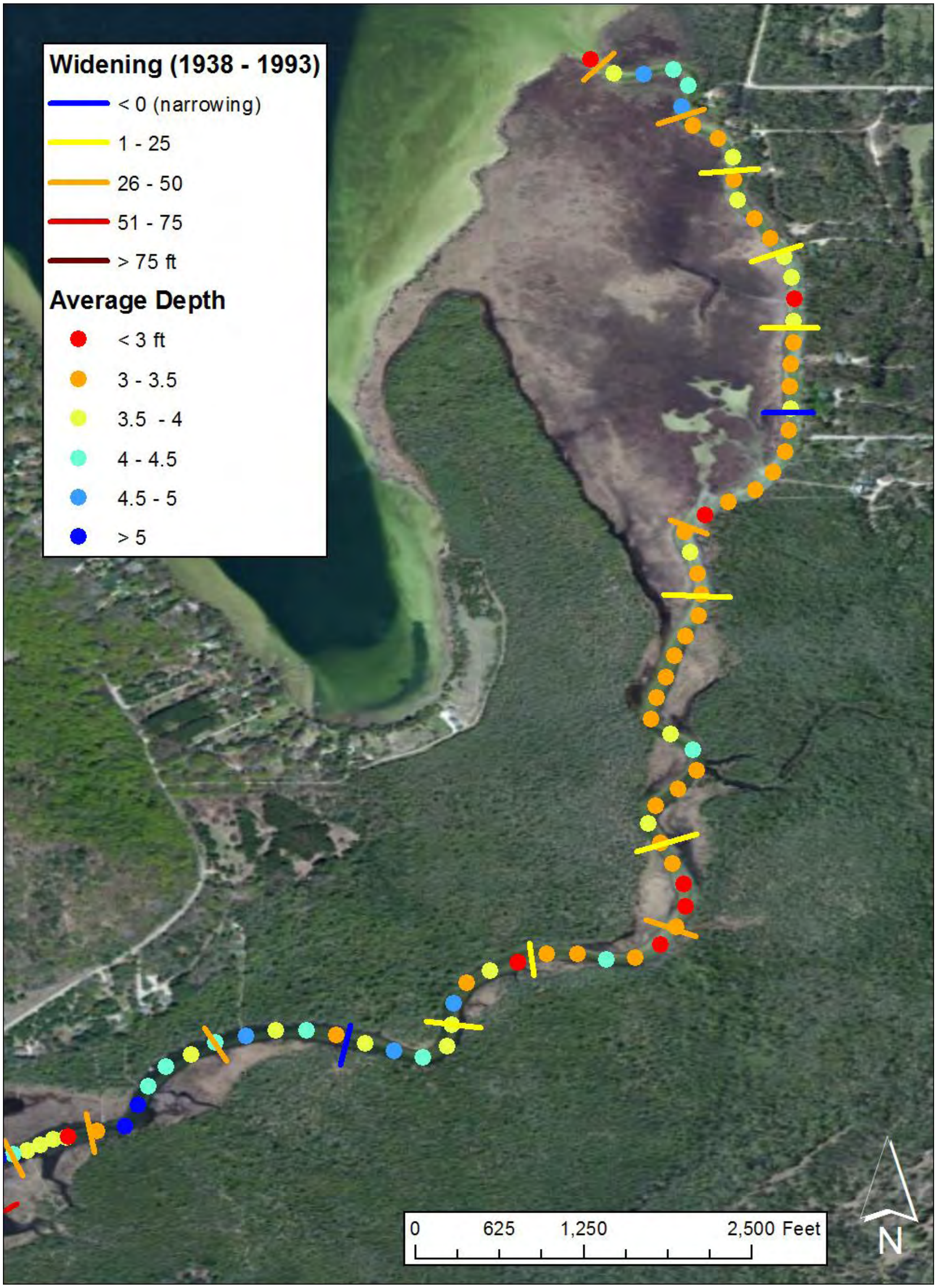

Figure 36. Map of average channel depths along the Grass River with historical channel width changes overlain.

