Evaluating Consumer-Grade Sonar for Documenting Inundated Archaeological Sites in Northwestern Ontario

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Abstract

This thesis assesses the application and effectiveness of consumer-grade sonar instruments for documenting inundated archaeological sites across Northwestern Ontario. Although the use of bathymetry and side scan sonar is commonly used by marine archaeologists, the acquisition of such data can be extremely costly, while also cumbersome in shallow water environments. Many Northwestern Ontario lakes and rivers have complicated histories involving both human-made and natural lake-level changes that have degraded and inundated shorelines containing archaeological resources. Four case studies throughout the Thunder Bay region were assessed using an inexpensive hull-mounted sonar system to test whether the instruments provide sufficient precision and resolution for further archaeological investigations.

Acknowlegments

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Chapter 1

Introduction

1.0 Introduction

This thesis presents research assessing the application and effectiveness of consumer-grade sonar instruments for documenting inundated archaeologically significant landscapes within Northwestern Ontario. The development of methods for documenting shallow water features is particularly important since many of the local freshwater lakes have been utilized as hydroelectric reservoirs since the early 20th century. Such anthropogenic water-level fluctuations have caused erosion, damaging many terrestrial archaeological sites that represent a significant part of the cultural history of Northwestern Ontario. While modern developments undergo cultural impact assessment, those dating before the 1970s regulatory requirement for environmental assessment received little attention prior to flooding. When cultural assessments did take place in these water fluctuation zones, it is not clear how useful and comprehensive such reviews are. This had led to Indigenous communities enquiring about lost cultural territory around reservoir basins (Blaire, 2005; Kowalczyk, 2005).

While underwater archaeological investigations are comparatively common, most studies involve the documentation of shipwrecks (Quinn, 2011). While such interpretation of past maritime cultures and seafaring abilities is important, shipwreck archaeology is not the only outlet for marine or underwater research. Increasingly, culturally significant landscapes have been investigated using geophysical surveying techniques. While such methods are well established in marine investigations, many of these studies comprise coastal sites that were impacted by post-glacial sea level rise (Loewen *et al.*, 2006), with few projects in Ontario focusing on inland freshwater lakes (Sonnenburg and Boyce, 2008; Sonnenburg *et al.*, 2012). This is likely a consequence of many inland lakes being inaccessible to large research vessels, with obstacles that would make towing sonar extremely challenging. To compound the issue, such studies are often subsidized by research grants, and thus, are too costly for archaeologists occupied with cultural resource management. This has led to a gap in our knowledge of cultural remains that continue to be inundated by natural and anthropogenic means.

1.1 Research Location

According to its census profile (Statistics Canada), Ontario consists of a land area of 917,741 square kilometers, with 158,654 square kilometers of freshwater resources. According to the Ontario Ministry of Tourism Culture and Sport (M.T.C.S.), areas within 300 meters of a primary, secondary or ancient water source are deemed to have high archaeological potential. With Thunder Bay's proximity to many freshwater resources, including Lake Superior, the possibility of the destruction or manipulation of culturally significant sites is high. Both natural and anthropogenic (hydroelectric reservoirs) water level fluctuations have been shown to erode shorelines, and thus expose the culturally sensitive material to degradation. For example, the shores of Dog Lake (McLeod, 1978; 1980), reveal the consequences of seasonal impoundment of water, the most serious of which is repeated flooding and shoreline erosion. While extensive artifact collections derive from these washed out shorelines, all contextual information is lost, and significant reworking of shorelines makes it difficult to interpret former shoreline configurations. With the rich local history, the Thunder Bay District represents a suitable case for the assessment of cost-effective techniques for underwater surveying.

1.2 Research Objective

The primary objectives of this thesis are twofold. First, it will address the uses, capabilities, and effectiveness of consumer-grade sonar for marine archaeological purposes, using case studies within the Thunder Bay District. Secondly, this project will highlight the procedures of underwater archaeology, and its methodologies for surveying and studying culturally significant, submerged landscapes in remote northern environments.

To achieve this, a series of objectives are proposed:

I. Address high water levels in NW Ontario, and their impact on cultural resources.
II. Refine methodologies for non-invasive data collection that is both cost-effective and accurate for cultural assessment.
III. Provide recommendations for future research.

1.3 Thesis Outline

This thesis is presented in the following parts. Chapter 2 discusses the cultural history of the Thunder Bay region and Northwestern Ontario, detailing various aspects of the cultural occupations over the last 10,000 years. It also provides a geographical and cultural context for the archaeological sites selected in this study.

Chapter 3 briefly introduces hydroelectric dams and their impact on archaeological sites. It also introduces the lake histories relevant for the case studies utilized in this research, and provides information regarding the reservoirs' geographical and archaeological history.

Chapter 4 reviews the rules and regulations applying to underwater archaeology in Ontario, and how they pertain to this research project. This section introduces the current methods associated with marine archaeology, including the key concepts in non-invasive data collection and their research utility. The practical implications for "cost-effective" sonar research will then be delineated to provide context for this investigation. Acoustic sonar methodologies will be employed to determine their capability in characterizing submerged landscapes, and aid in the reconstruction of former shorelines. Following the trials, the insight gained from underwater remote sensing will be tested by direct observation through drone mapping during periods of low water, physical inspection by divers, and through lake bottom coring. The strengths and limitations of such research will then be addressed. The chapter will conclude with some general remarks about the utilization of these concepts for their application to culturally submerged landscapes in a northern environment.

The results of the investigation are presented in Chapter 5. This includes the outcome of the acoustic surveys and remote sensing techniques. The effectiveness of such inexpensive methodologies will be assessed later in Chapter 6 with consideration of the quality and reliability of the data, and comparisons to similar studies found in the literature.

Chapter 7 presents conclusions regarding the use of such methods for marine archaeological investigations. Here, the implications of consumer-grade equipment will be addressed to see where it fits within the current approach to understanding submerged cultural landscapes on inland lakes. Finally, the thesis concludes with a discussion of future applications of cost-effective marine archaeological investigations.

Chapter 2

Culture History of the Thunder Bay Region

2.0 Introduction

With the northwards retreat of the Laurentide Ice Sheet during the Late Pleistocene, human occupation of Northwestern Ontario began (Dawson, 1983a; Fox, 1975). After the deglaciation of the Lake Superior basin 9,500 years ago, it quickly became biologically viable and attractive to animals and their human predators. Through successive environmental changes, coupled with the diffusion of ideas and technology from elsewhere, these groups repeatedly adapted to changing circumstances. Archaeological surveys over the past sixty years have led to slowly accumulating knowledge about these ancient cultures. However, water level change can pose a serious risk to the integrity of archaeological deposits throughout the region, both from human-caused erosion of shorelines, and inundation of former terrestrial surfaces. While this knowledge is not yet comprehensive, this chapter summarizes the regional culture history, with a focus on archaeological sites found in the Thunder Bay area. This information is significant as relics from these periods appear in the archaeological record, often on washed out beaches.

2.1 Culture History of the Thunder Bay Region

2.1.1 Paleo-Indian

The late Paleo-Indian (Plano) tradition in northwestern Ontario appeared in the Thunder Bay region shortly after the Marquette Re-advance (ca. 9500 cal BP) (Hinshelwood, 2004), and are characterized by a nomadic foraging lifestyle. While virtually no faunal material has been recovered from the acidic soils, it is assumed that fauna such as Caribou and Bison formed an important part of their economy (Dawson, 1983). Excavations at the Brohm site in 1950 and the Cummins site in 1962 represents the initial examination of the Late Paleo-Indians in the Thunder Bay district (MacNeish, 1952, Dawson, 1983). While often limited to small-scale excavations, there have been numerous accounts of Late Paleo-Indian sites being found in the area since this early work (Julig, 1994). Test excavations and surface collection throughout the 1960's and early 1970's culminated with a synthesis by William Fox that describes the Lakehead Complex. This synthesis resulted in the first formal description of traits defining Plano occupation in the Thunder Bay area (Fox, 1975, 1980; Langford, 2014). In 1995 William Ross defined the Interlakes Composite (consisting of several related Complexes), after comparing projectile point morphological features and other characteristics from sites throughout Northwestern Ontario. Characteristics of the Interlakes Composite include the use of lanceolate, parallel-flaked projectile points (**Fig. 2.1.1.1**), and the use of both exotic and locally derived lithic materials (Ross, 1995; Langford, 2014). Bifacially chipped knives, and unifacial scrapers were also a significant part of the Plano toolkit and were used for cutting and scraping (Irwin and Wormington, 1970). These tools were crafted by hard and soft hammer flint knapping techniques and were made from lithic materials such as Jasper Taconite and Gunflint Silica (Dawson, 1983), many of which were quarried from bedrock making up the Gunflint Formation. Salvage excavations at the Mackenzie I site (DeJf-9) recovered 370 Plano projectile points made from such local materials (Norris, 2012).

The spatial association of Plano artifacts with glacial Lake Minong landscape features has provided a contextual timeline for early occupation of the region. Dates recovered from beach ridges associated with the Minong phase of Lake Superior suggest that Plano occupation of the Thunder Bay area goes as far back as 9,500-9,300 years BP (Fox, 1975, 1980; Julig, 1994).

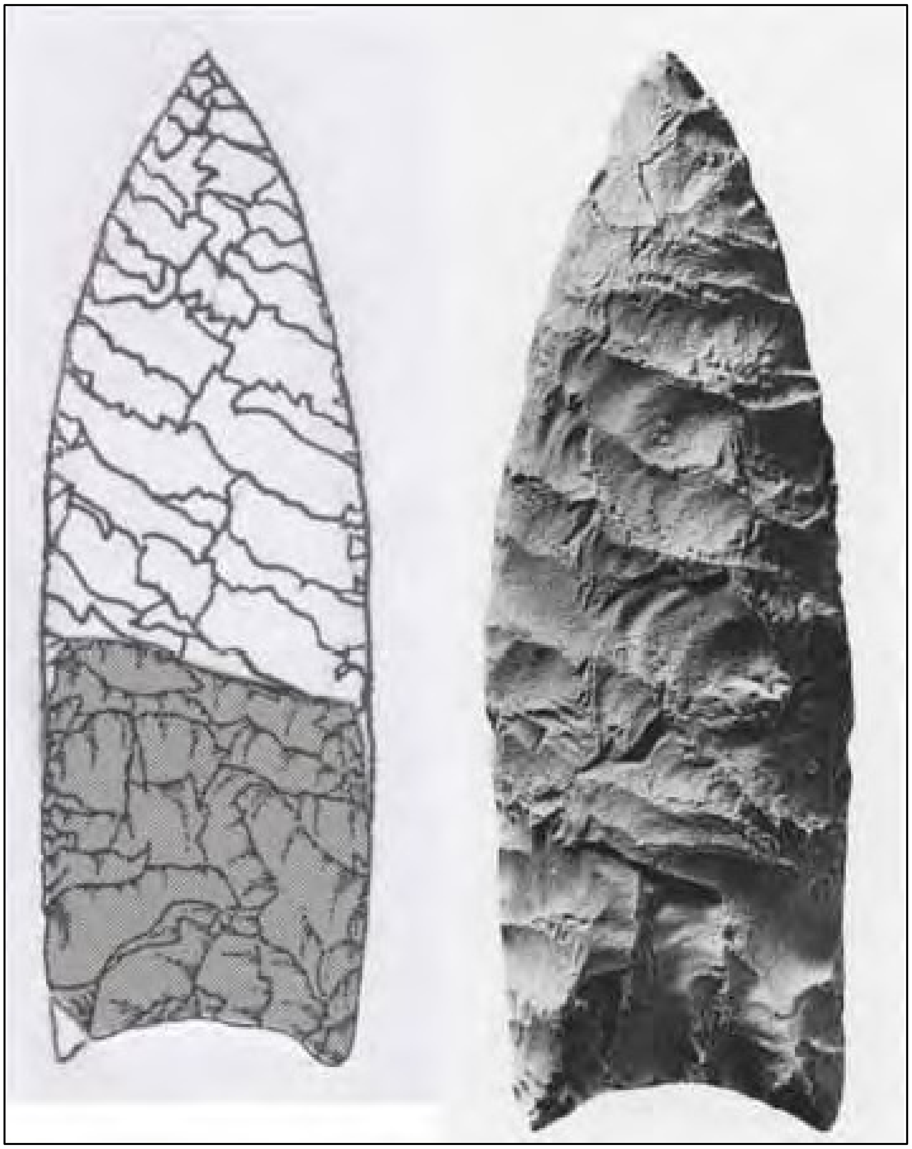


Figure 2.1.1.1. Late Paleo-Indian projectile point from the Thunder Bay region. Style includes the use of a lanceolate shape, basal thinning, and oblique parallel flaking. (From Phillips et al. 2012)

2.1.2 The Archaic Period

With deglaciation, sediment weathering and subsequent warming during the early Holocene period, a more diverse range of plant and animal species appeared as the early post-glacial 'tundra-like' environment became forested with pine, birch, and alder (Langford, 2014; Bjorck, 1985; Julig et al., 1990). This is thought to have led to a decline in big game hunting in favor of a more generalized foraging strategy. This perspective has been widely applied to help explain social, economic and technological trends throughout the Eastern Woodlands culture area (Wright, 1981). While it is not clear how appropriate it is, the Archaic concept has been applied to Subarctic culture history. The Archaic tradition in northwestern Ontario spans more than five thousand years (ca. 7,500-2,000 BP) and is defined by distinctive tool assemblages used in woodworking and the predation of wild game and plants (Dawson, 1983).

Archaeological investigations by J.V. Wright (1972,) classified the Archaic cultural tradition of the Boreal forest and Canadian Shield area as the Shield Archaic (**Fig**. 2.1.2.1). This broad synthesis, adapted from Elmer Harp's research in the Northwest Territories (Harp, 1961), is the first and still primary explanation of the early Archaic within the western Superior basin. According to Wright (1972), the Shield Archaic can be divided into the Early (7,000-6,000 BP), Middle (6,000-3,000 BP) and Late Archaic divisions. However, Hinshelwood (2004) argues that due to a lack of local typologies and dated sites, it is difficult to accept the divisions.

To further complicate things, much of our interpretation of Shield Archaic derives from analogy and extrapolation from archaeological sites in other regions of the country, or with some of the Subarctic data coming from surface collections and disturbed sites (Wright, 1978). According to Phillips and Ross (1995), much of the archaeological record that represents the transitional period from Paleo-Indian to Archaic is also missing. Robert Mason (1981) states that "the rarity of Early Archaic sites in the Great Lakes is something of a puzzle." Perhaps some of this apparent "rarity" might reflect the use of beaches associated with the Houghton levels of modern day Lake Superior. It is during this time (~9,000 BP), that water from Lake Agassiz ceased to drain into the Superior basin, leading the water levels to decline below modern-day Lake Superior (Farrand and Drexler, 1986). A publication by Boyd *et al.* (2010) suggests that a climatic shift to more arid conditions also contributed to the Houghton low stand event. Archaic sites that are found in the region are primarily associated with the beaches of the Nipissing Transgression (~7,000-~4,000 BP), where water levels rebounded and flooded the previously exposed land (Teller, 1985; Fisher and Whitman, 1999; Kingsmill, 2011). However, interpretations by Boyd *et al.* (2010) suggest that Houghton beaches along the north shore may have been preserved above the Nipissing Transgression by differential isostatic rebound.

