USING NAUTICAL CHARTS TO VISUALIZE 19TH CENTURY CHANNEL CHANGE ON THE ST. MARYS RIVER, SAULT STE. MARIE, CANADA AND U.S.A.

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ABSTRACT

The St. Marys River is a key international historic and geographic feature that has attracted little academic interest. In the Sault Ste. Marie area nineteenth century river navigators were blocked by high falls, therefore the channel was altered with locks and canals to aid navigation and enhance commerce. Visualizing spatial temporal change by comparing and analyzing historic cartography is difficult, and results in a lack of detailed knowledge regarding any sequence of changes. A fundamental step in analyzing temporal channel change is the creation of a historic GIS database (HGIS). Using ESRI software only, the 1913 International Waterways Commission (Boundary) Map was converted into raster DEM, TIN and 3-D models to create a visual representation of the historical bathymetric point data. To determine which model best interpolates soundings, the models were compared using RMSE. Draping the 1913 base map over the 3-D model creates a physical landscape for the sounding values. Combining other historical maps with the 3-D model enables a comparative visualization of the channel topography, and illustrates the evolution of channel and bed change. The gathering of international data into a temporal HGIS will provide a platform from which other users can store and analyze additional cartographic information. The use of a temporal HGIS to create a chronology of channel change will turn the 19th century history of the St. Marys River into a new dynamic and visual experience.

INTRODUCTION

Maps are the language of geography, and frequently contain spatial data and information that cannot be sourced from written documents (Sauer, 1956; Knowles, 2002). Therefore, one cannot ignore the thousands of years of history that has been graphically recorded on paper. Geographers and historians alike are interested in the whys and where of events, and view maps as graphic representations of the environment and as tools for understanding human behavior (Knowles, 2002; Kimerling *et al.*, 2005). Visualizing, comparing, and interpreting temporal events from a stack of historic maps can be very difficult. Utilizing the tools of GIS simplifies the organization of dated archival sources, and combining artifacts with modern tools, such satellite imagery, enriches both the qualitative and quantitative analyses (Knowles, 2002; Lo and Yeung, 2002; Black, 2003; Kimerling *et al.*, 2005). Using overlays and rectification processes enables one to combine and compare maps of different sizes and scales, to gauge errors of measurement and estimation in spatial relationships, locate artifacts missing from the modern landscape, and analyze temporal patterns of change, such as river migration. Draping historical maps onto a 3-D model enhances landscape recognition, and the dynamics of change can be re-created through the animation of several maps. One must be aware of the limitations of combining historical artifacts and GIS (HGIS). The accuracy of older maps cannot be improved. Historic maps can be difficult to spatially orient and interpret because the original features and environmental conditions have changed, and georeferencing maps changes the original lines, shapes and distances. Lack of geographic details can make a map unsuitable for quantitative interpretations, but will yield a wealth of historical information (Knowles, 2002; Kimerling *et al.*, 2005).

Bathymetric Data and GIS

Academics have combined bathymetric data with GIS tools to model river channel topography (Milne and Sear, 1997), and to study the effects of climate change on the Great Lakes water levels (Tupman, 2004). However, these studies use contemporary field surveys and remotely sensed data. Tupman combined sonar bathymetric data and pre-digitized data in ESRI (ArcINFO, ArcGIS 8.1, ArcView 3.2) software to create digital elevation models (DEM) and triangulated irregular network models (TIN) of Lake Huron's shoreline and lakebed. Van der Wal (2003) used historical navigation charts to access morphological change in British saltwater estuaries. Her study period starts in the mid 19th century, and is based completely on analogue bathymetric charts that record actual sea level and tide data. She found that the inconsistent location of sounding sites recorded on these charts were problematic for studying estuary morphology. Rusmey and Williams combined 1926 San Francisco Bay estuary bathymetric (analogue) data and 1998 NOAA (digital) contour maps using ESRI (ArcView 3.2 and 8.1) and Adobe Photoshop software (Knowles, 2002). They created a 1998 TIN model and draped the historical 1926 map over it. The resulting 3-D model showed elevation changes of the San Francisco Bay floor. Academic papers have not been published regarding this work; however, this shows that such casework can be done. There does not appear to be any research involving the historical reconstruction of a dynamic riverbed.

SAULT STE. MARIE AND THE INTERNATIONAL ST. MARYS RIVER

Historic Regional Cartography

In the Upper Great Lakes region, the Sault Ste. Marie (Sault) area has a rich history that has been shaped by the St. Marys River, which is a key international historic and geographic feature (Figure 1). The region was explored and mapped by Champlain's men (Brulé and Grenable, 1622; Jean Nicolet, 1634) long before Europeans were navigating Lakes Erie and Ontario (Woodford, 1994; Arbic, 2003). The area involves two nations, yet has aroused little academic interest and one will rarely find it discussed in national history books (Hele, 2002). The St. Marys River became part of the British/American border in the 1794 Jay's Treaty, although the exact boundary was not demarcated until 1913. All river users were blocked by high falls in the Sault area, therefore, the river channel was altered during the 19th century with locks and canals to aid navigation and enhance commerce (Hele, 2002). After the 19th century, the riverbed was modified to accommodate larger freighters carrying very heavy payloads. The St. Marys River was designated a Canadian Heritage River in 2000, to honour its "natural, recreational, and cultural significance" (CHRS, 2006).