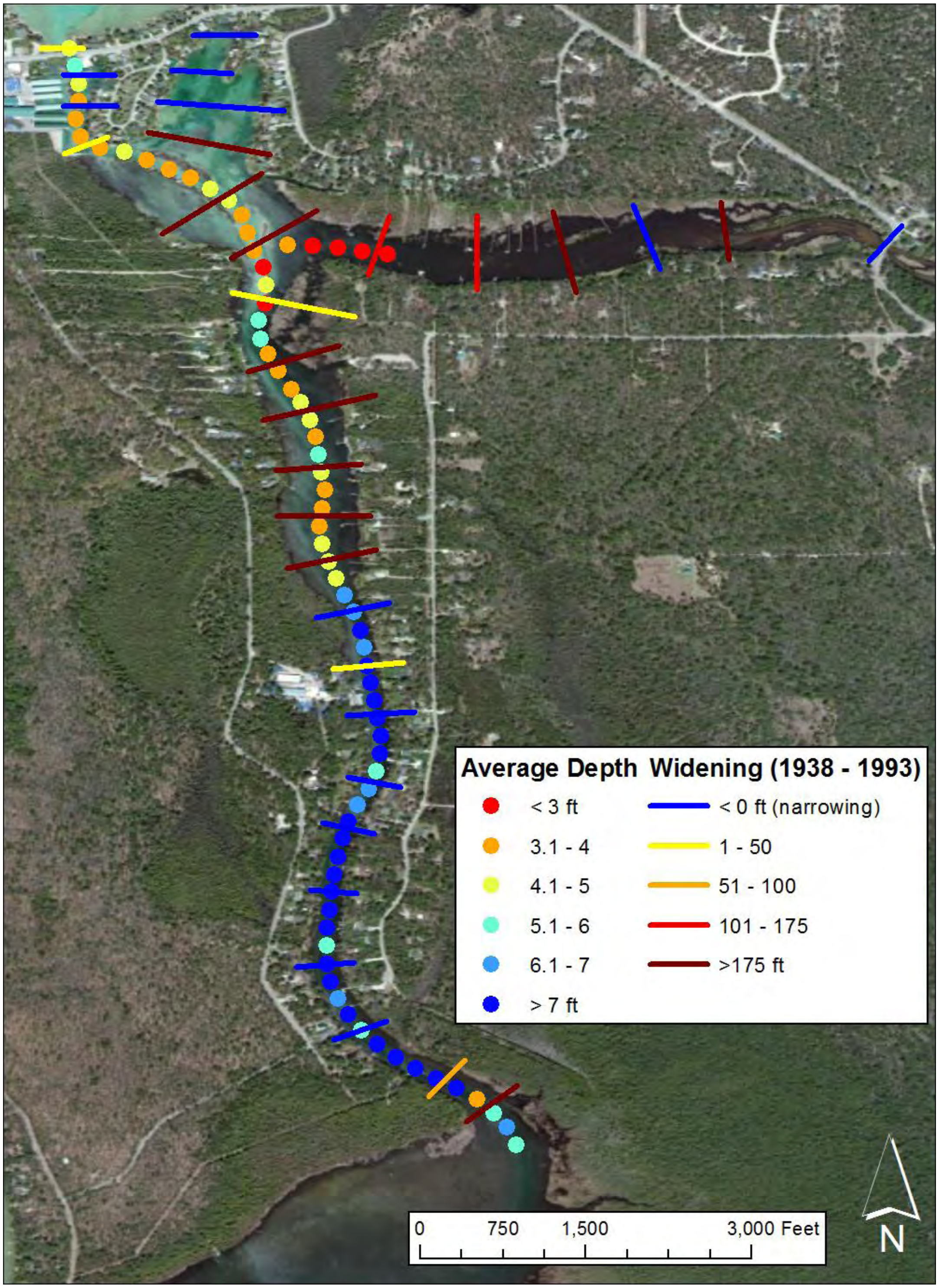

Figure 37. Map of average channel depths along the Torch and lower Rapid Rivers with historical channel width changes overlain.