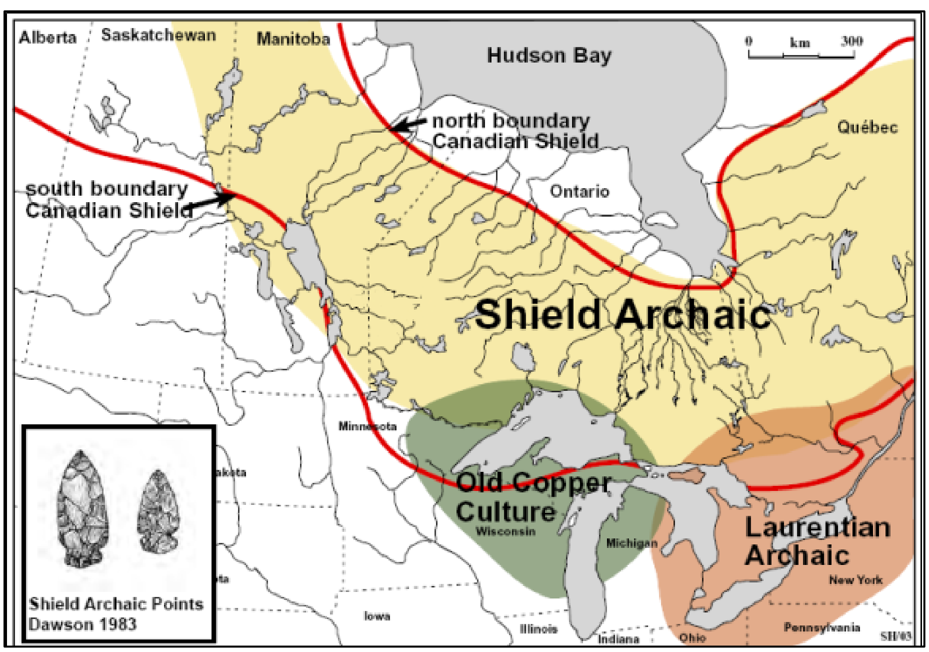


Figure 2.1.2.1. Distribution of the various Archaic cultures throughout central North America (from Hamilton, 2007)

What do we know about the Archaic Tradition in Northwestern Ontario? It is best represented by the changes in projectile point morphology, and the additional use of woodworking tools. According to Wright (1981), Archaic projectile points have side-notches with a decreased lanceolate shape. Other artifacts from this period, (**Fig. 2.1.2.2.**), also include scrapers, bifaces, blades, and ground-stone tools (Dawson, 1983a; 1983b). The Old Copper Complex, which is defined for its use of copper from the Lake Superior region, utilized tools such as stemmed projectile points, awls, spuds, fish hooks, gaffs, spears, pendants, and crescents. During this time, bone was also employed to rivet the copper tools (Wright, 1978; Fregni, 2010). The earliest known date from the Old Copper period is 7690+/- 40 BP, which derives from samples dated by Mark Bruhy in Northern Wisconsin (w. Ross – personal communications).

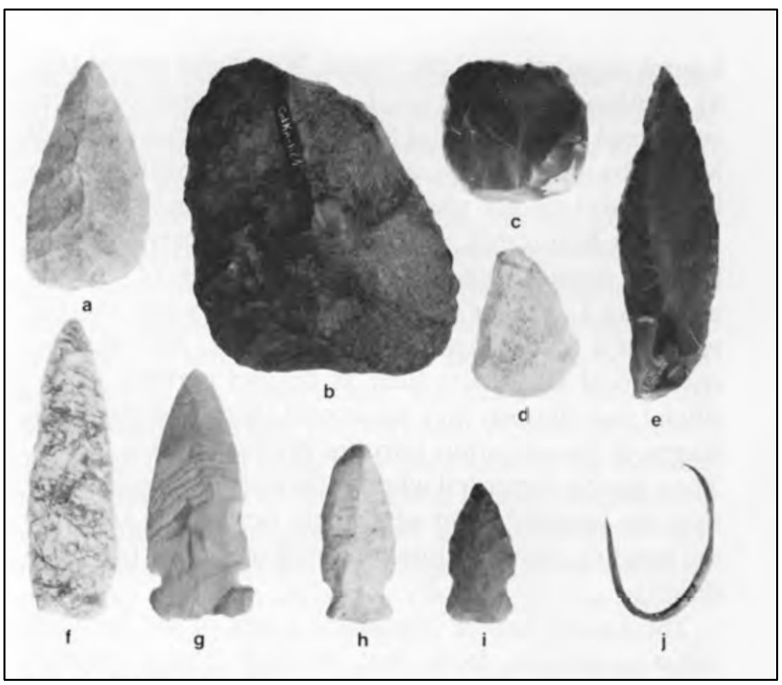


Figure 2.1.2.2 Shield Archaic artifacts from Ontario (from Wright)

2.1.3 Woodland Tradition

Approximately 2,200 years ago the archaeological record demonstrates the beginning of the Woodland Tradition throughout Northwestern Ontario. Originating in the Eastern Woodlands as early as 3,000 years ago, the Middle and Late Woodland cultures are characterized in large measure by the introduction of pottery, the use of smaller triangular projectile points, burial mounds, and widespread exchange networks (Wright, 1975). Current interpretations suggest that population levels climbed during the Woodland period, and it appears that plant foods became more important. This included wild rice as well as domesticates such as maize and beans (Boyd *et al.*, 2014; Dawson, 1983; Surette, 2008).

The first to synthesize the Woodland Tradition in Subarctic Ontario and link it to Ojibwa culture history was J.V. Wright (Dawson, 1983; Wright, 1965, 1968). The Woodland tradition is divided into three sub-periods (Early, Middle and Late Woodland), each of which is characterized by the different styles of ceramics used in the processing of food resources (Surette, 2009). Only the Middle and Late Woodland periods are currently recognized in northwestern Ontario. Here, they are sometimes referred to as the Initial Woodland (McMillan, 1995; Reid and Rajnovich, 1991) and the Terminal Woodland period (Dawson, 1983).

The Initial Woodland occupation of the southern Boreal forest is defined by the Laurel culture (**Fig. 2.1.3.1**) that dates between 2,500 to 800 years ago (Surette, 2009). It is characterized by medium-sized conoidal vessels with stamped decorations (Dawson, 1981; Wright, 1978). Past researchers (Hamilton, 1981; and Wright, 1967) have suggested that the use of pottery by the Laurel culture beganfrom the adaptation of pottery by Shield Archaic people.

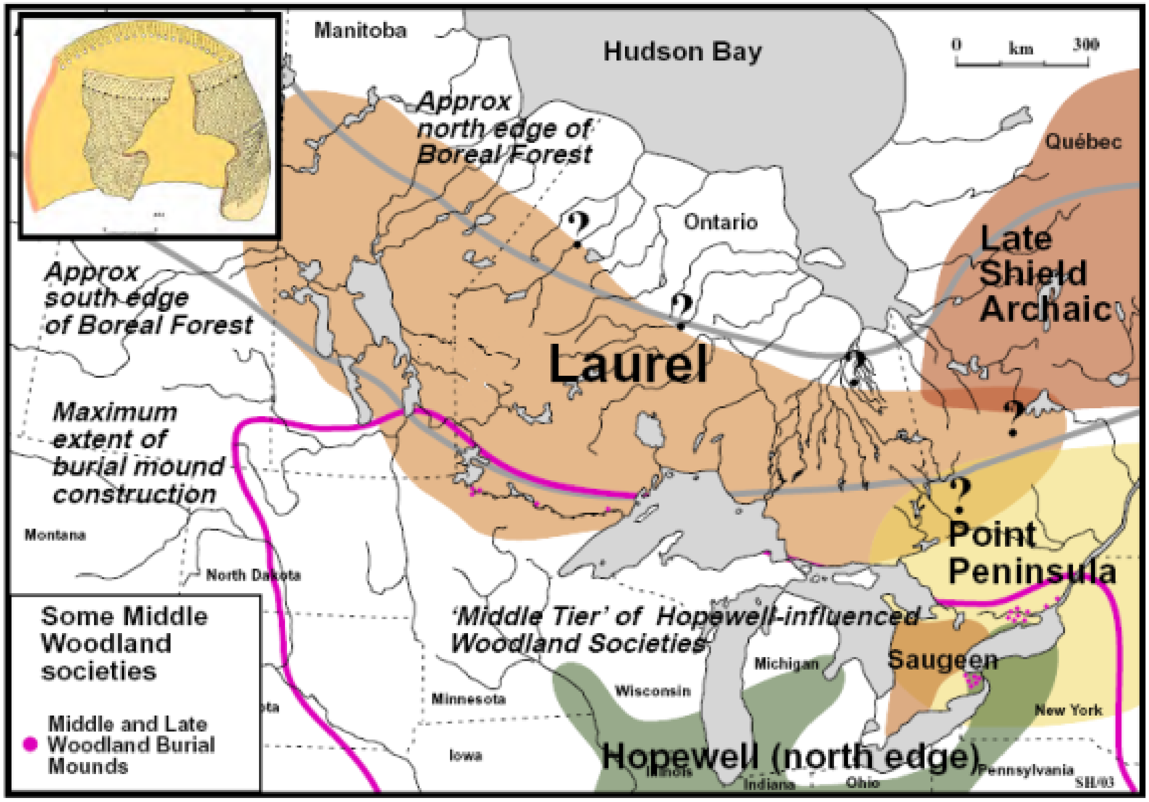


Figure 2.1.3.1 Distribution of Middle Woodland cultures throughout Ontario and central North America (from Hamilton, 2007)

The Terminal Woodland period (or Late Woodland period) of Northwestern Ontario is primarily composed of three archaeological cultures named Selkirk, Sandy Lake, and Blackduck (**Fig. 2.1.3.2**), and are defined by their distinctive ceramic vessels. For example, Blackduck (1,400 to 900 yrs BP) pots were globular in shape, with textile impressed bodies and with designs created by cord-wrapped dowel impressions over the neck and rim (Bursey et al.). In comparison, Selkirk pottery (1,100 to 500 BP), while also textile impressed, have somewhat different vessel shapes and generally lack the extent of cord-wrapped dowel impressions associated with Blackduck (Meyer and Russell, 1987; Surette, 2009). Sandy Lake Complex, on the other hand, consist of ceramics that have numerous types of surface finishes, including cord-marked body walls, with little to no decorations (Taylor-Hollings, 1999; Surette, 2009). In scattered locations along the southern

Boreal Forest, Iroquoian ceramics have also been observed. This, according to Dawson (1979) might reflect how populations in southern Ontario might have influenced in the north. The culture types highlighted here were prominent in the region until after the arrival of Europeans to Northwestern Ontario. It was at this time, where influences caused by fur trading saw the disappearance of traditional tool use.

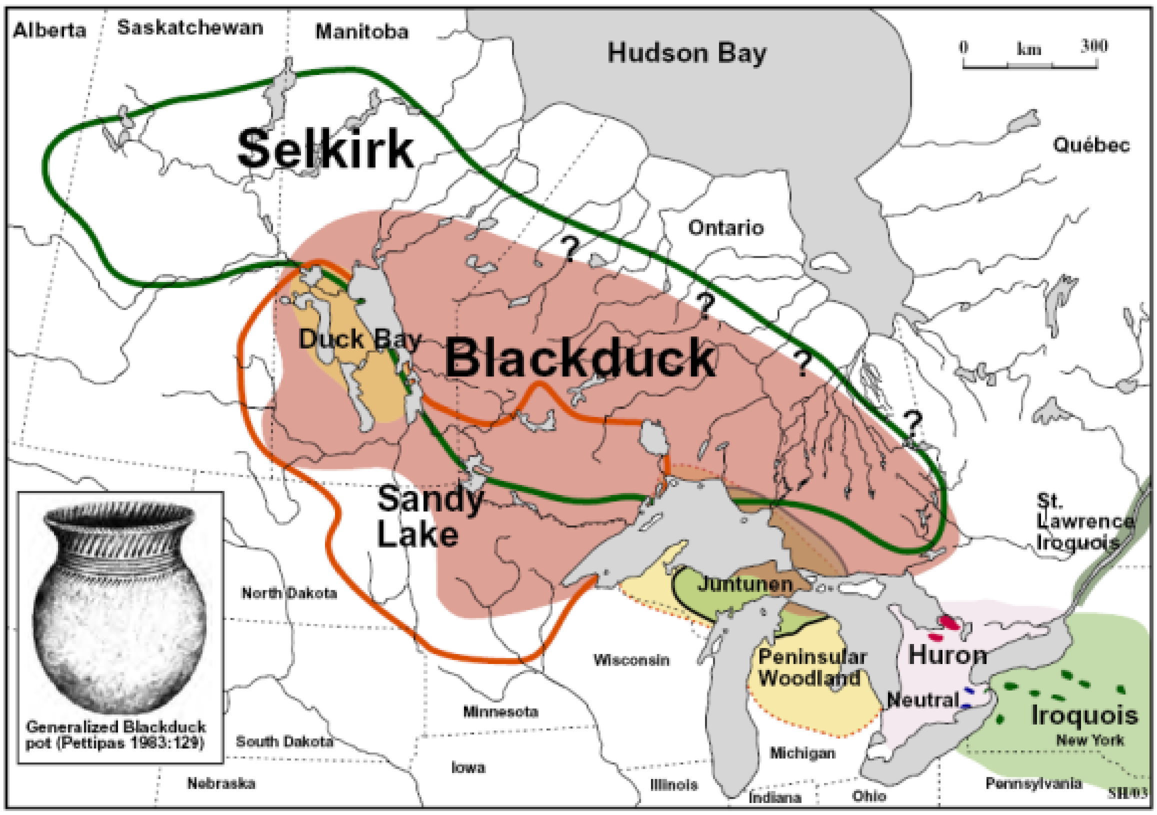


Figure 2.1.3.2. Distribution of Terminal (or Late) Woodland cultures throughout central North America (from Hamilton, 2007)

2.1.4 Historic Period and Fur Trade

The arrival of Europeans to the Americas brought considerable change to the Indigenous cultures, which gradually became more visible in northern Ontario after the early 1600s. Much of the earliest influence derived from the indirect impact of trade networks controlled by "Aboriginal middlemen traders" that enabled a modest amount of foreign technology to diffuse throughout northwestern Ontario (Hamilton, 2013). Authors Beaulieu and Southcott (2010) provide a brief synopsis of how both the English and French competed against one another during the 17th and 18th century Fur Trade. Among the significant developments dating to this time include the creation of the Hudson's Bay Company in 1670 and the eventual collapse of New France in 1760 (Beaulieu and Southcott, 2010).

With the fall of New France and the 1763 Treaty of Paris, the British gained Imperial control over most of northern North America (Dawson, 1972). This sparked an unprecedented geographic expansion of the interior fur trade, as Anglo-Scots merchants took over the former French Colonial fur trade and expanded it far into the continental interior. These Montreal-based merchants gradually consolidated into the North West Company, and continued their aggressive expansion into the interior, forcing the HBC to follow suit. The enormous transportation distances represented by this expanding fur trade hinterland led the Montreal merchants to establish an inland depot, first at Grand Portage, and later at Fort William, within modern Thunder Bay, Ontario. The fort remained under control of the North West Company until 1821, whereupon it amalgamated with the Hudson's Bay Company (Morrison, 2007). Beginning with the period of fur trade competition (ca. 1760 to 1821), and with the restoration of HBC monopoly (1821 to ca. 1870 CE), the fur trade was the economic engine that drove European expansion into the continental interior, bringing European technology, commerce, and disease to virtually every

Indigenous nation occupying what is now Canada (Beaulieu and Southcott, 2010). This regular and increasingly intensive contact led to rapid and profound change for Indigenous and Métis people. This transformation is archaeologically most visible with the rapid disappearance of traditional material culture and is replacement with European manufactured goods. While these material changes are significant, it is important to emphasize that many aspects of the traditional foraging economy, settlement system, and social organization remained in place. This continued through to the mid-1800s, whereupon new economic opportunities attracted Euro-Canadians northwestward into the Subarctic in greater and greater numbers.