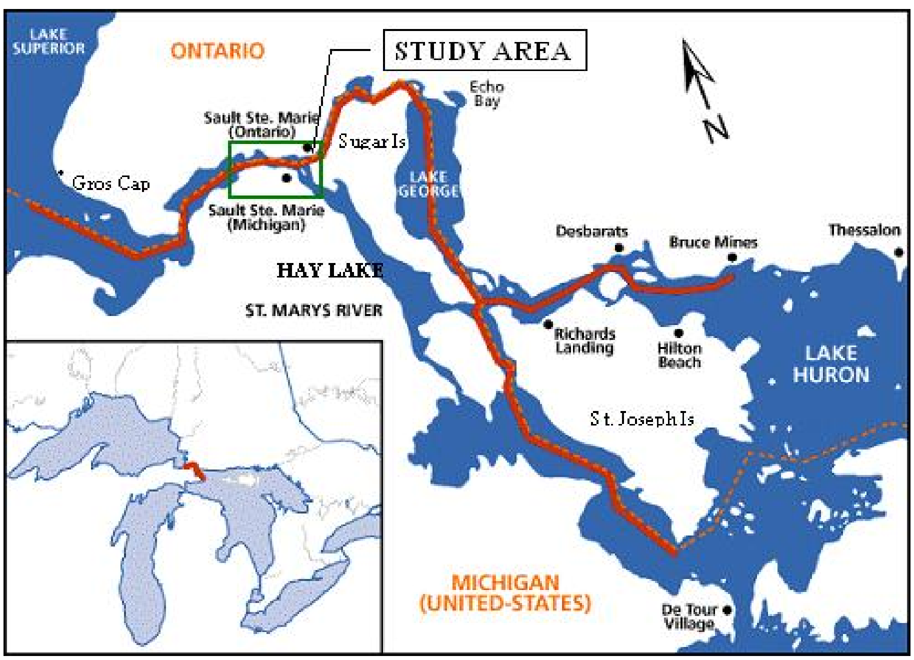

Figure 1. Location of the St. Marys River and Sault Ste. Marie. Red line is route of commercial river traffic. Modified from CHRS, 2006.

In the Sault area there is a span of nearly 300 years of regional cartography available, all with varying degrees of geographic accuracy. Due to the cultural and navigation significance of the falls, most historical maps recorded some bathymetry and attempted to show topographic detail with either written comments or symbols, such as hachuring marks. The British Admiralty conducted a complete hydrographic Survey of the (Great) Lakes during 1816-1825 for navigation purposes (Winearls, 1991). Lt. Henry Bayfield completed the St. Marys River portion of the survey in 1825, which include many lines of sounding depths that transverse the river's channel. While these British charts recorded excellent shore details, the bathymetry data was too sketchy for navigation safety and for planning channel and harbour improvements (Woodford, 1994). The American Corps of Topographic Engineers (Corps) completed the first detailed triangulation (topographic) and hydrographic surveys of the entire Great Lakes region between 1841 and 1882. The Corps conducted the first survey of the St. Marys River channel between 1853 and 1855, just prior to the opening of the Soo Canal. As water levels in the Great Lakes change, ongoing bathymetric resurveys are required to update navigation charts. In the Sault area, historic resurveys were conducted in 1892 and in the early 1900's. The 1908 Boundary Treaty between Great Britain and the United States authorized the accurate re-establishment of the International Boundary through the Great Lakes system. As a result, the St. Marys River and BOTH shores were intensively resurveyed in 1913 (Figure 2), as a supplement to the surveys of the International Waterways Commission (Woodford, 1994; International Waterways Commission, 1916). Other land surveys have been conducted adjacent to the St. Marys River channel; however, they rarely include international geographic data from the opposing shore. Historic and contemporary analogue and digital surveys are focused either on the American (south shore) or British/Canadian (north shore).

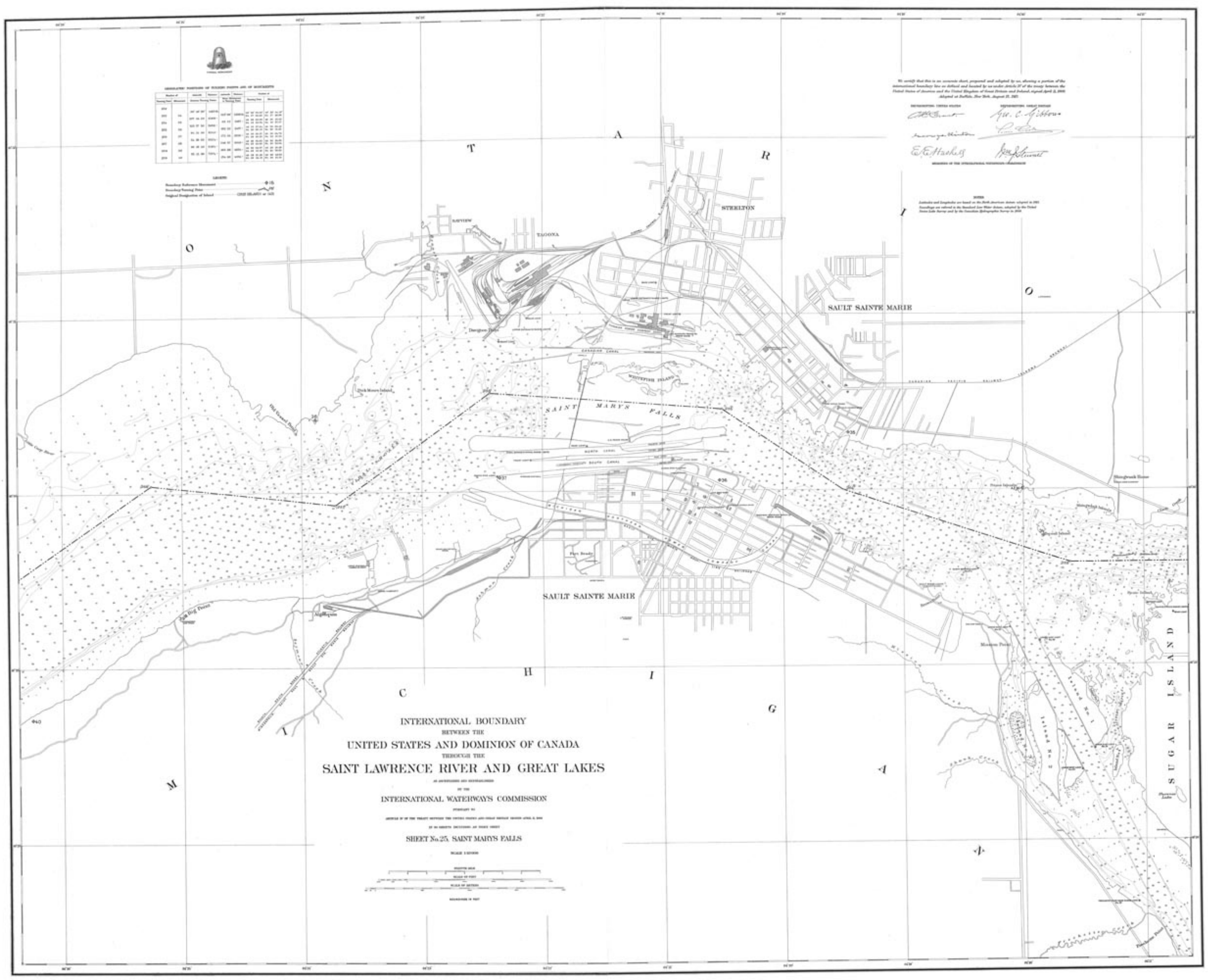

Figure 2. The 1913 International Waterways Commission (International Boundary) Map, used as the HGIS base map, contains the most accurate international land survey details and bathymetry points available.