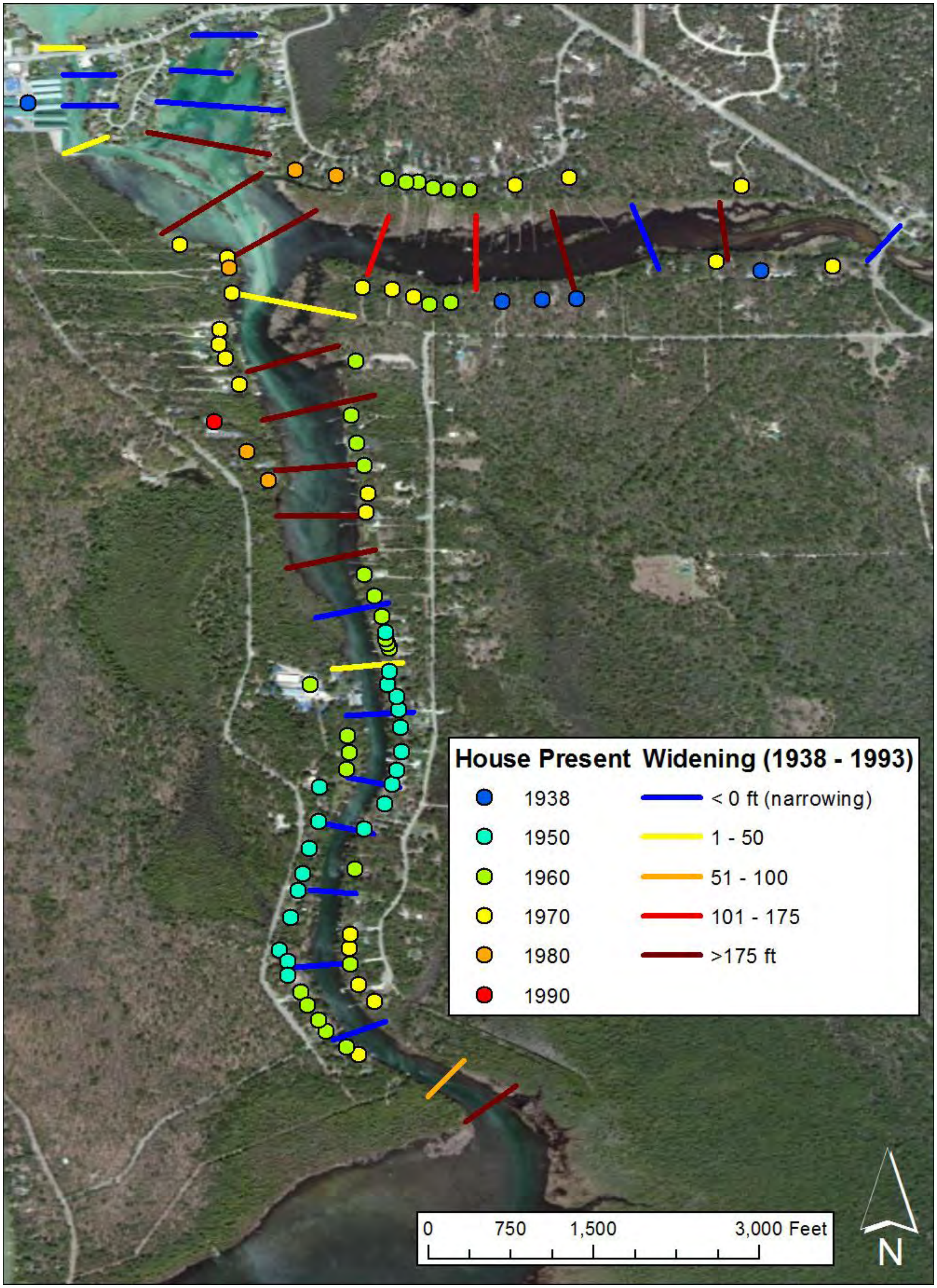

Figure 38. Map of year built vs. width change

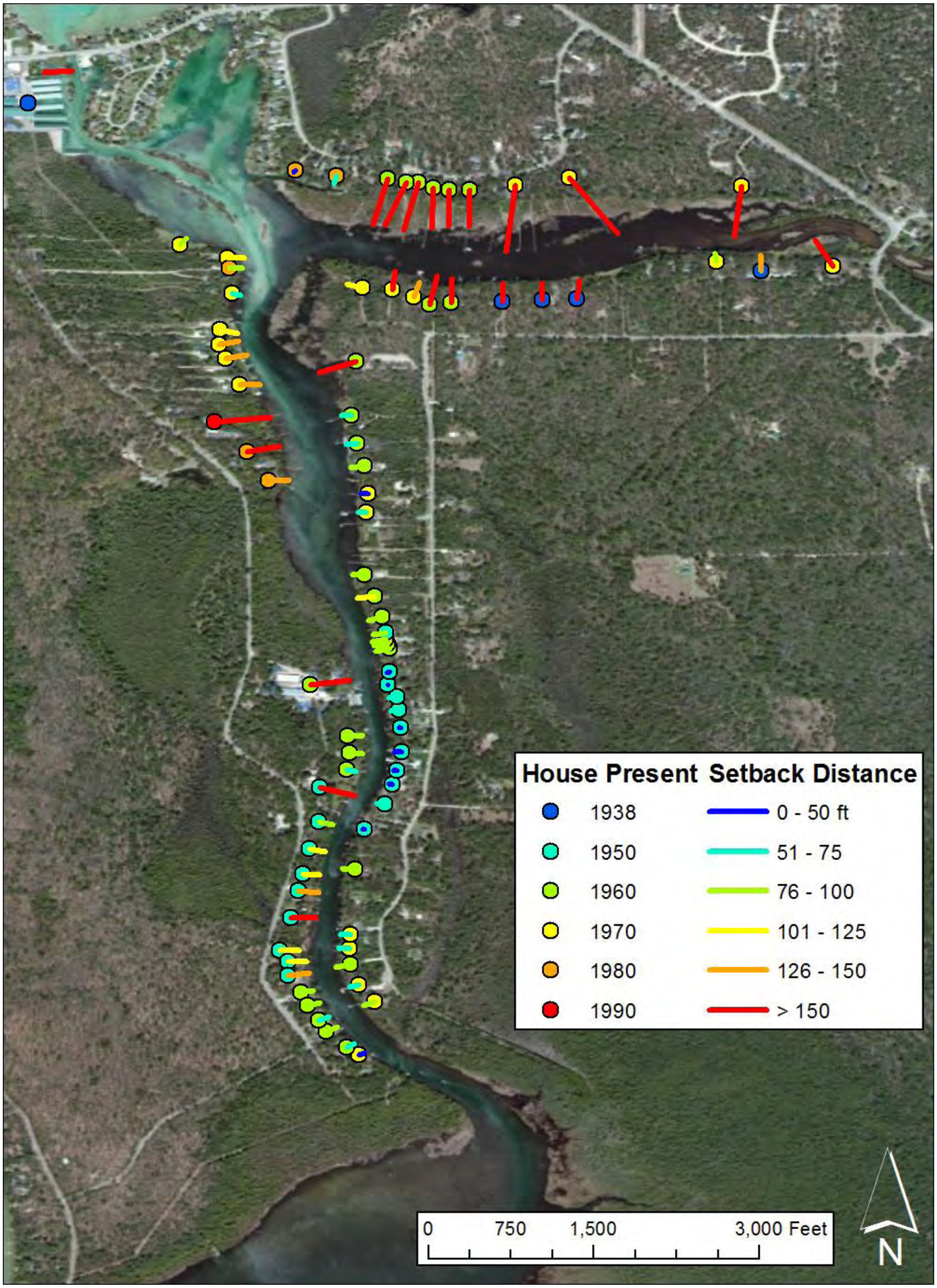

Figure 39. Map of house setback versus year built.

Figure 40. Image of the grassy banks of the Grass River.

Figure 41. Muskrat swimming along the shore of Grass River during data collection.