The establishment of the Robinson-Superior treaty in 1850, and the sale of Rupertsland to the Dominion of Canada in 1870, initiated a rapid escalation in European colonial expansion westward throughout the upper Great Lakes and into northwestern Ontario (McGuire, 2010; Beaulieu and Southcott, 2010). From the beginning of the 19th century, through to the early 20th century (1920's), the use of treaties continued as Canadian economic and settlement interests expanded westward. Over time, this pressure began to press Indigenous communities into weaker economic, social and political positions relative to their European neighbors. With political and economic realities increasingly focused on immigrant expansion westward, Indigenous people were increasingly disenfranchised and marginalized as they were confined on small reservation communities under the administrative dominance of provincial and federal government authority. Some communities during the early and mid-19th century were dispersed from their traditional territory due in part, to the construction of hydroelectric dams. Local examples of such negligent actions include the dispersal of Indigenous communities from Lac des Mille Lacs and Dog Lake (Alder, 2010; Wilson per comms, 2015).

2.2 Summary

After the retreat of the last glacial maximum, humans began to occupy the Thunder Bay region approximately 9,500 years BP, This culture period, known today as Paleo-Indian period, is defined by its exploitation of large megafauna as a primary source of food. Ancestors of the local Indigenous communities utilized local lithic materials to fabricate projectile points and scrapers for food procurement. As climate conditions evolved, hunting strategies followed suit. The Archaic period (ca 7,500 yBP), often described by their use of a more diverse toolkit, is defined by a more generalized exploitation of small animals and plants. As time passed, the introduction of pottery during the Woodland period (ca 2,200 yBP) allowed for the domestication of various plant species that were used until the arrival of Europeans in the 17th century.

The archaeological record of the Thunder Bay region and Northwestern Ontario is composed of numerous cultures that encompassed a ten-thousand year period. Archaeological evidence recovered from a multitude of sites, including those from submerged sites, suggests that past environmental changes have had an influence on adaptations to foraging and hunting strategies here in northwestern Ontario. However, additional information regarding past adaptations and cultural diffusions remain unknown, due to poor preservation and inadequate techniques. The inundation of terrestrial shorelines, whether anthropogenic or natural, is a detriment to the preservation of archaeological data, as water levels wash away contextual information (soils, dateable materials, small artifacts) that could provide additional information.

This is no more apparent than the lack of information relating to the transition from the Paleo-Indian period to the Archaic. Highlighted above, some researchers believe that sites that reflect the early stages of the Archaic period may likely be submerged under modern Lake Superior water levels. To begin researching this problem, techniques, skills, and methodologies that reflect the discipline of underwater, or maritime, archaeology must be appreciated.

This chapter highlights a vast culture history, which due to rising water levels in our lakes and river systems, is under threat. The archaeological case studies presented in this thesis (sites at Dog Lake, and Boulevard Lake) reflect those that are impacted by anthropogenic water level change. Chapter 3 will provide information on the hydroelectric history, and archaeology of the sites utilized to test the cost effective methodologies.

Chapter 3

Reservoirs and Their Impact

3.0 Introduction

Throughout North America, resource developments have had significant effects on Indigenous communities, and their heritage. Agricultural, transportation, mining, and forestry sectors have all played roles in the destruction of both culturally and archaeologically significant sites. These actions have created tension between Indigenous communities and the resource development sectors, which has led to many legal clashes (Nickens, 1991). One of the most severe disturbances of cultural heritage derives from the construction of hydroelectric dams. This chapter will briefly highlight hydroelectric dams, and their impact on archaeological sites found within the region.

3.1 Hydroelectric Dams and Reservoirs

Stimulated in part by technological innovation, large-scale capitalization and population growth at the early 20th century, hydroelectric development is also associated with pulp and paper and mining development. With rapid development of industrial capacity and urbanism throughout the country, the need for electricity prompted the construction of multiple dams. Some of the earliest large-scale constructions include Chaudiere Fall, ON (1881); Bow River, AB (1893); DeCew Falls, ON (1898); Shawinigan Falls, QB (1898); Petty Harbour Hydroelectric Station, NL (Lee, 2011).

Hydroelectric dams and power plants enable the capture and generation of electricity using Canada's abundant and renewable water resources. Hydroelectric plants utilize kinetic energy (falling water) and convert it into mechanical energy using turbines. In turn, this is converted into electric energy (Castaldi *et al*., 2003). Storage of water within head ponds or reservoirs upstream from the generator is essential for the year-round generation of electricity. This is achieved by construction of dams to hold water, and allow its controlled release to the generator via penstocks (**Fig. 3.1.1**). This stored water often exceeds the original shorelines, inundating extensive areas that were formerly terrestrial surfaces (Majumder and Ghosh, 2013). According to the SFPC (Southeastern Federal Power Customer), multiple forms of hydropower facilities exist. These include Impoundment, Diversion, and Pump Storage facilities. Though all types of hydroelectric development impact their surrounding biological and physical environments, the primary focus in this thesis is directed at Impoundment facilities, as each case study presented in chapter 4 involves this kind of hydroelectric reservoir.

Multiple studies have shown that the anthropogenic elevation of water levels has adverse effects on the surrounding landscape and environment. Physically, raised water levels inundate, or drown, the surrounding banks that were once habitat for terrestrial wildlife and vegetation (Biswat, 1981; Castaldi *et al*., 2003; Ledec and Quintero, 2003).

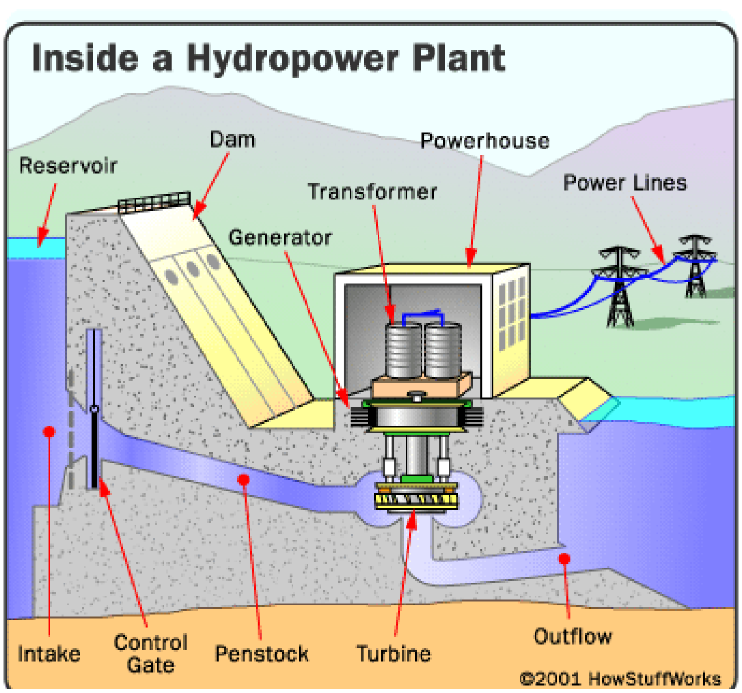


Figure 3.1.1. Schematic highlighting the many components of a Hydroelectric plant (borrowed from Castaldi et al, 2003).

This process can also harm people since such systems can destroy properties and redistribute communities. Between 1872 and 1923, two hydroelectric dams were constructed on Lac des Mille Lacs, a freshwater lake located at the head of the Seine River. The inundation that followed resulted in the loss of territory, resources, and reservation lands belonging to Lac des Mille Lacs First Nation. According to Alder (2010), this ultimately resulted in the dispersal of the Lac des Mille Lacs Ojibwa. Unfortunately, these issues are not isolated. According to Blair (2005), hydroelectric developments have resulted in the flooding of burial grounds and sacred sites across the province of Ontario.

Multiple studies have shown that the conversion of lakes and rivers into hydroelectric reservoirs has resulted in increased mercury levels in the local fish populations (Landa, 1969; Loney, 1987; Waldram, 1980). Two prominent examples of the effects of mercury contamination include the Churchill River Diversion Project in 1960's that impacted the Nelson House Cree, as well as the 1950's construction of a dam on the that impacted the Indigenous population at Grassy Narrows (Loney, 1995). With the influence of hydroelectric development on modern populations still under scrutiny, what effect has impoundment had on material remains that reflect the ancient past?

3.2 Impact on Archaeological Sites

In the 1970's, the National Reservoir Inundation Study was formed to examine the impact of hydroelectric development in the United States. This early study, commissioned by the Army Corps of Engineers, examined the various influences that affected cultural material after inundation (Lenihan et al., 1978). Their findings showed that the Littoral zone of a reservoir- the area between the high water mark and permanently submerged shoreline-is affected by the mechanical (waves, currents, and submersion), biochemical (pollution and sedimentary organic input), and anthropogenic (human use) processes commonly found in freshwater systems. Surveys and experiments across multiple lakes throughout the United States of America found that there are three zones of inundation that are impacted by these processes (**Fig. 3.2.1**). The zone that had the most significant impact on erosion, and the ultimately the redistribution of artifacts, was the near-shore '*Shoreline Fluctuation'* zone. It is within this zone where seasonally fluctuating water levels mechanically and fluidly erode and redistribute artifacts, thus causing them to lose their contextual relevance (Lenihan et al., 1982).

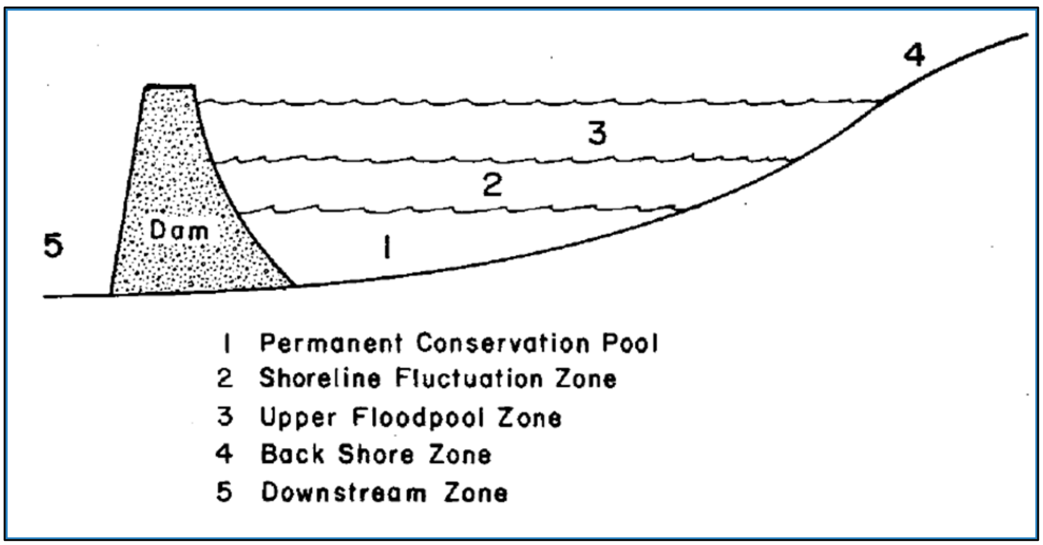


Figure 3.2.1. A schematic labeling the different pools and zones that are impacted by a hydroelectric dam (borrowed from Lenihan et al., 1982).

Examining case studies found within Canada, hydroelectric reservoirs have been responsible for the inundation, erosion, displacement, and destruction of both cultural landscapes and archaeological material (Ware, 1989). In Quebec, for example, the water levels on Lac Mégantic have inundated the Plage-Duquette site, which has evidence of occupation form 8,800-5,800 BP. An underwater survey commenced in 2003, resulted in the discovery of the 1893 pre-dammed shoreline. The geological analysis would later determine that the submerged terrace was exposed for thousands of years in the postglacial past (Loewen et al., 2005).

In 1966, one of the most significant hydroelectric projects ever undertaken occurred in northern Manitoba. The Churchill River Diversion Project affected both cultural landscapes of the Nelson House Cree, as well as their lands that held archaeological significance. Archaeological projects conducted in 1976-77 and again in 1991-92, revealed nearly 300 sites that had been eroded by the fluctuation zone and removed from their primary context (Linklater, 1994).

In northwestern Ontario, numerous hydroelectric stations have had an impact on archaeological sites as well. Lakes such as Lac des Mille Lac, Dog Lake, Lac Seul, Lake Nipigon all contain evidence of prehistoric societies living amongst their shores, and it their recent history have all been impacted by hydroelectric development (Bishop and Smith, 1975; Ontario Power Generation, 2018).

3.3 Case Study Lakes

3.3.1 Arrow Lake

Arrow Lake is a medium-sized freshwater lake that is situated 76km southwest of Thunder Bay, Ontario (**Fig. 2.3.1.1**). The surrounding area is vegetated with jack pine, white spruce and balsam fir growing upon bedrock landscapes that feature diabase cliffs, and glacial outwash deposits (Ontario Parks; Knowles, 1985). According to Ontario Parks there is a control dam located on the southern shore of the lake. Researching the dam (time of construction and use) proved futile since virtually no information was found. To the east, cottages and a private campground (Ryan's Resort) are utilized by local outdoor enthusiasts. In the centre of the lake, Arrow Lake Provincial Park provides local access to the north shore of the lake, with free to use boat launch.

Figure 3.3.1.1. Map showing the location of Arrow Lake, and its proximity to Thunder Bay, Ontario.

While Arrow Lake contains archaeologically significant shorelines, the fundamental objective of this case study was to test the Humminbird© sonar system and ReefMaster© software, in gathering and producing bathymetric data respectively. With this goal in mind, the entrance into Frog Portage was chosen (**Fig. 3.3.1.2**) as it was easily accessible. This location is found along the northeast section of the lake and consists of a series of shallow sand-bars features that frame the entrance into a separate section of the lake (Frog Portage).

Figure 3.3.1.2. Maps reflecting the survey area utilized at Arrow Lake, Ontario.

3.3.2 Dog Lake

Located approximately 45 km north of Thunder Bay, Ontario (**Fig 3.3.2.1**), Dog Lake is found within a zone of metamorphosed clastic sedimentary rocks making up the Precambrian Shield, which has been intensively modified by Wisconsin glaciation. This modification continued with deglaciation that began between 10,000 and 12,000 years ago (Fox, 1975; Julig, 1994; Boyd *et al.*, 2010). This led to the formation of the Dog Lake Moraine which acted to contain glacial Lake Kaministikwia. The recession of the glacial ice lobe allowed this proglacial lake to drain, reducing the water levels to their pre-hydroelectric dam configuration (Burwasser, 1977). Located on the northwest side of the lake basin, the Dog River is the primary water system supplying the 14806ha lake (Ontario Power Generation, 2015). The Kaministiquia River drains the lake from the south and flows into Lake Superior near the city of Thunder Bay (Clement, 1997).