The St. Marys River Morphology

The St. Marys River is a 120 km long artery that links Lake Superior with Lake Huron. The river flows in a west to east direction through a geologically constricted passageway of rapids and islands from Lake Superior (about 183 meters above sea level), past Sault Ste. Marie into Lake Huron (approx. 177 meters ASL) (Figure 1). The river drops about 21ft/6.4m between the headwaters and mouth. However, more than 90% of the drop occurs at the St. Marys Rapids. The river is sub-divided into three distinct hydrological reaches:

1. Upper Reach: This 22.5 km. reach has a generally shallow, sandy coastline with offshore sand and gravel shoals. It extends from Gros Cap, at the mouth of Whitefish Bay (eastern most end of Lake Superior), to Sault Ste. Marie.

2. Middle Reach: This 2.5 km. section includes a set of long rapids that drop 6.1 meters (21 feet) over a long shallow fall of boulders and sandstone outcrops. Today the falls are not evident. The shoreline of the reach includes the twin Saults (Sault Ste. Marie, Michigan and Ontario); Whitefish Island (immediately south of the Canadian Canal), and the American south shore Soo Locks and canals. Post-nineteenth century dredging has artificially created a deep straight channel bed below the falls.
3. Lower Reach: Flows 100 km. through broad shallow lakes and rock-fringed channels to Bruce Mines to the north, and De Tour to the south. At Sugar Island, it splits into Lake George (to the east) and Hay Lake (now Lake Nicolet) to the west. At St. Joseph's Island, the northern most channel becomes the St. Joseph Channel or The North Channel, and the southern, or Neebish Channel, is the present-day commercial shipping channel.

Local History

Archeological evidence indicates that Sault Ste. Marie region lay in the cultural heartland of the Ojibwa people for nearly 2200 years (Dickason, 1992). The movement of First Nation trade goods was along the St. Marys River, and the rapids (named Bawating) were the hub of Ojibwa culture and religion, and an important gathering spot and summer fishery for more than 2000 First Nation people (Hele, 2003). Seventeenth and eighteenth century European explorers and entrepreneurs used this watery arterial link in their quest for primary resources (land, fur, timber, and minerals). The area was labeled as Sault (French for rapids) de Gaston on Champlain's 1632 map, and the Jesuit Fathers Dablon and Claude changed the name to Sainte Marie du Sault after they arrived in 1641. They mapped the area during the 1650's and established a Jesuit mission (1668-1689) on the south shore (Woodford, 1994; Gutsche, 1997). France's Louis XIV claimed the region as a seigneury in 1671, and the French subsequently established a military fort on the south shore in 1750. After America began enforcing its borders in 1796 (Jay's Treaty, 1794), the North West Company (NWC, established 1783) relocated to the swampy north (British) shore. At this point in time, river users started ongoing channel modifications along the St. Marys River's middle reach because the 21-foot (6.1m) drop over the long rapids presented a significant navigation barrier for international commerce (Table 1).

Table 1. Chronology of pre-20th century St. Marys River Channel Modifications

Year	Event	Description
1797-1814	North West Company Canoe Canal and Portage Road	North Shore Canal: 2600 ft/795m long; Canoe lock: 38 x 8.75 ft., 9 ft. deep (11.5 x 2.7 x 2.7m); Drag Road (12 ft/3.7m wide) ran parallel to the lock and canal. Oxen dragged canoes up 12 ft/3.7m of lift. Destroyed in War 1812.
1822	Fort Brady, Michigan	Water race used as transportation canal.
1839	Michigan State Canal	Abandoned construction; destroyed part of mill race and Ojibwa burial ground. Goods (including a dozen ships) were subsequently portaged around rapids.
1850	Horse-drawn Strap Railway, Sault Mich.	Railway made of wooden metal-sheathed rails could not meet transport demand. In 1850 railway transported 6,000 tons of freight, in 1851 increased to 12,600 tons worth $1,000,000.
1855	Tandem State Locks (now Soo Locks)	State Lock: 350x70 ft. (106x21m), 12 ft/3.7m deep. Steamer locks in 11 hours. Soo Locks: (1968, Poe Lock largest): 1200 x 110 ft. (366x33.5m), 32 ft/10m deep. A 1000 x 105 ft. (302 x 32m) lake freighter locks through in 20 minutes.
1894	Hay Lake Channel (Lake Nicolet)	Locally known as the "Canoe Channel" Hay Lake was dredged from 4 ft/1.2m to 24 ft/7.3m deep, and widened to 600 ft/183m. This divided Islands Number 1 and 2 in half. This route was 11 mi/17.7km shorter than George Lake route.
1895	Canadian Sault Ship Canal	Result of international political disagreement; canal cuts St. Mary's Island. Larger than 1895 Soo Locks, 900 x 60 ft. (274x18.3m), 22 ft/6.7m deep. Lock powered by electricity generated on-site by Lake Superior Power Company. Today, Canadian Historic Site; rebuilt smaller lock for small pleasure craft.
1902	Electricity (water) Power canal	Power canal (1902) for Union Carbide Company, 200 ft/61m wide, 17ft/5m of head, water flow rate of $30{,}000^3$ ft/second. Powerhouse by Edison Sault Electric Company, 0.25mi/400m long.
1902	Compensating Works	16 moveable gates, an International Joint Commission Board continues to control Lake Superior water levels.

During the fur-trade era, a single NWC canoe transported four tons (3700 kg) of furs and freight between Grand Portage, Minnesota and Montreal, Quebec (Arbic, 2003). The voyageurs ran the rapids going downstream, but portaged freight when upbound. As a result, in 1797, the NWC built a canoe lock, canal, and drag road for oxen to pull the canoes around the rapids (Table 1). This engineering marvel was destroyed in 1814, but is recorded on most pre-1825 maps. Other channel modifications appeared on the south shore with the establishment of Fort Brady, Michigan, with its water race that doubled as a transportation canal. Cargos were floated up the race, unloaded and portaged around the rapids, and repacked onto waiting sailing vessels (Gutsche, 1997). Further shoreline modifications occurred on both sides of the river with the slow establishment of the twin Sault's with warehouses and docks (Hele, 2002). After the discovery of copper reserves on Lake Superior during the late 1840's and the subsequent increase in freight volume (backlogs of 12,000 barrels of goods were common by 1851), the U.S. Congress approved the construction of a series of toll-free shipping canals. The first tandem "State Locks", completed in 1855 (Table 1), evolved into the Soo Locks (Gutsche, 1997; Arbic, 2005).