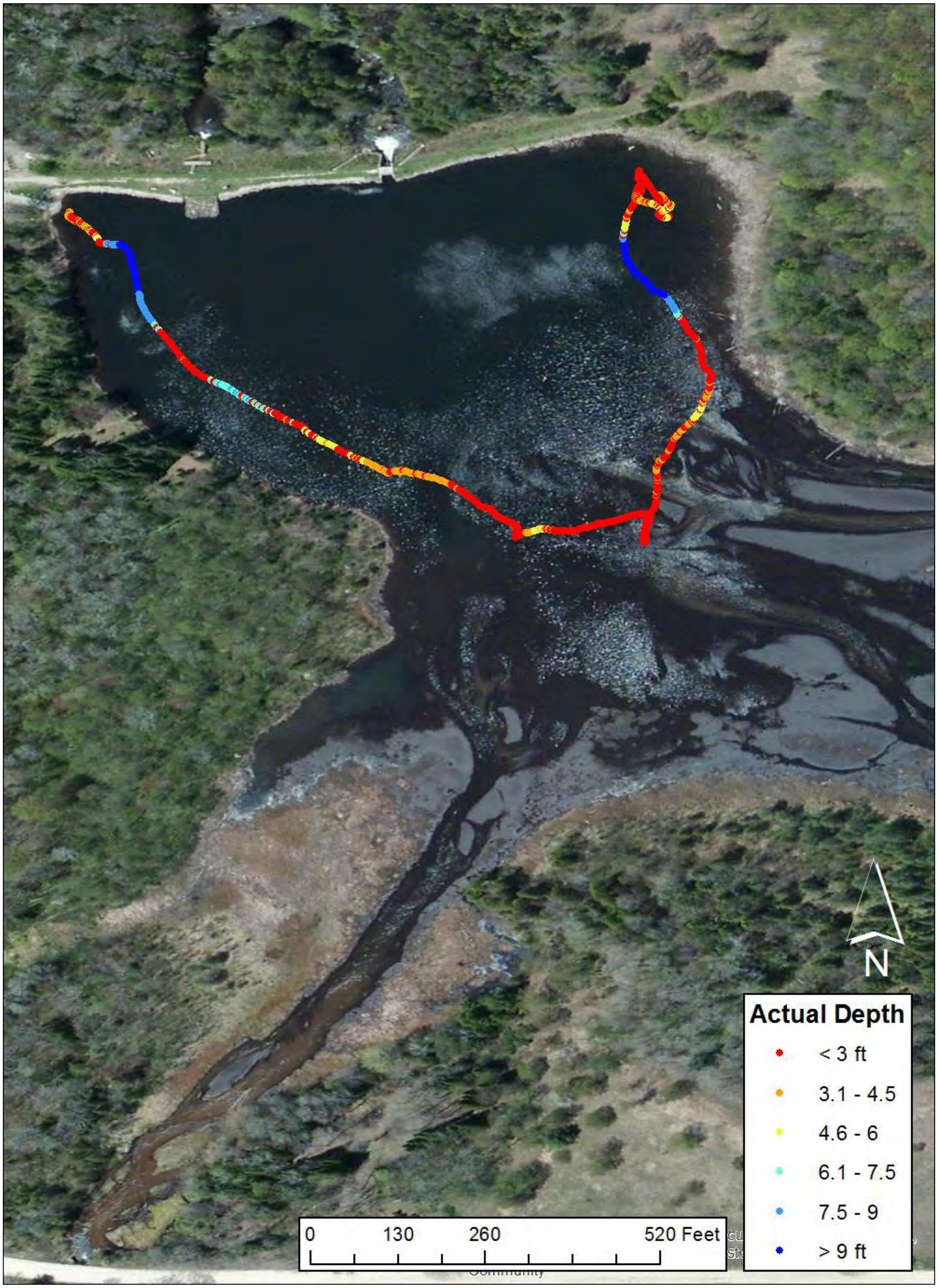

Figure 42. Rugg Pond with overlain bathymetry samples. Note, because of GPS equipment malfunction the positions of the samples are considered approximate.

Figure 43. Comparison of aerial and satellite imagery from 1938 and 2011 of Rugg Pond.