Figure 3.3.2.1. Locational of Dog Lake, Ontario.

First impounded in 1939, Dog Lake now annually generates approximately $15 million in power for Ontario Power Generation, with generating stations located on the Kaministikwia River (Haidef and Rasid, 2013). The dam is found on the west side of the lake, within Silver Falls Provincial Park. In total, the lake has a mean depth of 29.6 meters, with the deepest part of the lake measuring to 117m. As of data gathered in 2015 (**Fig 3.3.2.2**), lake impoundment results in water levels that exceed 420 meters asl during the summer months, while they drop to 418 meters ASL during the late winter (OPG, 2015).

Examination of pre-dam shorelines, compared to their modern equivalent (**Fig. 3.3.2.3**) dramatically illustrates the consequences of over a century of transformation. Multiple sources (Dawson, 1972; and McLeod, 1978; 1980; Wilson per comms, 2015) have theorized as to what the natural shoreline would have looked like before inundation. With erosion and combined with periodic low water levels, the reservoir has provided ample opportunity for avocational archaeologists to discover artifacts along washed out shorelines. Over multiple decades, such enthusiasts have systematically collected and documented a number of sites, and have shared their knowledge with professional archaeologists. The exact number of archaeological sites around Dog Lake is not known, however, Figure 3.3.2.4. demonstrates how attractive the lake basin was to prehistoric people.

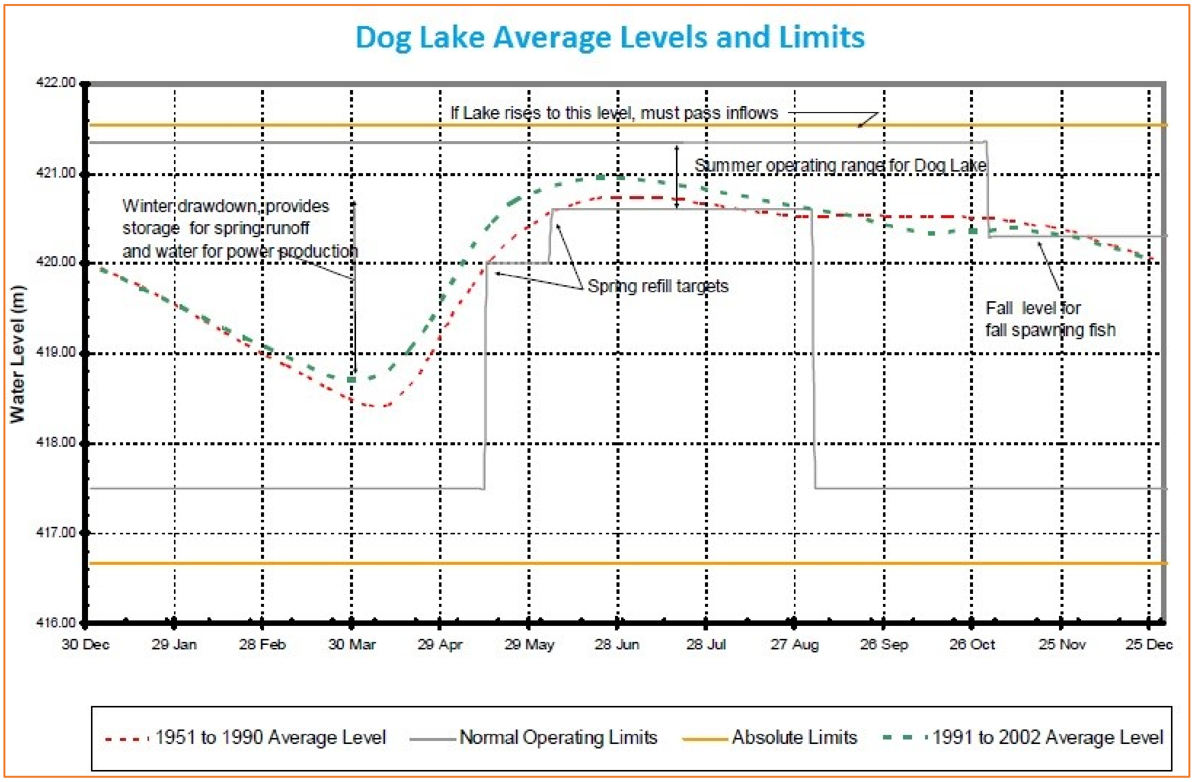
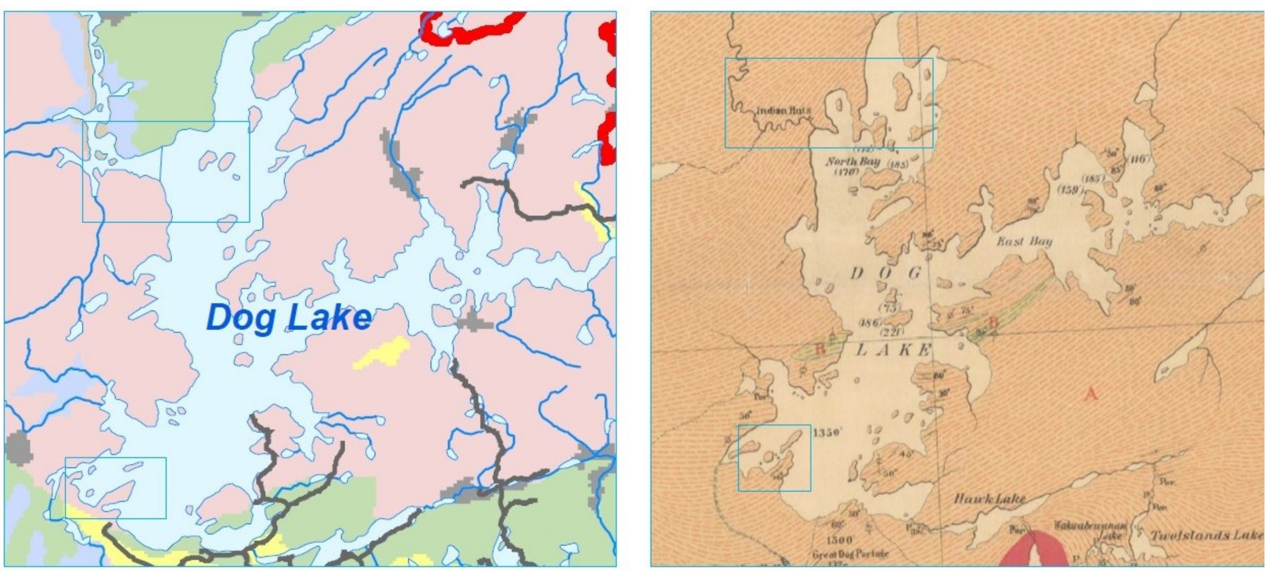


Figure 3.3.2.2. Season water level fluctuations in the Dog Lake basin (from OPG Water Management Plan Kaministiquia River System)



Left: Lakehead Source Protection Area Map; Right: From Canadian Geological Survey of 1896.

Figure 3.3.2.3. Comparison of shorelines between two maps over 100 years apart. Blue rectangles highlight some of the geographical changes that have occurred due to higher lake levels.

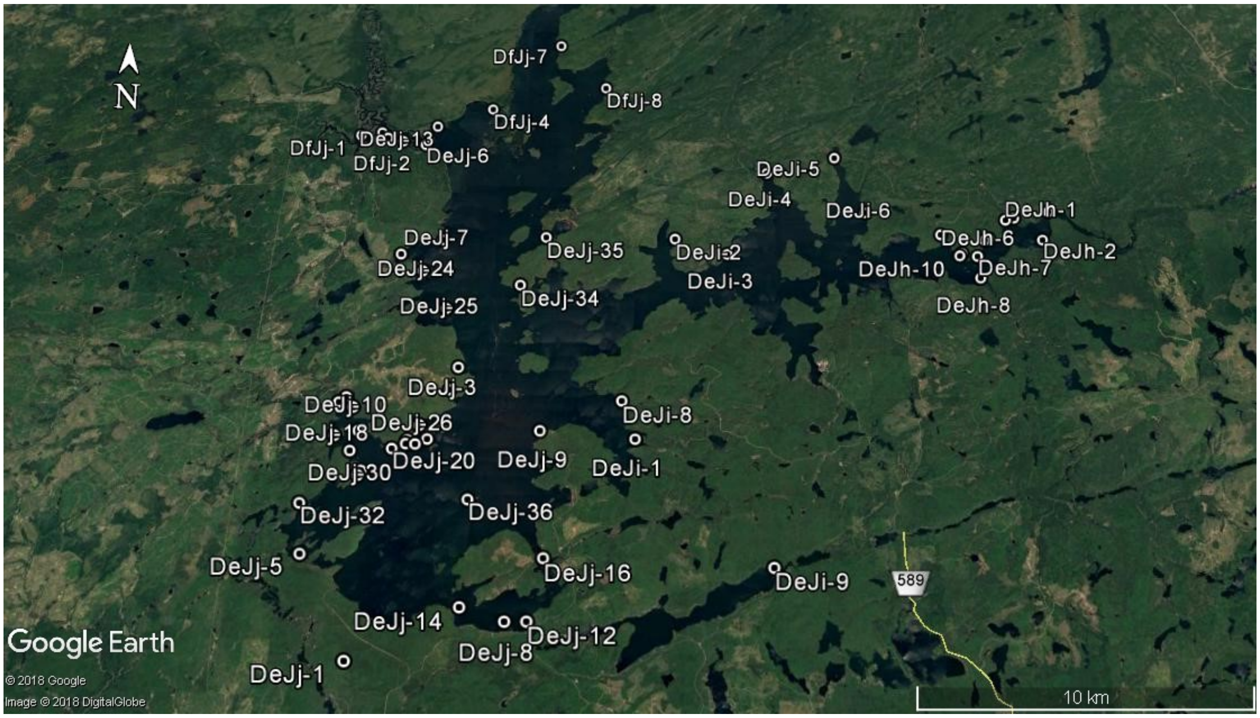


Figure 3.3.2.4. Currently known (bordenized) archaeological sites found along the shores of Dog Lake, Ontario.

The Hawk Bay Site

Located on Crown land, this archaeological site is situated on the northwest end of Hawk Bay in the southern part of Dog Lake (**Fig. 3.3.2.5**). DeJj-2 is located on the east side of a narrow rocky point that is now dominated by reeds and cattails. The site is submerged during the summer months, while throughout the late fall and winter, water levels decline and leave the site exposed to erosion, ice damage, and surface collection. The site was first discovered by Hugh Cummins in 1963 (McLeod, 1978), and was later officially documented by Ken Dawson in 1969 (Dawson, 1972). In 1977 both Ken Dawson and Mike McLeod visited the site during a time of low water. They collected artifacts representing all periods (Paleo-Indian, Archaic, Woodland, and Fur trade), as well as recording a historic cabin just north of the site (McLeod, 1980).

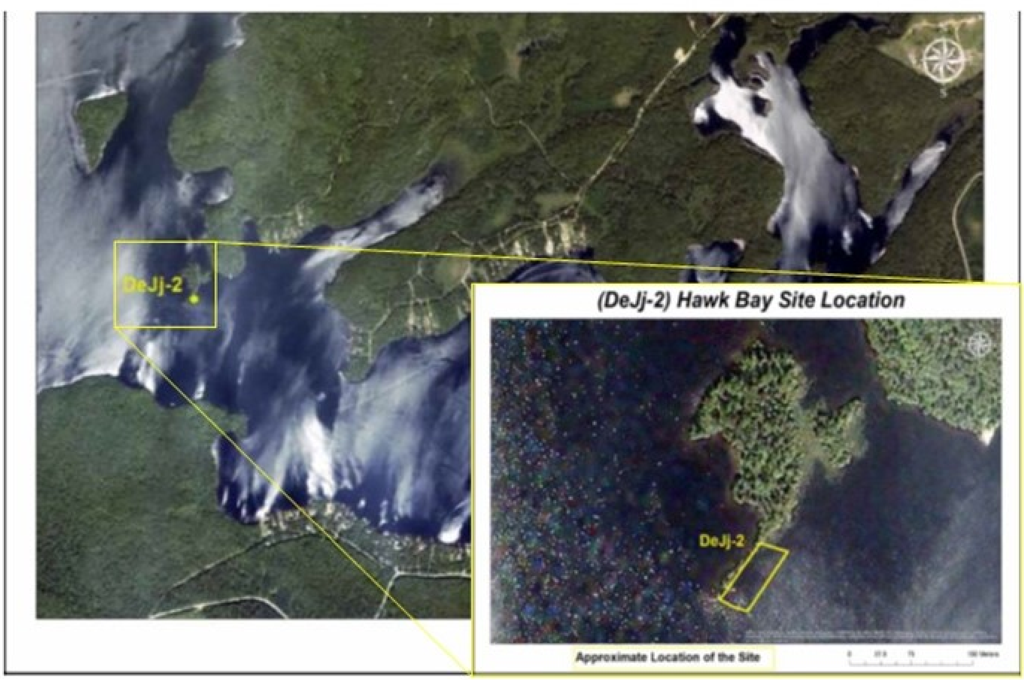


Figure 3.3.2.5. Maps dep
location of the Hawk Bay Site (DeJj-2).

The Portage Island Site

Also situated on Crown land, the Portage Island archaeological site is found in the southeast corner of Hawk Bay in Dog Lake (**Fig. 3.3.2.6**). The site is specifically located on the east end of the island and is composed of vegetation and cobble armor (Image 6 Appendix B). During times of low water, the island would have likely been a broad point of land that was connected to the mainland and would have provided protective shelter from strong winds and large waves. The site was originally documented by Ken Dawson in 1966 (McLeod, 1978) with artifacts that include Archaic and Woodland projectile points, copper tools, and Middle-to-Late Woodland ceramics (McLeod,1980).

Even though the designated archaeological site does not extend to the east, this thesis continued documentation to the mouth of the small river located at the southeast corner of the bay. The objective is to utilize the submerged shoreline to test if both utilities (SSS and SBE) provide accurate data about the inundated landscape. To this day, local enthusiasts scour the Hawk Bay, and Portage Island sites looking for items of heritage value. Collector Oliver Antilla, who passed away in 2014, provided a series of photographs and maps documenting where some of his artifacts were found. Images provided in Appendix B (Image 26-28), reflect Dog Lake's water fluctuation, as the area highlighted can experience extrems in water level height, and low. Due to these anthropogenic water level fluctuations, this case study provides an excellent opportunity to test both the sonar system and post-production software, in gathering and developing side scan images and bathymetric elevation maps.