In 1879, the American government denied passage of the Canadian warship "Chicora" heading west to Manitoba to assist in the Red River uprising. As a result, Canada proceeded to build a toll-free Canadian Sault Ship Canal, north of the rapids (Table 1). Opening in 1895, the canal was the first electricity-powered canal system in the world, and larger than the Soo Locks (Gutsche, 1997; Arbic, 2003; Arbic 2005). During the 1890's approximately 70 vessels per day negotiated the hazardous St. Marys River and rapids (Arbic, 2005). Two miles downstream from the rapids, where Sugar Island splits the river, commercial shipping traffic was forced to negotiate, single file, the easterly hazardous meandering route of Lake George (Figure 1). Hay Lake (now Lake Nicolet), the shorter westerly route at 4 ft/1.22m deep, was dredged, widened and straightened into a safer channel that opened in 1894 (Table 1) (Woodford, 1994, Arbic, 2005). In 1902, the Michigan Northern Power Company completed a power canal through Sault, Michigan. The power generating turbines required 40% of Lake Superior's outflow; therefore, to prevent a water level drop in Lake Superior, a compensating dam was built at the head of the rapids. Completed in 1921, the "Works" keep Lake Superior water levels at approximately 21ft/6.1m above the rest of the St. Marys River and Lake Huron. This is the height of the original rapids (Arbic, 2003).

This plethora of historic and cartographic detail makes the St. Marys River an excellent study area to reconstruct the details of the river channel and bed, using HGIS to represent "the structure and distribution of [historical] features in geographical space" (Heywood, 2002, p. 47). However, temporal sources are generally scattered across two continents, tend to focus on only one side or the other of the St. Marys River, and have not been integrated. These limitations make it difficult for the academic to reconstruct and visualize what the Sault Ste. Marie area looked like prior to European settlement or during a later period of change. Today, historians and regional academics are asking how did the St. Marys River, with its falls and rapids, look prior to European settlement. How has the river changed? Has it changed, and if so in what specific areas?

RESEARCH OBJECTIVE

To illustrate historic or contemporary channel change on a river, a base map should be created from which all other maps can be compared and measured. Therefore, a base map of the St. Marys River channel is created using the digitized 1913 International Waterways Commission (International Boundary Map) (Figure 2). Raster models of bathymetric data, including DEM, TIN and 3-D visualizations will enable the user to create digital geo-visual and mathematical representations of the St. Marys River bathymetry. The specific area of study includes the 2.5 kilometer middle reach, which contains major navigation impediments and has undergone extensive channelization.

METHODS

The 1913 International Waterways Commission (base map) (Figure 2) was obtained from the Serge A. Sauer Map Library at UWO, London, ON. Due to its large size, the 1913 analogue map was folded in two and scanned at 400 dpi on a KIP Engineering Scanner, which uses rollers to feed the paper through the scanner during the copying process. Adobe Photoshop CS® software was used for image processing (Figure 3). The two digitized TIFF halves were merged, cropped and converted to grayscale. Digital data including Ontario OBM 1:20,000, and State of Michigan digital orthophotos (DOI) and road shape files, were obtained free from online sources. All data processing and analysis was completed using ESRI ArcGIS 9® software. The Michigan DOI, in SID format, were assigned the same projection as the Michigan roads shape file (Oblique Mercator (Hotline)). The projections of all the Michigan and Ontario files were converted to NAD83, UTM Zone 16, and the OBM and Michigan road shape files were merged to assist with future cross-border rectification processes. The 1913 base map was subsequently georectified to NAD83, UTM Zone 16.

The creation of vector layers for the 1913 base map included creating line shape files of the streets, canals, and riverbanks. Polygon shape files were created of the islands, prominent buildings, docks, and the river (for future masking processes). Names and pertinent points of information were recorded in attribute tables. The depths, in feet, of 3,900 bathymetric points were recorded as negative elevations in the point attribute table. Using the point data files, an interpolated clipped TIN model of the St. Marys River was created using ESRI 3-D Analyst, and four interpolated masked DEMs were created in 2-D Analyst. ArcGIS will create Inverse Distance Weighted (IDW), Natural Neighbor (NN), Spline, and Kriging DEMs.

The four interpolated DEMs and TIN of the St. Marys River were statistically compared using RMSE of depths (negative elevation) to determine which interpolated model best represented (mathematically) the natural riverbed morphology. The comparison used the same 50 X,Y points across the study area, and points ranged from the shoreline (0 ft) to the deepest point (-57 ft). Twenty-five control points were actual bathymetric data points, and twenty-five were located where the models interpolated the depths. The TIN was input into ArcScene to create a 3-D model, vertical exaggeration of 10 times, of what the 1913 actually looked like. The georectificed 1913 base map was then draped over the 3-D model.