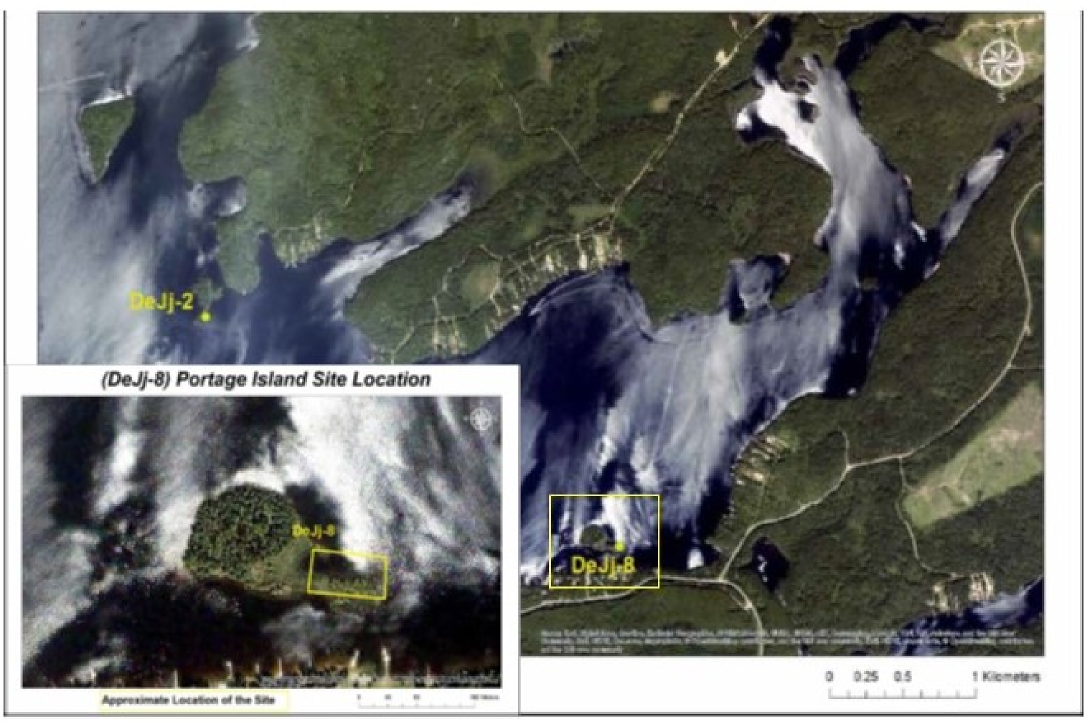


Figure 3.3.2.6. Maps depicting the location of the Portage Island Site (DeJj-8).

3.3.3 Boulevard Lake

Considered one of Thunder Bay's top recreational areas, Boulevard Lake has a long and interesting history that dates to the turn of the twentieth century. Beginning in 1891, the town of Port Arthur (now part of Thunder Bay) began to purchase land from the municipality of Shuniah in order to develop steam power plants at the mouth of the Current River. The first dam was constructed in 1901 and consisted of an eight-foot wooden structure at the Current River falls. Shortly thereafter, development was expanded, and a concrete dam was completed in 1910, with further lands around the reservoir being donated to facilitate a public park. According to Bobrowicz (2011), much of the modern lake configuration existed back in 1924. Throughout the century, many additions and developments were added around the reservoir to provide attractions for the people of Thunder Bay. Some of the additions include playgrounds, a boathouse, mini-golf course and the Lyon Boulevard Park Drive (City of Thunder Bay website).

Surrounding Boulevard Lake is multiple archaeological sites that reflect the area's ancient history. According to the Hamilton (2017), twenty-nine sites can be found within the vicinity of the lake, with fifteen likely dating to the Paleo-Indian period. Analysis of **Figure 3.3.3.1** reflects the distribution of archaeological deposits around the lake and river basin. Many of the sites found just north of the lake basin have yielded artifacts that suggest a Lakehead Complex presence (see Chapter 2), while their location above 220m ASL also suggests an occupation at or above the shores of Glacial Lake Minong. The sites around the south end of the lake are dominated by copper artifacts suggesting Archaic Mid-Holocene occupation, perhaps associated with the shores of the Nipissing Transgression.

Boulevard Lake Rock Circle

Located near the southern shore of Boulevard Lake (**Fig. 3.3.3.2**) is a rock circle that is likely anthropogenic in origin. It is located on what was once the west bank of the Current River a short distance above the Current River falls (where the dam is now located). This 30m wide structure is only visible during the fall and winter months and is fully inundated during times of high water through the spring and summer. Little is known about the structure. In 2016, Stephenson and Hamilton recorded the rock circle with the help of a UAV to acquire elevation and photogrammetry data of the site while water levels were low. Their data will be compared to side scan imagery captured as part of this thesis. The case will provide an excellent experiment to analyzed in conjunction with acoustic images to test the capabilities of the side scan sonar in acquiring images from a known site of anthropogenic origin.

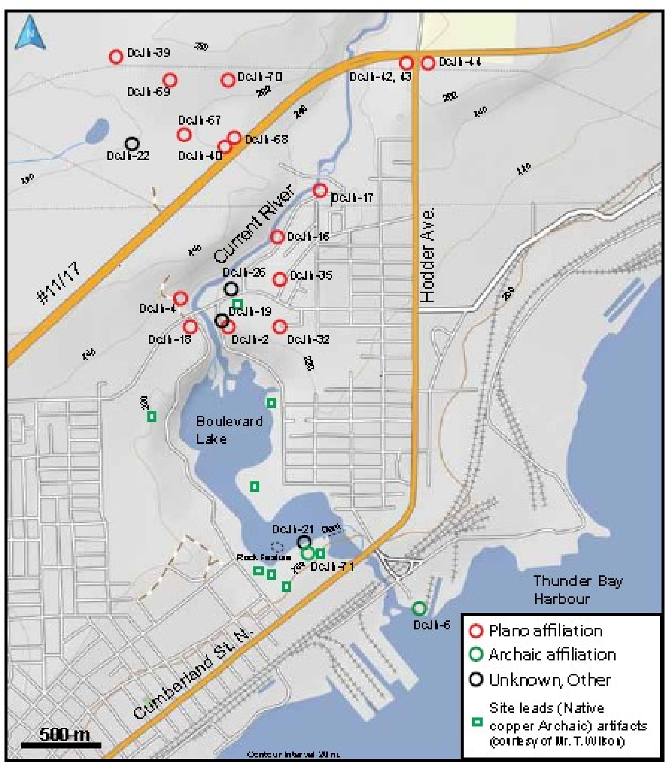


Figure 3.3.3.1. Boulevard Lake (centre) with nearby archaeological deposits (from Hamilton, 2017).

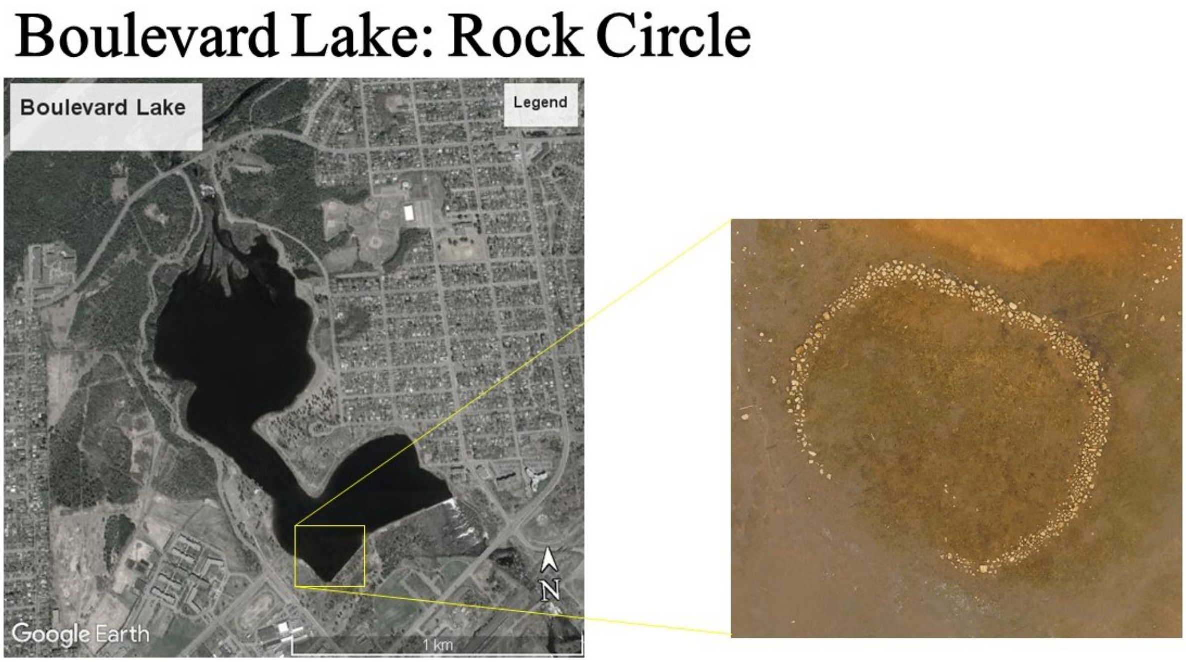


Figure 3.3.3.2. Location of the Boulevard Lake Rock Circle.

3.4 Summary

With shorelines flooded during the summer months, when power generation is at its highest, archaeologists have sought different ways to obtain the remaining archaeological data. With water levels at their highest during the typical field season (summer), researchers have relied on bathymetric and side scan sonar to create underwater maps of areas that have been impacted by anthropogenic water level changes (Passaro *et al.,* 2007). The case studies presented above will provide a unique opportunity to test the cost-effective methodologies presented in this research, as each lake has a unique history of human occupation.

Chapter 4

Methodology

4.0 Introduction

According to the Ontario Ministry of Tourism, Culture, and Sport (MTCS), a marine archaeological site is one “that is fully or partially submerged, or that lies below or partially below the high-water mark of any body of water” (Schoenhofer per comm, 2015). With this broad definition, any object that is partially or fully submerged at the highest shoreline water mark, and that is deemed to have heritage value, must be assessed by a licenced marine archaeologist. As discussed in earlier chapters (**Chapter 1**), regionally submerged archaeological sites might vary in type and antiquity from 20th Century shipwrecks to pre-contact terrestrial sites inundated by hydroelectric development or natural lake-level transformation. This represents a significant challenge to be addressed by a comparatively small number of licenced marine archaeologists. When addressing the approaches used to physically study these underwater environments, George F. Bass once stated: “There will remain, however, only three broad avenues leading to the study of an underwater site: going underwater to the site, removing the water from the site, or removing the site from the water” (Bass, 1966). New opportunities are offered by the development of remote sensing methods in the half-century since Bass’s observations.

With regulations imposed by the M.T.C.S., removing any artifact or material deemed to be of cultural value is prohibited. With these limitations, the only avenue left to study submerged archaeological sites and cultural landscapes is through non-invasive documentation techniques. Since the 1960’s, such methods include the use of geophysical techniques to survey and document the underwater world (Broadwater, 2002). Current methods for such research include the use of side-scan imaging, bathymetric swaths, sub-bottom profiling, and single-beam echo-sounders

(Quinn, 2011; Westley and Mcneary, 2016). Though these methods are well established in the maritime archaeological community, their application has been less common on inland lakes and river systems. Some authors argue that this stems from a lack of interest in what inland waterways archaeologically have to offer, and as such, “there is less impetus to commission or conduct” underwater surveys (Westley and Mcneary, 2016). Due to these limitations, a significant amount of submerged cultural landscapes lack the appropriate methods for proper documentation and management by the M.T.C.S.

To acquire side-scan images for large-scale projects, researchers rely on towed array sonar systems (Quinn *et al*., 2000; Geraga *et al*., 2016). This method usually requires large research vessels to systematically tow the hydrophones via a tether, back and forth across an area of interest. Though advantageous for projects in deep water bodies, such systems are cumbersome (and perhaps unusable) in shallow, confined spaces, such as small river systems and inland lakes (Parker *et al*., 2010; Toth, 2006). Similarly, acquiring bathymetric data from conventional acoustic devices can be unrealistic given the size of watercraft needed to access shallow and constricted freshwater systems (Bates, 2013; Westley and Mcneary, 2016). A further impediment to the application of conventional sonar equipment is the considerable cost of such sophisticated technology. To address and resolve these issues, researchers have begun experimenting with less costly, consumer-grade sonar systems capable of collecting both side-scan imaging and bathymetric data (Toth, 2006; Hare, 2008; Powers *et al*., 2015; Richter *et al*., 20016; Westley and Mcneary, 2016).

This thesis sought to develop methodologies using accessible technology to collect information about the submerged environment, and then assess its precision and utility for investigating shallow fresh-water heritage resources in areas neglected by the archaeological community. This trial involved the Hummingbird 899cii series fish finder, with data processing using the ReefMaster© software. Field evaluations involved archaeologically significant localities within the Thunder Bay area. Divided into two sections, this chapter first outlines the methods used to collect and interpret the sonar data and then details the methods used to independently test and validate the interpretations.

4.1 Instruments

Bathymetry and side-scan imagery are two standard geophysical techniques used by maritime archaeologists to document submerged cultural resources. These applications range from the reconstruction of submerged coastlines (Breman, 2003; Loewen *et al*, 2006; Sonnenburg and Boyce, 2008; Westley *et al.* 2010), to their use in the discovery and mapping of shipwrecks (Foley *et* al., 2005; Quinn, 2006; Quinn and Cooper, 2000; Oxley, 2001; Warren *et al*., 2010).

According to Lurton (2002), bathymetric sounders specialize in the acquisition of depth measurements for the production of marine charts. Utilizing either a pole- or hull-mounted transducer, acoustic pulses are transmitted through the water and are reflected back from the bottom to the receiver. The depth is calculated by measuring the time interval between when the acoustic pulse was transmitted to when the reflection is received. Until the early part of the 20th century, depth measurements were captured manually using a “lead and line” method. The first large-scale use of single beam echo sounder (SBES) was in 1926-1927 by the German Atlantic Expedition. Since that time, multiple forms of echo-sounding have been employed on archaeological projects, including the use of multi-beam and swath sounders (Quinn, 2011).

Such equipment first served in military applications during the Second World War to search for submarines beneath the waves (Klein, 2002). Early civilian application of side-scan sonar for non-invasive archaeological documentation occurred in the early 1960's when Dr. Harold Edgerton experimented with a 12 kHz side-scan sonar to detect a shipwreck (Broadwater, 2002). Similar to echo sounders for the acquisition of bathymetric data, side-scan sonar (SSS) utilizes acoustic pulses to acquire images of the seafloor. The distinction here is how the acoustic energy is transmuted and received. Instead of acoustic pulses being transmitted directly below the boat, side-scan sonar systems transmit the acoustic energy on a horizontal plane, sweeping the bottom obliquely away from the transducer (Lurton, 2002). As this occurs, a real-time image of the lake or seabed is projected on a screen and continuously recorded (Fish and Carr, 1990; Klein, 2002). The material properties of the bottom determine "the acoustic response" of the bottom (Quinn, 2011). Variation in the texture and roughness of the bottom is reflected in changes in the acoustic signal. From an archaeological perspective, the most significant phenomenon associated with side-scan sonar evaluation of the bottom is the presence of acoustic shadows. With objects standing off the bottom, the acoustic signal will rebound back to the receiver, leaving a 'shadow' on the leeward side of the object. This creates a multi-dimensional perspective to what is normally a flat, two-dimensional picture (**Fig. 4.1.1**). With objects that protrude from the bottom, the acoustic shadow is what first alerts researchers to the presence of an object. Until recently, such devices were towed behind vessels utilizing a tether system to gather images of the sea or lake bed (Fish and Carr, 1990; Quinn, 2011). This configuration is associated with a series of strengths and weaknesses that differ based on the water body being assessed. In large, open bodies such as the ocean, towed array sonar systems work well to capture detailed information of the bottom. However, this equipment configuration becomes problematic when working within confined spaces littered with deadheads and boulders that are commonly found in small inland lakes and river systems. While some researchers have resorted to mounting towed array sonar systems to the bottom of the boat (Artur *et al*., 2015), others have begun to apply less expensive, hull-mounted systems to acquire data in shallow restricted spaces

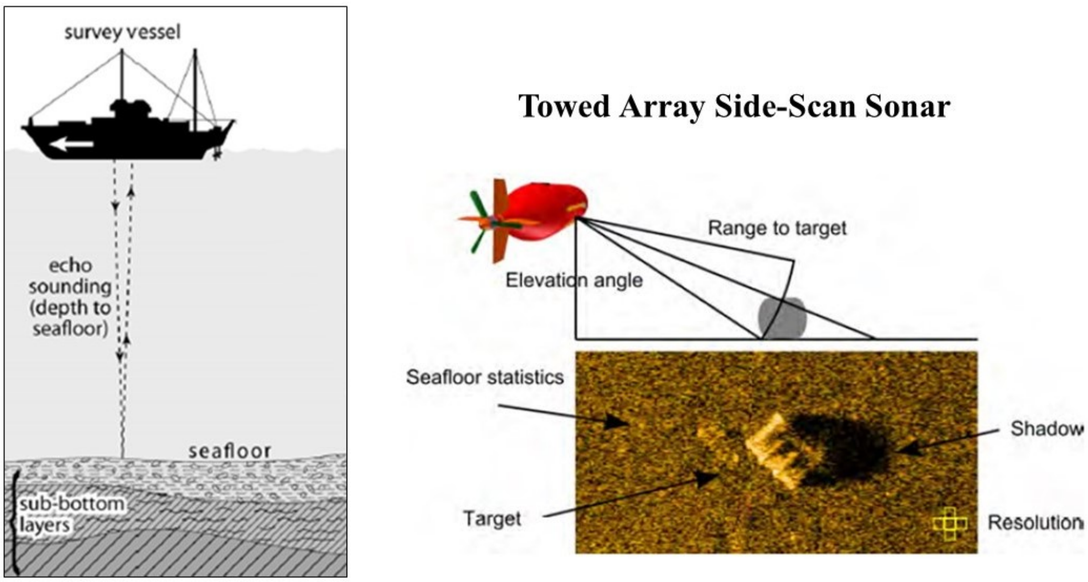


Figure 4.1.1. Left: Schematic depicting how acoustic pulses reflect off the bottom to determine depth (after Powers et al., 2010). Right: Representation of how the range and angle of the sonar beam reflect off the target, and create a shadow (from Hansen, 2012).

4.1.1 The Sonar System

With the principal objective reflecting the use of consumer-grade sonar systems for archaeological data collection in Northwestern Ontario, careful consideration was taken in balancing purchase cost with technical capability of the device. Since "consumer-grade" and "cost-effective" are vague terms, one must first justify the grade or category of sonar system selected for evaluation. The device chosen must be able to address the needs of the researcher while also being as affordable as possible. The Humminbird 800 Series 899ci HD SI fishfinder and accompanying transducer (XNT 9 SI 180 T) was selected for approximately $1,200 at the time of purchase (summer 2014). It is one of the least expensive sonar systems on the market to have both down- and side-imaging capabilities.

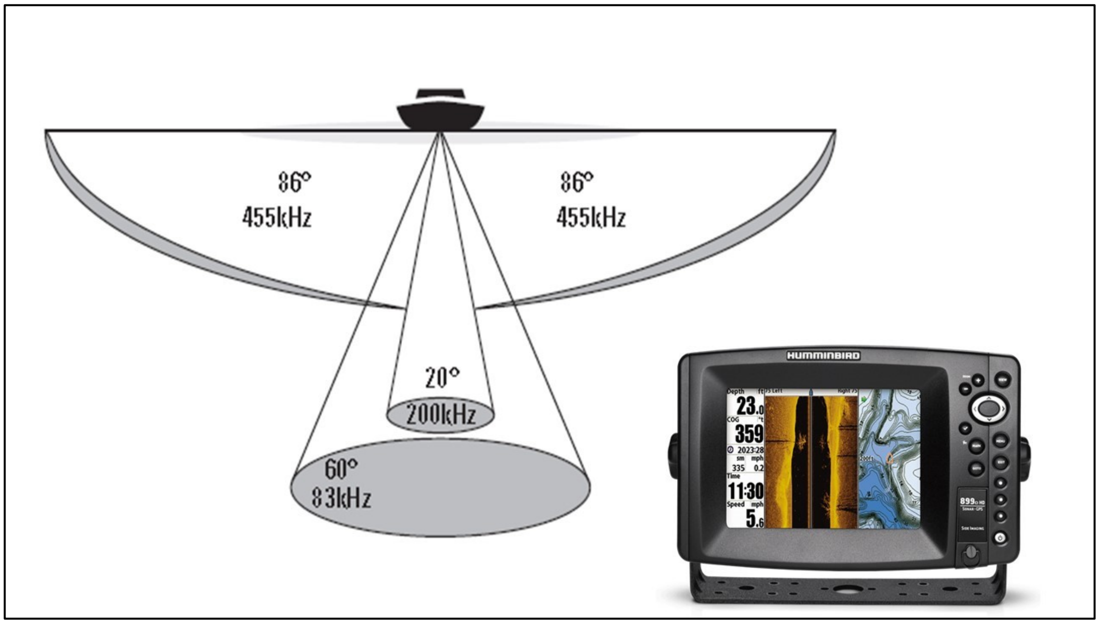


Figure 4.1.2. Left: frequency of and coverage area of the side scan and down imaging beam. Right: Counsel of the acquisition of bathymetric and side-scan data. Humminbird 899ci SH HD fish finder.

The Humminbird 899ci HD SI fishfinder has many features and settings that allow for diverse data collection needs. For the acquisition of bathymetric information, the XNT 9 SI 180 T transducer can deploy one, or multiple sonar beams to gain depth measurements. The Dual Beam Plus™ system can utilize one or a combination of a 200 kHz (20° wide) and 83 kHz (60° wide) centre beam frequencies. Figure 4.1.2. illustrates the approximate coverage areas of each beam. According to the 899ci manual, each beam offers advantages and disadvantages for down imaging. The higher frequency (200 kHz) is best used for acquiring data from shallower depths as it provides a higher resolution, while the lower frequency (83 kHz) offers less resolution but greater depth penetration (up to 150 feet). The built-in GPS receiver is accurate within ± 3.5 meters, depending on conditions and the available satellites.

The side imaging capabilities of the Humminbird 899ci HD SI are regulated by the sonar frequencies selected by the user. The Humminbird 899ci HD SI can operate at the frequencies of 262kHz or 455kHz. According to the Humminbird manual, the latter (455kHz) provides a stronger signal that can search an area up to 240 feet on each side. Experiments were conducted to determine which frequency would best suit the needs of this research, and the results suggested that the 455kHz provided more detail than the 262kHz option.

General Procedure

Before the researchers start capturing any side-images, a track (or lane) must be chosen to start the recording process. According to Fish and Carr (1990), side-scan sonar operators usually follow a series of tracks or imaginary lanes that run parallel across the targeted area. For this research project, most of the case studies are characterized as near-shore submerged landscapes. As such, each transect was set up to run parallel to the nearest shore (Fig 4.1), to allow for the acoustic signal to fill in the differentiating contours of the beach. Swaths that overlap each other allow for the entire research area to be covered without missing any detail, while also providing 'forgiveness' for vessel track variations caused by a distracted pilot. The range of the sonar pulse, as well as the amount of overlap between transects, were both adjusted between recordings, and thus varied between transects.

The rate at which the acoustic signal was transmitted, known as ping rate, is also set before the survey. According to the sonar manual, the number of pings per second can affect the quality, and quantity of the acoustic imagery. With a higher ping rate, the acoustic signals capture more detail, but at a cost to image distortion and file size. Due to these restrictions, the ping-rate chosen for this project reflected the needs of shallow water surveying.

With the transducer mounted on the starboard side of the stern, and the Humminbird sonar system set-up in the middle of the boat (approximately 1 to 1.5 meters away from the transducer), the researchers can begin the documentation of survey area. Once the sonar system is turned on, the operator should switch the screen to the 'Snapshot and Recording' view. With the boat lined up with the first transect, the sonar operator will start recording. Keeping the boat on a steady linear course, and at a speed of 3-6 km/h, the side-scan images are logged and saved onto SD memory cards inserted in one of two slots available on the unit. When the boat reaches the end of the track, the recording is stopped. This allows for each transect to be stored as a separate file, enabling easier data management during post-processing activity. At the end of each transect, the boat pilot does a u-turn to set the boat on a parallel transect line, taking care to aim the vessel at a distant target in order to stay on course. Navigation was also aided with the use of handheld GPS to keep the boat on parallel transects and to ensure suitable spacing between transects and uniform coverage. During this time, the operator of the sonar system should monitor and evaluate the side-images for objects of interest as they appear on the screen. These points of interest were noted, but care was taken to not interrupt the transects.

Consistent with the acquisition of the side-scan imagery, the bathymetric depth measurements were captured using much of the same settings and methods. With the capabilities of the Humminbird 899ci sonar system, some depth measurements were attained during the side-scan survey. Utilizing the Dual Beam Plus™ function, depth measurements were recorded at both 200 and 83kHz. This is recommended by Humminbird© as each frequency is best suited for different depths (see above). With depth recordings captured during the side-scan survey, extra transects running perpendicular to the shore were used to acquire further data in areas that were overlooked. With this strategy, in combination with a reduced travel speed and an appropriate ping-rate, the aim was to capture as many data points as needed to recreate the topographic nature of the bottom.

Case Study: Arrow Lake

As discussed in Chapter 3, the first tests of the Humminbird sonar system took place along the north shore of Arrow Lake, near the entrance to Frog Portage. The aim of this case study was twofold: 1) to determine how efficient the Humminbird 899ci SD HD sonar system was at detecting objects through the side-scan imaging; 2) to see if the sonar system is adequate to collect enough data points to highlight the known topographic changes (sandbar) on the lake bottom. The results are later compared to data collected with a Garmin 525 chart-plotter. Table 4.1.1. displays the settings employed during the July survey at Arrow Lake.

Observed below (**Figure 4.1.3**) are the attempted survey transects highlighted in yellow. As discussed above, the depth measurements and the side-scan images were usually acquired simultaneously. Two additional transects were recorded running perpendicular to the previous lines as to ensure full coverage of the site.

Table 4.1.1. Settings used during Arrow Lake survey.

Date	**2015-04-04**
Speed	3-6km/h
Ping-Rate	Auto
Number of Transects	9
Down Imaging Frequency	200kHz and 83kHz
Side-Scan Frequency	455kHz
Side-Scan Beam Width	25m

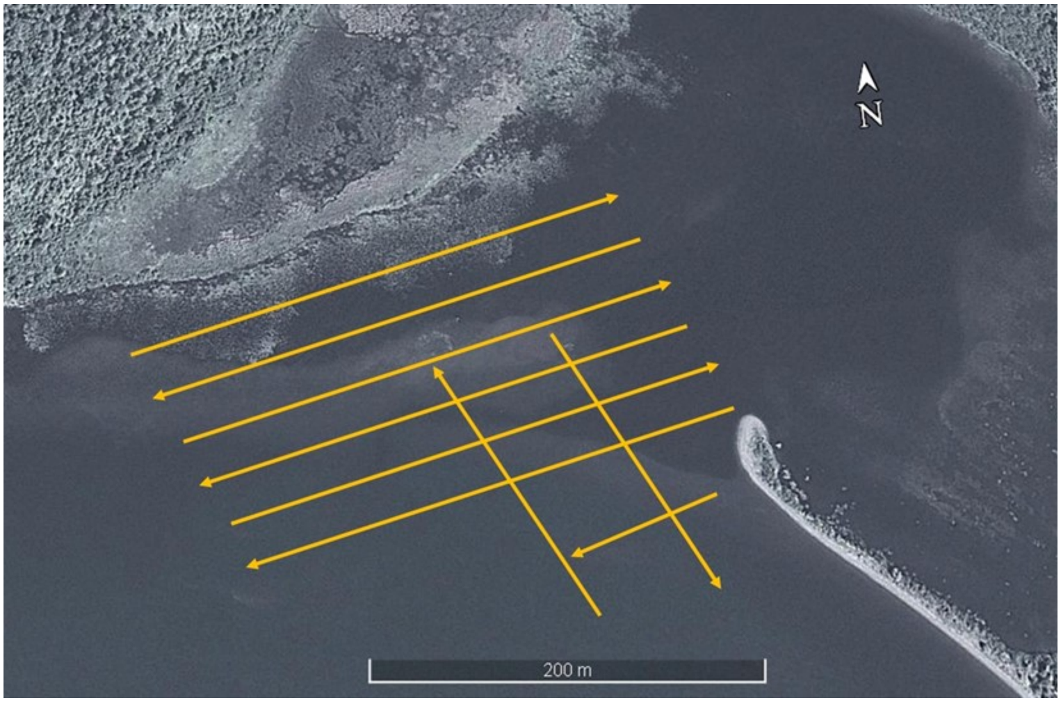


Figure 4.1.3. Survey area and entrance inro Frog Portage, on Arrow Lake

Case Study: Hawk Bay Site DeJj-2

The Hawk Bay Site (DeJj-2), on Dog Lake, is a multi-component archaeological site that was inundated early in the 1900s through the construction of a hydro-electric dam. This site is located on a narrow rocky point that is composed of cobbles and vegetation. The Hawk Bay Site surveys took place at intervals over three years to address data output with water at various depths. Multiple transects were completed at intervals over this time, and include both side-scan sonar images and bathymetric depth measurements. Table 4.1.2. highlights the information and settings used throughout this case study. Side-scan transects were run parallel to the shoreline to acquire clean images of the inundated area. Depth measurements were recorded simultaneously, with only a few additional tracks recorded perpendicular to the shore to gain more data points for the bathymetric reconstruction of the site (**Fig 4.1.4.**).

Table 4.1.2. Settings used during the survey at the Hawk Bay Site (DeJj-2).

Date	**2015-17**
Speed	3-6km/h
Ping-Rate	Two pings per second
Number of Transects	43
Down Imaging Frequency	200kHz and 83kHz
Side-Scan Frequency	455kHz
Side-Scan Beam Width	25m

Figure 4.1.4. The Hawk Bay Site and the approximate locations of the transects recorded during the archaeological investigation.

Case Study: Portage Island Site DeJj-8

The Portage Island location on Dog Lake is located approximately 1.5 km east of the Hawk Bay Site. As addressed in Chapter 3, this island contains a multicomponent site that spans nearly tent housand years. Although the site is located upon washed out shorelines along the east side of the island, the survey area extended east from the island to a nearby river mouth.

Similar to the Hawk Bay site, this case study sought to assess the capabilities of the sonar and its usefulness for documenting inundated archaeological surfaces to aid in reconstructing the pre-inundated shorelines, while also seeking to detect objects of anthropogenic origin. Below, Table 4.3 reflects the settings and information from the Portage Island survey.

As with the previous case studies, the bathymetric and side-scan data were recorded at the same time. Given the shape of Portage Island and its proximity to the main shore, no additional transects to document depth measurements were obtained. As seen in **Figure 4.1.5.**, the tracks recorded around the island follow a parallel path to the shoreline. This strategy continued east, towards the river, where shallow waters and obstructions were encountered. Both sites at Dog Lake were surveyed during the summer months, as water levels were at their highest.