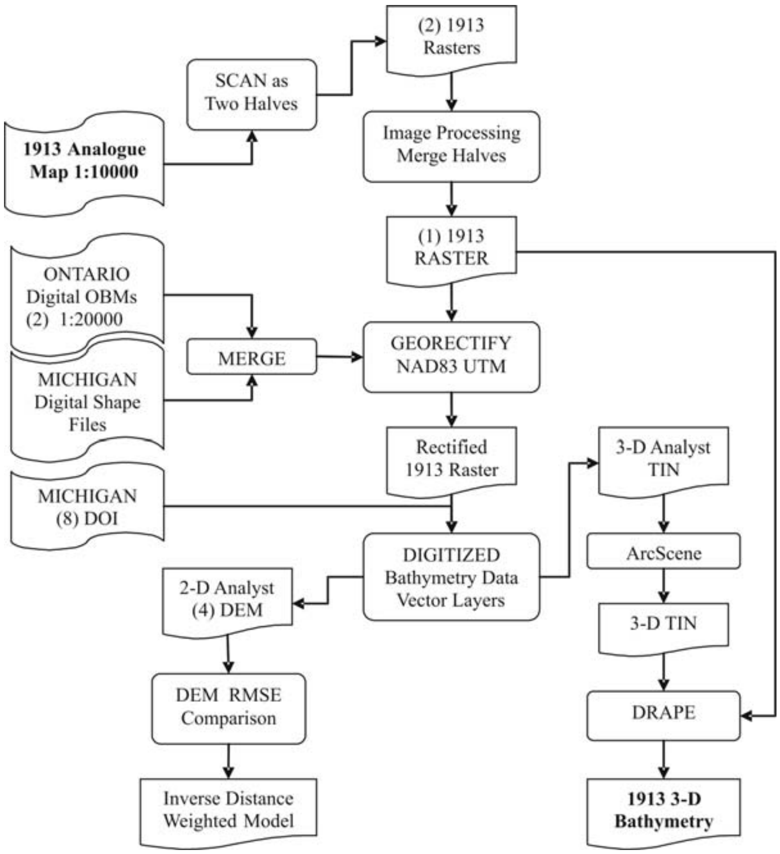

Figure 3. The geo-processing steps involved in converting the analogue 1913 International Boundary Map, with St. Marys River channel bathymetry, into interpolated 2-D and 3-D digital elevation models of the riverbed.

DISCUSSION AND RESULTS

International Border and Georectification

Locating large-scale, contemporary and compatible digital data from both sides of the international border proved problematic. The Ontario OBMs were easy to obtain but coverage stopped abruptly at the border – as if the St. Marys River did not have a south shore. The 1998 Michigan data did include DOI that extended beyond the international border to show the St. Marys River north shore, and some parts of Sault Ste. Marie, ON. Having a river as the main feature on all maps eliminated many anthropogenic artifacts that could be used to align the national maps, and as control points. Only one road was common to both maps – the International Bridge; therefore, the Michigan and Ontario road shape files were merged, and with the visual aid of DOI and topographic maps, the Sault streets were properly aligned.

The 1:10,000, 1913 International Boundary Map (Figure 2) was selected as the base map because it contains detailed coverage from BOTH sides of international river channel, and contains the most up-to-date international topographic and hydrographic survey data available at that period in time (IWC, 1916). Sheet No. 25, Saint Marys Falls, covering 8mi./13 km of river channel, also shows all the post-1850 channel modifications (Table 1) including the Hay Lake channel and four of the sixteen gates of the Compensating Works. At this point in time, very little of the riverbed has been modified near the rapids and locks, and the flow of the St. Marys River has not been artificially controlled. It is a good historical time frame from which to compare other historic or contemporary maps.

The size of the map, 4.4ft/1.34m by 3.5ft/1.08m, created problems during scanning. It was folded (top to bottom) and scanned in two halves. The archival significance of the artifact prevented it from being folded further, so there was no overlapping image. A slight skewing occurred on the folded edge (near the Canadian Canal) as a result of scanning the large document in a roller feeding mechanism, on a humid summer day. The skewing was reduced in Photoshop when the halves were merged. In addition, the analogue map's straight survey lines became slightly wavy after scanning. The degree of waviness increased with zooming, and required some interpolation if road allowances were used as ground control points (GCP). When locating sufficient GCP for georectification, the HGIS user must understand the local history and the significance and period of artifacts (points) drawn on the map. If significant landscape changes have occurred, or names have changed, intermediate maps may have to be used to georectify period maps with contemporary data. Occasionally, the HGIS user must interpolate the location of an artifact, if reference to the original location appears in written text.

Creating Vector Layers

Understanding the local history and the significance of artifacts is also important when creating vector layers. For example, when drawing a river shoreline as morphologically correct as possible, one must decide what artifact is natural or anthropogenic. Are the docks floating or concrete? If the later, what are the depths at shore, and where does the HGIS user draw the exact shoreline in a vector layer? The 1913 streets of Sault ON were drawn with 3 lines that included the surveyed street allowance and a "center line" that was the streetcar line. On many older maps, the streets were drawn as a single wide line or as a single thin line on the 1998 digital data. Consistent interpolation was required when using intersections as GCP, and for using the 1913 street line data for vector layers.

A vector layer of channel depths was created using bathymetric point data (soundings) measured for navigation purposes (boat draft depths). Soundings are exact water depths measured from the surface to the bed, in feet (Woodford, 1994). Navigation charts (such as the 1913 base map) include shorelines and anthropogenic features, sounding depths, and contour lines shown in fathoms, or six-foot intervals (one fathom is six feet) (Figure 4).

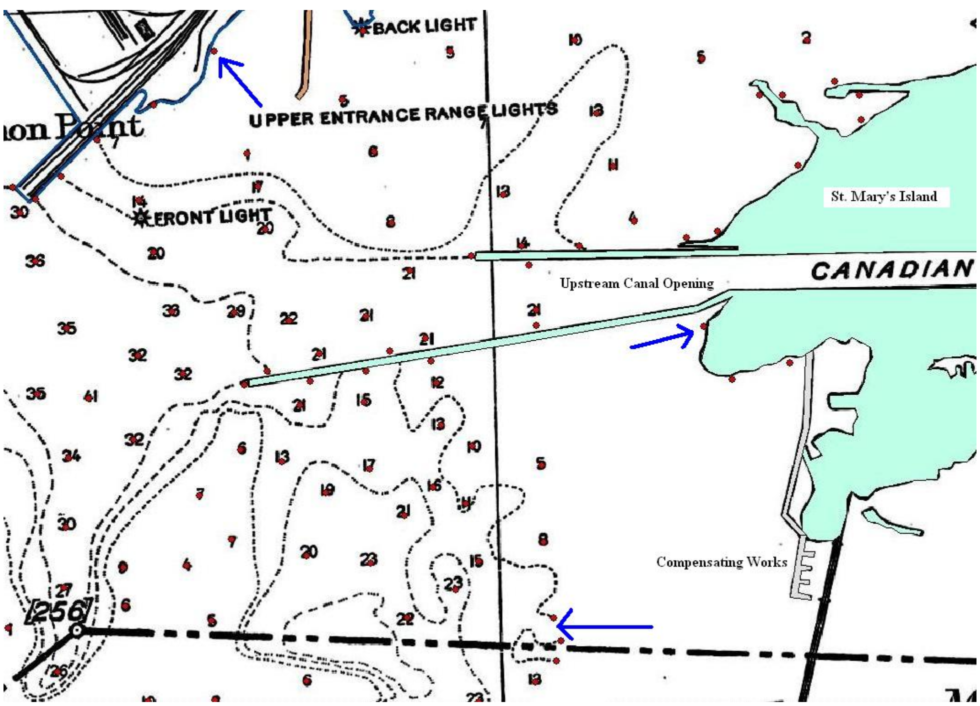

Figure 4. Close up of the 1913 Base Map. A vector layer, recording channel depths, was created from points (in red) of sounding data, contour lines and ends, the shoreline (0ft/m) and interpolated depths near anthropogenic features (blue arrows highlight interpolated points).

Historically, sounding measurements were obtained as a crew traversed the area in a cutter, and measured and logged the depths using either a lead line in deep water (lead weight is attached to a line and dropped), or from a sounding pole that is used in shallow water. Point soundings are accurate only if the bed is regular, and historic soundings do not have the accuracy of the contemporary remotely sensed depths, which are still recorded in feet (Woodford, 1994; van der Wal, 2003). The Corps conducted detailed hydrographic surveys of the entire Great Lakes region between 1841 and 1882. With time, the Corps significantly improved the world science of soundings, including equipment and methodology (including triangulation) to overcome inadequacies. For example, after 1895, 135,000 soundings were taken on Hay Lake during the winter months, and the triangulation was so precise that each point could be relocated within "a couple of feet" (Woodford, 1994, pg. 73). The 1913 base map includes this accuracy (IWC, 1916).

When inputting the sounding X, Y, -Z data, one must be aware of how a model might interpolate the values. For instance, there are no soundings recorded for one kilometer down the rapids, and the Hay Lake channel is a challenge for ArcGIS modelling because the values abruptly change from depths of 1 foot to 24 feet. In addition, sounding points are recorded without the exact X,Y location being shown. The HGIS user must consistently interpret where they record the X,Y-,Z data because as one zooms into the map, the numbers get larger – without the safety net of a X,Y point being shown. Exact sounding point data, and interpolated data taken from contour lines, anthropogenic features, and the shoreline (zero feet) were included (Figure 4). In preparation for making models of the St. Marys River channel, 3,900 X, Y, -Z bathymetric data points were recorded in the point attribute table (Figure 5).

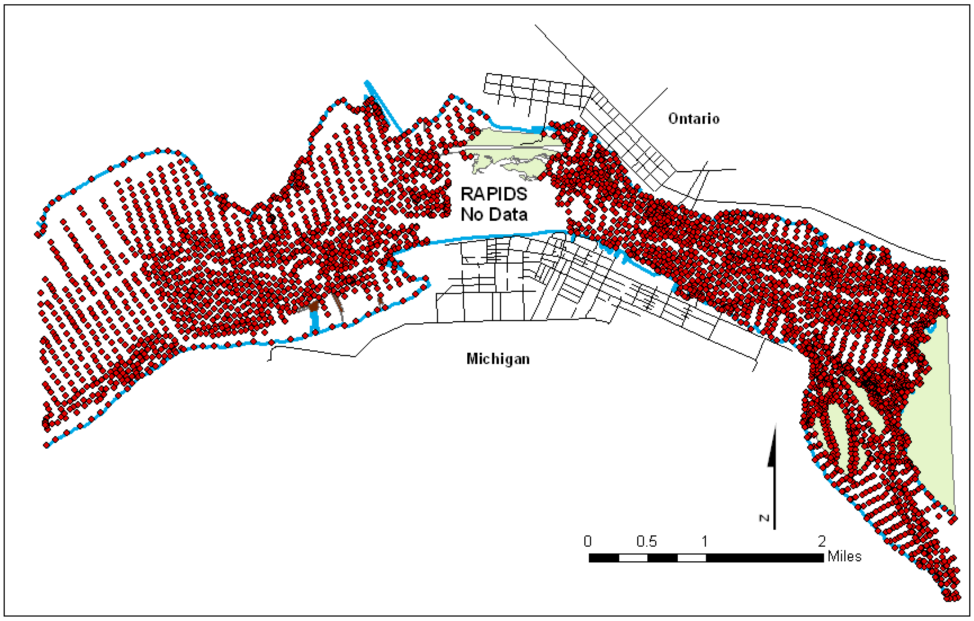

Figure 5. 3900 points of data were recorded in the point attribute table.

Interpolated Models

In academic studies that have compared digital terrain models, such as Thiessen polygons, TIN, grid DEM, and spatial moving average, TIN is considered the best model to use for irregularly spaced point data (Lee, 1991; Krumler, 1994; Heywood, 2002; Knowles, 2002; Wise, 2002; Tupman, 2004). Krumler (1994) compared the representation of terrain between TIN and DEM models over 25 study sites. He used digitized contours and reduced the number of input points for the TINs. Krumler found that TINs were as efficient

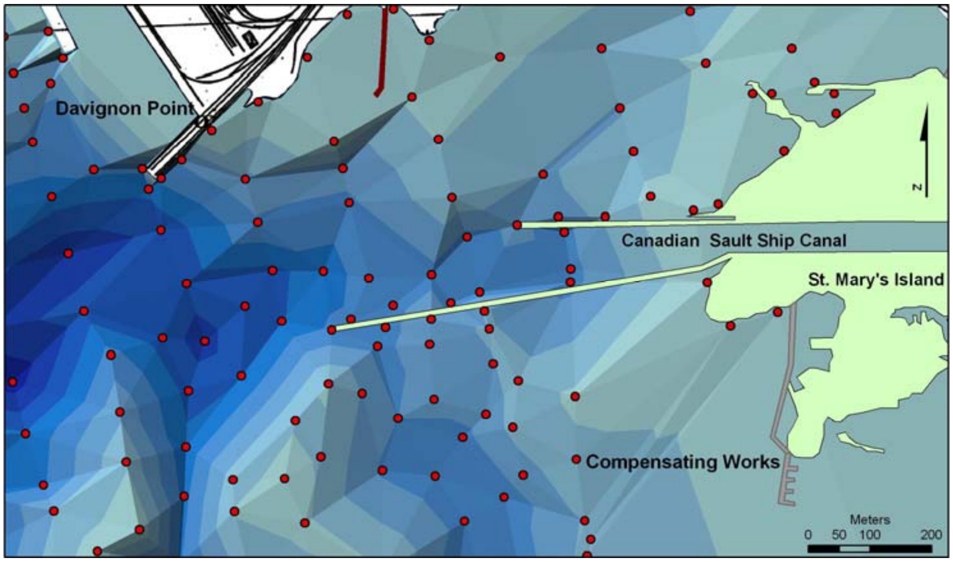

Figure 6. TIN model created from sounding points (red) as illustrated in Figure 4. Deepest channel points are dark blue.

as DEMs, and the IDW was statistically inferior to a linear interpolation; however, he was using a much older ESRI product (ArcInfo5.0). A more recent study by Carrara *et al* (1997) also compared TIN and DEM; however they used more than one type of software to compare data derived from digitized contour lines. Heywood (2002) found that TIN showed the least error and minimized edge effects in error maps; however, TIN exhibited a high inaccuracy in areas of high relief. This did not seem to present a problem for Rumsey (2002) who worked only with bathymetric point data, and depth ranges of 400 feet to create a 3-D model of the San Francisco Bay (vertical exaggeration of 7), with ESRI software.