Table 4.1.3. Settings used during the survey at the Portage Island Site (DeJj-8)

Date	**2015-17**
Speed	3-6km/h
Ping-Rate	Two pings per second
Number of Transects	40
Down Imaging Frequency	200kHz and 83kHz
Side-Scan Frequency	455kHz
Side-Scan Beam Width	25m

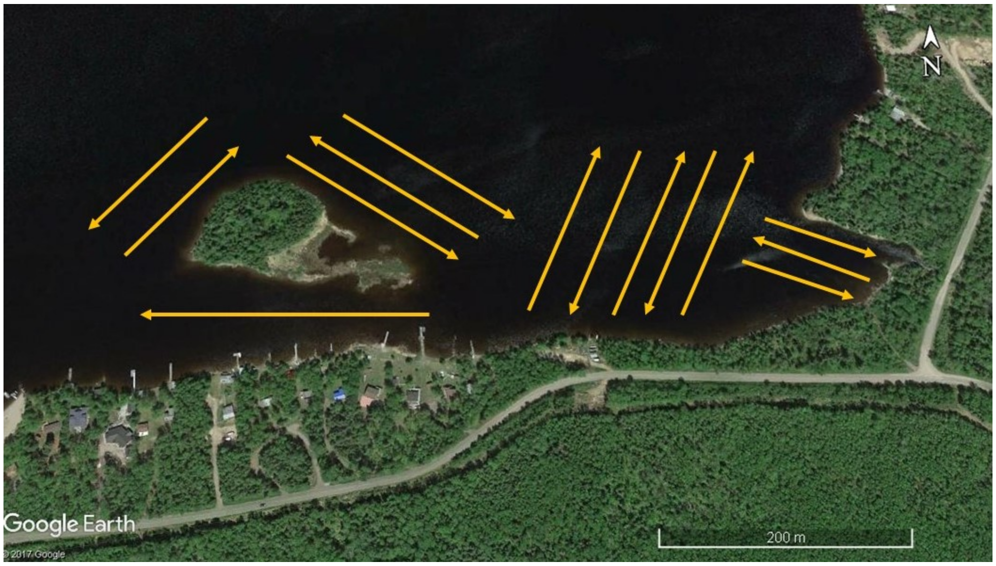


Figure 4.1.5... Portage Island and the eastern river located within Hawk Bay. Yellow arrows represent approximate location of recorded transects

Case Study: Boulevard Lake Rock Circle

At the final case study, side-scan imaging was used to assess the mysterious rock circles at Boulevard Lake. The focus of this case study was to evaluate the sonar instrument's ability at detecting known anthropogenic structures. Information regarding the settings used during this survey can be found below in Table 4.1.4.

Low water levels during the time of the survey impeded efforts to get close to the targeted area. Below, **Figure. 4.1.6.** shows the approximate location of the rock circle (yellow circle) with arrows representing the transect routes that were employed during the survey.

Table 4.1.4. Summary of settings and information used during the survey at Boulevard Lake.

Date	**2016-10-16**
Speed	3-6km/h
Ping-Rate	Two pings per second
Number of Transects	13
Down Imaging Frequency	200kHz and 83kHz
Side-Scan Frequency	455kHz
Side-Scan Beam Width	25m

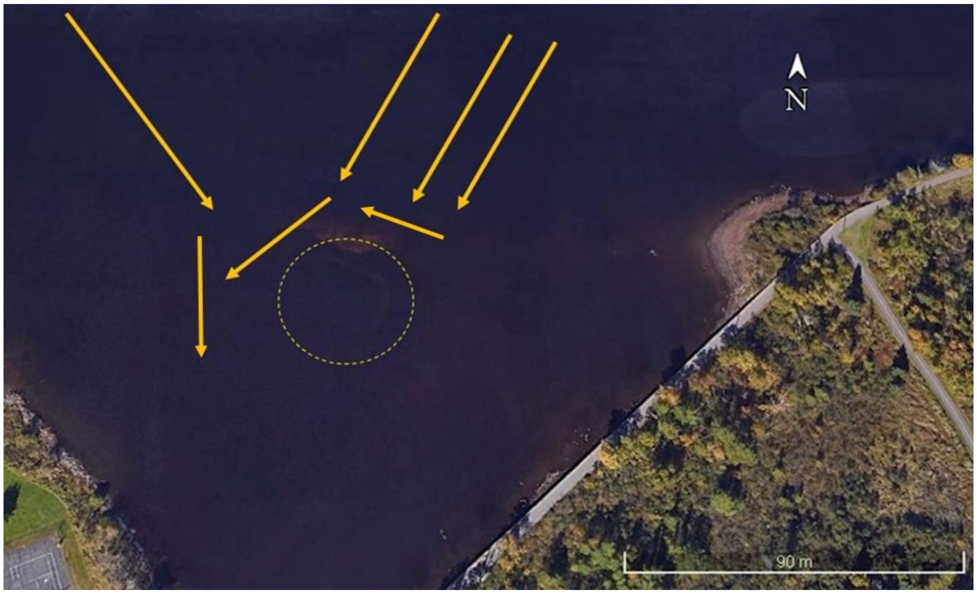


Figure 4.1.6. The Boulevard Lake Rock Circle (yellow circle) and the estimated tracks (arrows) that were recorded during the side-scan survey

4.3 Post Processing

4.3.1. Software

After the field data collection, the next step is to process and display the data using computer software. Such spatial data is often examined in Geographic Information Software (GIS), often characterized as a relational database that present multi-variant data in layers georeferenced by a standard Cartesian coordinate system (Mahaxay *et al.*, 2012). In recent years, underwater archaeologists have used GIS to reconstruct coastal sites with bathymetric data (Breman, 2003), map the spatial representation of shipwrecks off the coast of Australia (Kimura, 2006), and manage submerged cultural resources all over the world (Oxley, 2001; Cornish, 2003). The most common institutional GIS is Esri's ArcMap™, but this can require access to quite expensive professional licenses. Other GIS software is available as open source freeware (i.e., QGIS) that, in general, may require considerable training to overcome the rather steep learning curve. While such training is required for most sophisticated software, a more intuitive and 'user-friendly' approach to underwater mapping was sought.

The program chosen to process the bathymetric and side-scan data is called ReefMaster. Created by Australia-based ReefMaster Software Ltd., the software provides the capabilities to create bathymetric maps and side-scan mosaics that can easily be uploaded into other programs such as ArcMap or Google Earth. Though similar programs exist, there are three primary reasons ReefMaster was chosen: 1) ReefMaster is directly compatible with both Lowrance and Humminbird sonar systems; 2) ReefMaster Pro is marketed at an affordable price ($250);and 3) the software is user-friendly and is intended for amateurs and recreational users.

Using ReefMaster to process sonar data to support research is relatively new, with only two publications being observed at the time of this research. Westley and Mcneary (2016) utilized ReefMaster in combination with SonarTRX to evaluate submerged archaeological sites in Ireland, and Mizuon *et al*. (2017) employed it to create a bathymetric map for a seagrass study in Mayo Bay, Philippines.

All datasets created within ReefMaster were imported into Google Earth to display both the bathymetric and side-scan output. With all the data georeferenced, the use of either Google Earth or Google Earth Pro allows for all maps, images, and sonar mosaics to be displayed in their spatially correct locations. Google Earth, rather than a GIS program, was used to display the output due to its ease of use, and because both Google Earth and Google Earth Pro are currently freely available.

Bathymetry

Production of bathymetric maps requires interpolation of sparse data points, which, according to Chang (2012), "is the process of using points with known values to estimate values at another point." By using mathematical formulas to account for data voids between known values, interpolation can create estimated representations of the surface being studied, the accuracy of which is often a function the number and spacing of the known points available for analysis. Most GIS programs include multiple forms of interpolation to recreate a landscape. However, ReefMaster relies solely on Triangular Irregular Networks (TIN) to generate its bathymetric maps. According to DeVantier and Feldman (1992), this form of terrain mapping uses nonoverlapping triangular lines to connect between points of information to generate elevation data. Some sources, however (McGrath *et al*., 2007) suggest that TINs can also produce sonar artifacts when used to generate maps from a bathymetric survey.

Within ReefMaster, two data models are available for the production of bathymetric charts: The first, vector models, rely on the use of lines, points, and polygons to represent the x-,y-, and z-coordinates when generating charts. While raster, on the other hand, relies on a grid system where each value is represented by a numerically coded grid cell (Couclelis, 1992; Congalton, 1997). **Figure 4.3.1** (below) characterizes the difference between vector (top) and raster (bottom) model types with data points gathered from Cloud Lake, Ontario. Here, the topography of the lake bottom is represented by polygons (top) versus the use of cells (bottom). Both techniques have their purpose, though ReefMaster suggests using raster models to highlight "small variations in depth."

Caution must be taken adjusting the various settings, so as to not to create a series of isoblaths that are inaccurate. For the processing of the archaeological data, careful attention was given to ensure that the bathymetric output is sufficient in its accuracy and resolution. To accomplish this goal, the settings described below reflect the density of data points captured during the survey. It is imperative that all bathymetric information be as accurate as possible for continuity purposes.

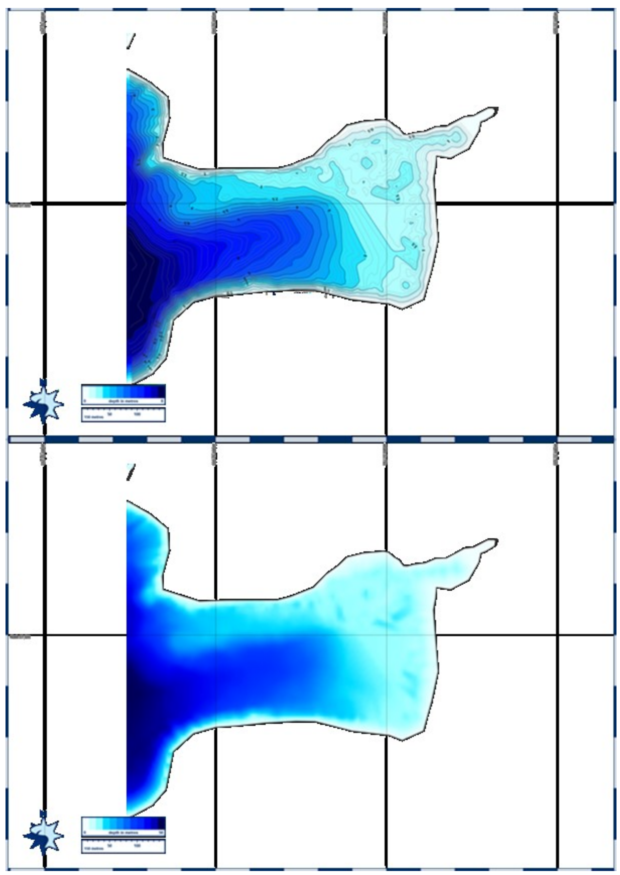


Figure 4.3.1. Top) Vector bathymetric map of the southeast bay located on Cloud Lake. Bottom) Raster map representing the same southeast bay on Cloud Lake.

Case Study: Arrow Lake

Map Settings	*Applied Settings*
Max Interpolation	75m
Contour Grid Resolution	5
Grid Smoothing	10
Colour Palette	Black/Grey
Colour Mode	Vector
Contour Intervals	Major 0.5m. Minor .125m
Generate Minor Contour Levels	Yes

The *Max Interplation* setting allows for the construction of depth values to be generated in areas where no data was collected. ReefMaster does allow for a maximum interpolation of 150m, however, using a greater interpolation distance can generate inaccuracies in the finished map. For this reason, a maximum interpolation of 75m was chosen for all case studies.

For the Arrow Lake Case Study, a Vector map was generated to compare the output from a series of experiments that were conducted prior to this study. A *Contour Grid Resolution* of 5, *Contour Intervals* of 0.5m and .125m, and a *Grid Smoothing of 10* was used to ensure that the Vector map be as detailed as possible.

Case Study: Hawk Bay Site (DeJj-2).

Map 1

Map Settings	*Applied Settings*
Max Interpolation	75m
Contour Grid Resolution	5
Grid Smoothing	10
Colour Palette	Red/Orange/Blue
Colour Mode	Raster
Contour Intervals	Major 0.5m. Minor .125m
Generate Minor Contour Levels	Yes

Map 2

Map Settings	*Applied Settings*
Max Interpolation	75m
Contour Grid Resolution	5
Grid Smoothing	10
Colour Palette	Red/Orange/Blue
Colour Mode	Raster
Contour Intervals	No
Generate Minor Contour Levels	No

Case Study: Portage Island Site (DeJj-8).

Map 1

Map Settings	*Applied Settings*
Max Interpolation	75m
Contour Grid Resolution	5
Grid Smoothing	10
Colour Palette	Red/Orange/Blue
Colour Mode	Raster
Contour Intervals	Major 1.0m. Minor None
Generate Minor Contour Levels	Yes

Map 2:

Map Settings	*Applied Settings*
Max Interpolation	75m
Contour Grid Resolution	5
Grid Smoothing	10
Colour Palette	Red/Orange/Blue
Colour Mode	Raster
Contour Intervals	None
Generate Minor Contour Levels	No

For the case studies at Dog Lake, Rasters were generated as colourized cells to help highlight any variations in depth. Like the map produced for the Arrow Lake case study, a *Contour Grid Resolution* of 5, and a *Grid Smoothing of 10* was used to ensure that the maps are as detailed as possible. Unlike the Arrow Lake case study, *Major Contour Intervals* of 1.0m were utilized for Maps 1 at the Hawk Bay Site (**Fig.** 5.1.2.1) and Portage Island Site (**Fig**. 5.2.3.1). This was done to provide a numerical depth to one of the maps (instead of just relying on cell colour) while keeping organized and uncluttered.

Side-Scan Mosaic

Before the generation of a side-scan mosaic, each track must be evaluated for errors and inaccuracies deriving from data acquisition. This is accomplished by assessing each sonogram and evaluating its suitability for inclusion in the final mosaic. Sonograms with significant distortions or lack of resolution were left out of the final mosaic.

Alterations to each sonogram can be accomplished through the Edit tab available in ReefMaster. Here, a colour palette, auto gain adjustment, brightness, contrast, curve and speed filter, and segment (length) adjustment can all be used to produce a mosaic that fits most needs. The starboard and port sections of each side-scan image can also be manipulated to help decrease (or increase) overlapping images. With the mosaic complete, there are four file options for saving the side-scan mosaic. MB files, PNG image, KML super-overlay and AT5 raster layer are available to the user.

Case Studies

The case studies utilized to test the side-imaging capabilities were processed using settings designed to achieve the best detail and view of the lake and subjects observed on the bottom. Single or multi-tracked images (mosaics) were edited and created to extract as much detail as possible.

Case Study: Hawk Bay Site (DeJj-2) Mosaic

Map Settings	*Settings Employed*
Swath #	43
Colour Palette	Green
Brightness	-32
Contrast	+72
Auto Gain Adjustment	Yes
Min Curve	0
Max Curve	0

Case Study: Portage Island Site (DeJj-8) Mosaic.

Map Settings	*Settings Employed*
Swath #	40
Colour Palette	Green
Brightness	-32
Contrast	+72
Auto Gain Adjustment	Yes
Min Curve	0
Max Curve	0

Case Study: Boulevard Rock Circle Single Track.