There is not a paucity of data in the 1913 base map due to the extensive Corps surveys. For this study, an interpolated TIN of the St. Marys River was created from X,Y,-Z point data recorded on the 1913 base map, using ESRI 3-D analyst (Figure 6). Four interpolated DEM were also created using ESRI 2-D analyst. The digital terrain models (DTM) (Natural Neighbour, Inverse Distance Weighted, Kriging, Spline, and TIN) were masked and clipped so the models would not interpolate the non-existent topographic details of the land. The 1913 St. Marys River channel morphology was represented well in all the interpolated models. The channel bed had a maximum depth change of fifty-seven feet, which all DTM models maintained (56-57 feet), except for Kriging. The Kriging model reduced the maximum depth change to fifty feet. The DTMs generally maintained the same sounding depths, except near the edge of the map or in areas where abrupt elevation changes occurred, such as in the dredged areas near the docks. Overall, all the models recreated the Hay Lake Channel depths very well.

To determine which ESRI derived DTM best represented the St. Marys River channel morphology, the RMSE of all five models was compared, using 50 points selected from across the 8mi/13km study area (Figure 7). They represented depth changes of 0 to 57 feet. Of the 50 points, 25 were sounding point locations that had recorded –Z values (control points), and 25 were model interpolated X,Y,-Z locations. Initially, the RMSE of the 25 control points were calculated and compared to determine which model best interpolated these points of bathymetric data (Table 2). TIN yielded the best RMSE results. Therefore, TIN was used as the control model from which the other DEM RMSE were calculated, using all 50 control and interpolated points. IDW yielded the best RMSE and can be used for future analytical and visual channel change comparisons (Table 2, Figure 7).

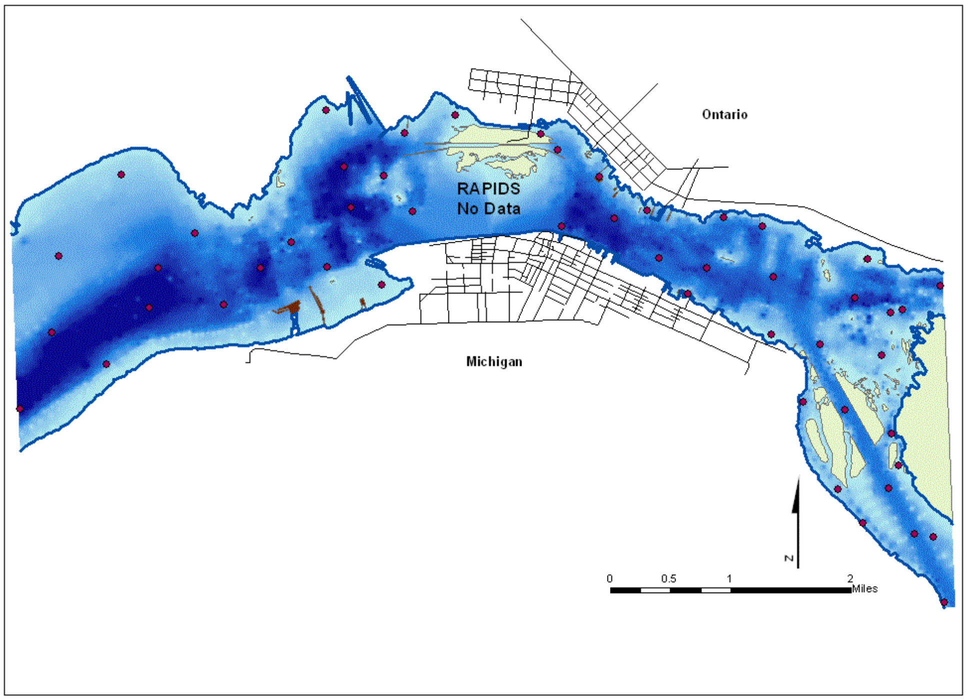

Figure 7. IDW model showing the placement of the 50 TIN control points (red) used for RMSE calculations.

Table 2. RMSE comparison of all DTM models

MODEL	TIN	IDW	NN	Spline	Kriging
	RMSE Results				
25 Bathymetric Control Points	0.87	1.29	2.28	1.85	8.11
50 TIN Control Points		1.32	1.89	2.59	5.90

The final step in the modelling of the 1913 river channel is the creation of a virtual reality representation, from the bathymetric data, of the physical landscape. The TIN model was input into ArcScene, a sub-extension of ArcGIS 3D Analyst. An excellent 3-D visual representation of the 1913 St. Marys River bed was created. A vertical exaggeration of 10 times enhanced the relatively gentle elevation changes, and showed a 'snapshot' of the 1913 engineering marvel of the dredged Hay Lake Channel (Figure 8).

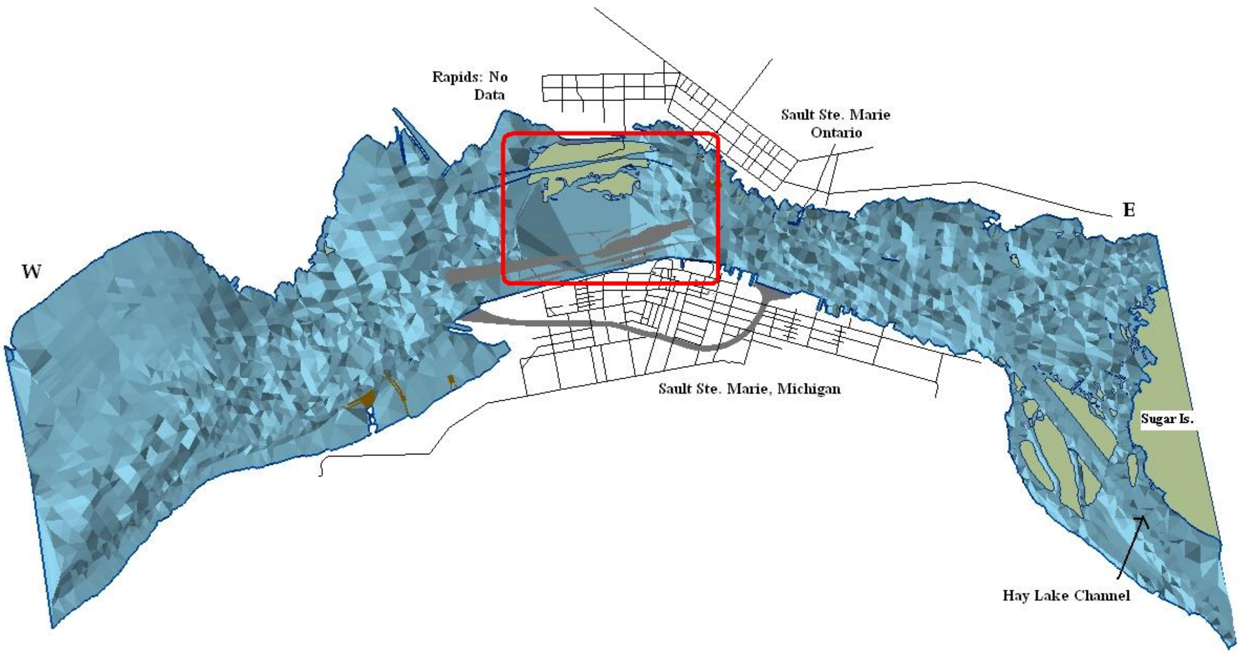

Figure 8. 3-D TIN, a Virtual Reality Representation of the 1913 St. Marys River channel topography illustrating the relative heights and depths of the riverbed. The model creates a flat surface across the rapids, where there is no bathymetric data. Dark blue represents depth.

ArcScene enables the HGIS user to view the 3-D topography from different angles, including elevation (Figure 9). The georeferenced 1913 base map was also draped over the TIN 3-D model. This created a three dimensional representation of the "old flat" 2-D map with its numerous bathymetric values. This helps to create a visual depth for the numeric text, by illustrating the relative heights and depths of the riverbed topography.

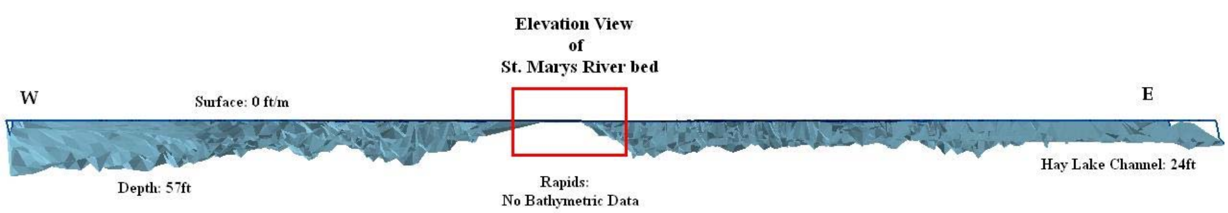

Figure 9. A 3-D Elevation representation of depth, using a north facing view of the St. Marys River channel. The flat surface across the rapids (no bathymetric data) is apparent.

CONCLUSIONS

Combining the 1913 International (Bathymetric) Boundary Map with GIS techniques shows that historic bathymetry can be interpolated to accurately reconstruct a feature's physical structure. Maps are the windows to the past. Using historic cartography to reconstruct past channel morphology pushes the knowledge of a channel's physical structure to an earlier time frame than is possible with contemporary remote sensed data. Duplicating this

HGIS methodology on additional regional historical maps will enable the HGIS user to create a temporal series of quantitative and qualitative change, and to create virtual reality representations using ESRI's advanced visualization and animation techniques. Future HGIS St. Marys River channel studies involve the modelling of other 19^{th} century bathymetric maps. Using the first (1855) Corps of Engineers bathymetric survey of the St. Marys River will enable the HGIS user to quantitatively compare maps with similar sounding X,Y locations, and to determine if and where channel changes have occurred during the 60 year time period. It will be interesting to determine if the early 19^{th} century cartography, such as Lt. Henry Bayfield's 1825 surveys of the St. Marys River, which have fewer sounding points, will yield useable channel and riverbed information. The 3-D models of the river channel will enhance the underwater topography, and enable viewers to take a virtual reality tour of the riverbed, as Rumsey and Williams did in the San Francisco Bay (Knowles, 2002).

Disciplines other than geography and history, such as engineering, environmental science, incorporate the history of river use and channel change within their research. Geomorphology studies encompass a holistic understanding of both historic and contemporary channel change, and river channel management practices require "an understanding of temporal change in river channels" (Downs, 2004, p.4) to understand the dynamic behavior of a river in the landscape. Combining archival scientific data, such as river flow data, with quantitative channel changes measured from historical maps, will provide scientists with a snapshot of biotic habitats. Understanding how a river and its habitats behaved and reacted to past changes will provide tools to aid in future conservation and restoration projects. This could be of use to such organizations as the Conservation Authorities of Ontario who have a mandate to "ensure the conservation, restoration and responsible management of Ontario's water, land and natural habitats" (CO, 2007).

The gathering of international St. Marys River data into a temporal HGIS will provide a platform from which other users can store and analyze additional cartographic, archival, and contemporary data. The St. Marys River, as an Area of Concern, is being studied and internationally monitored with regard to fish and habitat restoration (Great Lakes Fishery Commission, 2002). An understanding of how the river bed reacted to anthropogenic channel change can be used as a predictive tool for future navigation safety (dredging, future construction). In addition, today's society is 'digitally visual' and appreciates virtual reality representations. Many find that history and geography are easier to perceive and understand if they are digitally rendered to be entertaining and fun. Using historic artifacts and cartography in partnership with GIS software, to record the chronology of channel change in the St. Marys River and create 3-D models of the cartographic charts, will make the 19^{th} century history and topography of the St. Marys River a contemporary reality.

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