Map Settings	*Settings Employed*
Swath #	40
Colour Palette	Green
Brightness	-32
Contrast	+72
Auto Gain Adjustment	Yes
Min Curve	0
Max Curve	0

4.4 Validating the Methodology

To evaluate the interpretations deriving from the sonar, direct examinations of the lake bottom were undertaken at two of the Case Study sites. Three evaluative methods took place at the Hawk Bay and Portage Island sites: 1) physical inspection of the lake bottom using scuba diving during times of high water levels (summer); 2) coring to directly evaluate the sediment found on the surface of the lake bed; and 3) drone (or UAV) flights to capture images of the evolving shoreline throughout the year.

Diving

According to Bass (1966), archaeological surveying seeks "to study the pattern of habitation for various periods and cultures, and to select promising sites for more thorough study by excavation." This is as true for underwater research as it is for land-based investigations. The Nautical Archaeological Society (NAS), one of the world leaders in nautical education, states that the purpose behind underwater surveying is to "produce an accurate picture of the site" by drawing or digitally acquiring the supporting information. Marine archaeological surveys are a common global practice with projects of varying purpose and scope. Whether it is the documentation of a lone ancient shipwreck (Wachsmann *et al.,* 1997), or the mapping of a lost Roman harbour (Oleson, 1988), the goal is the same: to produce a 2 or 3-dimensional picture of the site as it presently exists (Bowen, 2009).

Using methods described in the Nautical Archaeological Society (NAS) Level 1 course, features found on the lake bottom were photographed and georeferenced as part of what the NAS calls a '*topographical survey.'* Here, the lake bottom and its features (sediments, rock structures, and vegetation) are observed and photographed in order to accurately depict the sea or lake floor (Bowen, 2009). The photographic survey was completed to test the capabilities and accuracy of the Humminbird sonar system, and to identify the potential surviving archaeological material. By physically inspecting the bottom conditions, the interpretations deriving from the sonar results at DeJj-2 and DeJj-8 can be evaluated and compared to one another.

Case Study 1: Hawk Bay Site (DeJj-2)

Underwater photographic documentation took place on the Hawk Bay site on the morning of September 12th, 2015, under sunny conditions. To perform the *topographical survey*, a southwest to northeast oriented baseline transect was established for about 200 meters along the shore. At 20m intervals, orange flagging tape and rope was placed to mark the transect points. At each flagged location, a Garmin GPS waypoint was established to geotag it. This allowed replication of the baseline within the mapping software.

Using basic scuba equipment, divers took underwater compass bearings from each waypoint location and then swam out into the lake perpendicular to the baseline, photographing points of interest with a GoPro camera. Each of these underwater transects measured approximately 100m in length (**Fig. 4.4.1**).

Figure 4.4.1. GPS positions and dive survey routs from the Hawk Bay Site (Top) and the Portage Island Site (Bottom).

With a GoPro Hero 3 (Black edition) in hand, photographs of objects, changes in sediment and vegetation, and potential artifacts were documented. After each image was captured, one of the divers returned to the surface to provide a reference point for waypoint tagging using a Garmin GPS, allowing all photographs to be georeferenced. Consistent with Ministry of Tourism, Culture, and Sport requirements, special care was taken not to touch anything of cultural value.

Case Study 2: Portage Island Site (DeJj-8)

Throughout the afternoon of September 12, 2015, the *Portage Island Site* was photo documented. Like the *topographical* survey at the Hawk Bay site, the purpose for the dive was to record features found on the lake bottom. A baseline transect was established on the east side of the island, utilizing orange flagging tape to mark off the transect points, with a Garmin GPS employed to geo-tag each position.

Starting in the north-west section of the beach, the divers swam a series of perpendicular transects along the length of the easterly shore of Portage Island (**Fig. 4.4.1.**). The dive distance was approximately 170m down the length of the beach, with each transect measuring 100m in length. As with the survey on DeJj-2, a GoPro Hero 3 (Black Edition) was used to capture images of points of interest, while a Garmin GPS (2m-5m accuracy) was used at the surface to georeferenced the photographs.

All images from the dive survey of DeJj-2 and DeJj-8 can be found in the Appendix B, with the results chapter (chapter 5) assessing and comparing the dive results to what is observed in the sonar data.

Coring

The extraction of cores to aid the study of the archaeological record has been used since the mid-20th century. First used to help date prehistoric deposits, coring methodologies have become a standard technique in archaeological investigations. With minimal disturbances, researchers can acquire continuous segments of sediment that can help provide information on the ecological, climatic, and cultural history of a regional landscape (Stafford, 1995; Stein, 1986). Regionally, projects have utilized coring for multiple purposes. This includes sediment sampling to document the use of wild rice by prehistoric cultures (Boyd *et al*., 2014; Surette, 2008), ecological and climatic reconstruction of prehistoric sites in northern and southern Ontario (McAndrews, 1982; 1994), and to recover microdebitage from submerged archaeological sites within Rice Lake (Sonnenburg *et al*., 2013; 2011).

Similar to the work of Sonnenburg and Boyce (2008), cores were acquired, in part, to help build a sedimentary profile of each site at Dog Lake. The primary objective at Dog Lake was to sample the sediments from the bottom to test the side-scan sonar's ability to differentiate between sediment types. This was accomplished by evaluating the texture, colour, and particle size of the sediments removed from the cores.

(Note*) Cores were not taken at Boulevard Lake, as the 'rock circle' is the primary focus of that case study, and was only selected to see if the structures can be observed on the side-scan sonar.

Field Exercise

On October 20, 2015, cores were extracted from both sites (DeJj-2 and DeJj-8) at Dog Lake. A Russian and Universal Corer were used to sample at 20m intervals, along a baseline that followed a similar transect that was established during the underwater photographic survey. Each core was assessed and documented on site, with some samples returned to Lakehead University for future research.

Drone Imaging

Unmanned aerial vehicles (UAV) have become a valuable tool for the reconnaissance, documentation, and assessment of archaeological sites (Gutiérrez and Searcy, 2016; Eisenbeiss *et al.*, 2005; Bendeael al, 2007). Researchers have also begun to realize the practicality of consumer-grade drones to support research here in the northern Ontario. Hamilton and Stephenson (2016) established a series of methods for the acquisition of aerial photographs for photogrammetry and detailed elevation modeling. For this project, the DJI Phantom 3 Advanced quadcopter (**Fig. 4.4.2**.) and the applications (MapPilot, and MapsMadeEasy), were utilized to create a photo-mosaic of the Hawk Bay (DeJj-2) and Portage Island (DeJj-8) sites. The rock circle feature at Boulevard Lake was also photographed in the fall of 2015. The objective here is to compare each form of output (bathymetry and side scan imagery) to the aerial images, allowing the data to be assessed for accuracy and the quality of the resolution.

Following protocols identified by Hamilton and Stephenson (2016), the imaging included in this thesis share the following characteristics:

- Height: 40m
- Flight Speed: 2m per second
- Photograph Overlap: 80%.

After the flights were completed, all the raw data was sent to MapsMadeEasy web application, where within a day, the output was processed, and the photomosaic created. For a comprehensive account of the methods used, see Hamilton and Stephenson (2016)

Figure 4.4.2.. DJI Phantom 3 Advanced midflight.

4.5 Conclusion

The examination of remote sensing methods using consumer-grade equipment required independent means to evaluate their capabilities for shallow underwater surveys in northwestern Ontario. Once the side-scan images and bathymetric information were obtained from three case studies, alternative sources of information were sought to test the resolution and accuracy of the device and method. Such comparison includes the use of published literature (Fish and Carr, 1990; Powers *et al.*, 2014; Richter *et al.*, 2016; Buscombe, 2017) , and ground-truthing (dive survey, cores, and drone imagery) to compare the accuracy and resolution of the side-scan and bathymetric data. Testing the accuracy and capabilities of the post-processing software followed suit. Here, blind tests were used to create similar bathymetric maps utilizing both ReefMaster and ArcGIS.

The comparisons between geophysical data and literature review, when combined with the results of the ground-truth survey, formed the basis through which the sonar system was tested. The results from the data collection, as well as the assessments, can be found in the following chapter.

Chapter 5

Results and Interpretations

5.0 Introduction

Using case studies at four localities, sonograms and bathymetric depth measurements were collected to explore the application and effectiveness of consumer-grade sonar instruments for documenting seasonally flooded landscapes. Supplementary data was acquired (i.e., SCUBA ground-truthing, UAV imagery, coring, and post-processing experiments), to examine the precision and accuracy of the methodologies. In this chapter, results from the inquiry are offered, with the case studies used as a framework to which the information is presented. Afterwards, a series of criticisms and observations are offered to highlight capabilities of the methodology.

5.1 Case Studies

5.1.1 Arrow Lake

The bathymetric study results from Arrow Lake reflect the complexities often associated with underwater geophysical research. The Vector TIN output generated by ReefMaster (**Fig. 5.1.1.1.**) documents only some of the elevation changes that are present near the opening into Frog Portage. Observed in **Figure 5.1.1.1.** one can easily distinguish the contours of the lake floor, with the darker regions representing, the deeper parts of the lake. The maximum depth is 3 meters (Black regions) within the survey area, while the shallow areas are represented by lighter colour. The major contour intervals (dark blue) reflect a 1m change in elevation, while the minor contours observed in Figure 5.1.1.1. represent a 12.5 cm interval. Though the output does reflect a broader representation of the lake bottom, the Vector map struggles to illustrate the two sandbars that are present within the survey area.

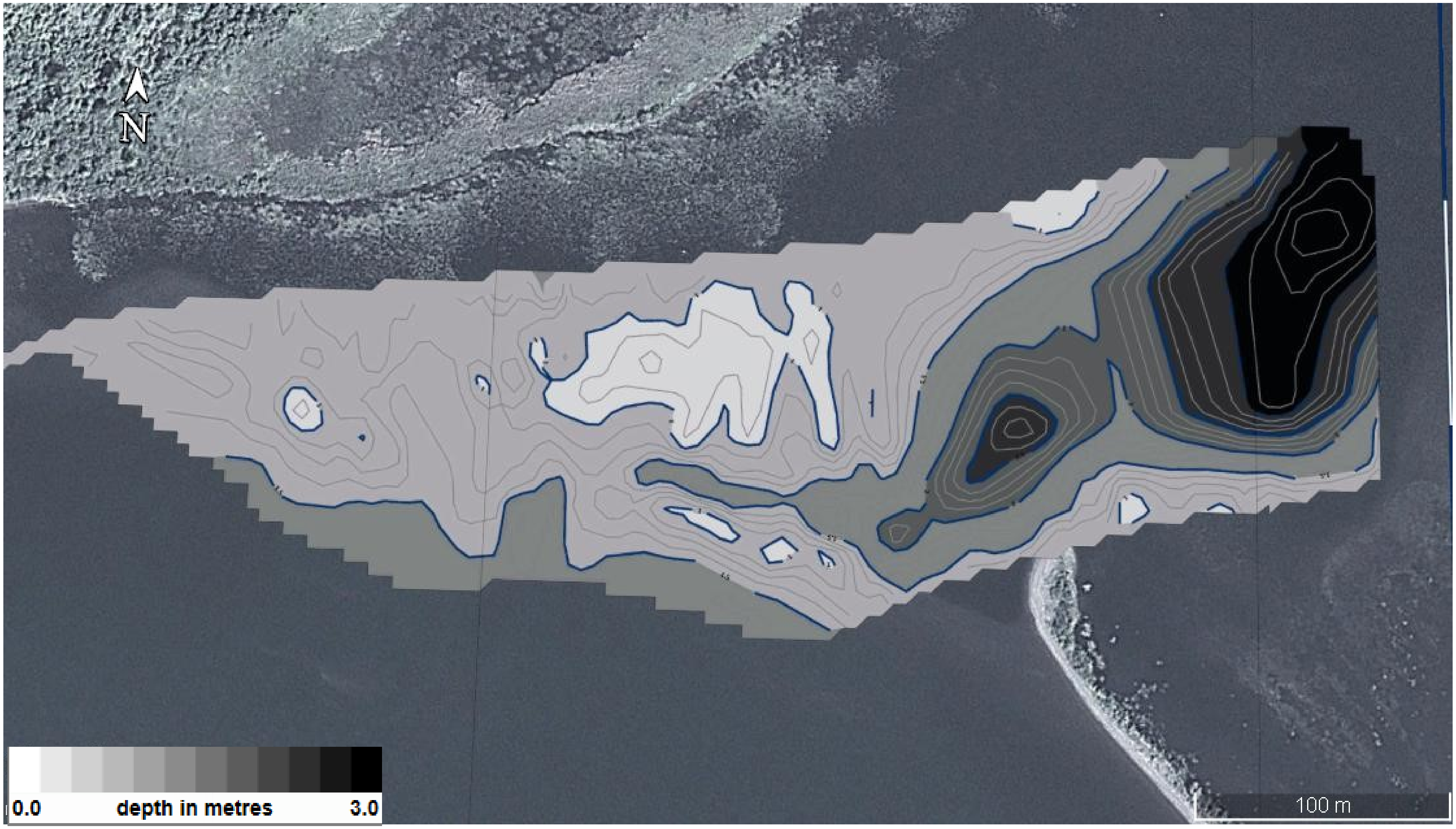


Figure 5.1.1.1: ReefMaster Vector map is representing the opening of Frog Portage on Arrow Lake.

Nevertheless, the map does appear to be spatially accurate, as the southern sand-bar feature (highlighted in yellow **Fig. 5.1.3**) is located in its correct position. It is probable that the apparent inadequacies of the bathymetry output is more a function of insufficient survey coverage rather than weaknesses of the data processing and presentation.

Using the methodologies described in the previous chapter, **Fig. 5.1.1.1** represents the best representation of the survey area. When the vector output is compared to bathymetry created during a preliminary study, subtle changes are observed (**Fig. 5.1.1.2**). Though the same area was surveyed in both studies, the preliminary survey captured greater levels of detail, especially along the two sand-bar features (highlighted in yellow). While a different device was used to capture the depth measurements (Garmin chart-plotter), the lack of detail in the primary survey is likely caused by two defects in the methodology. The first is the sensitivity of the triangular irregular network used by ReefMaster. With the most defined resolution occurring at 12.5cm (Minor Contour Levels), any elevation changes below 12.5cm in elevation will not be captured and displayed in the output. ArcMap, an ESRI product, has greater capabilities when interpolating subtle changes in elevation, as observed in **Figure 5.1.1.2**. Though each interpolation used different algorithms (ArcMap: IDW, ReefMaster: TIN), the greater detail in the ArcMap output is likely due to the programs ability to manually adjust cell size, power, and other settings, when generating the bathymetric maps.

The second flaw with the method consists of the number of data points collected during the primary survey. In total, 2,807 depth measurements were acquired using the Humminbird sonar system, in an area approximately $.30^2$ km in size. This may seem dense, however, the juxtaposition of the data points throughout the survey area (**Fig 5.1.1.3**) reveals that only a portion of the sand-bar features were recorded. Deficiencies in navigation and the inability of the crew to recognize where the targets were located, relative to the boat, meant that the number of depth measurements was too sparse to provide a highly detailed representation of the lake bottom.

Top: **Vector** (IDW) bathymetric output from a preliminary survey on Arrow Lake, near the mouth of Frog Portage. ESRI's ArcMap was used to interpolate the data points originally collected using a Garmin 525 Chart Plotter sonar system.

Bottom: **Vector** (TIN) bathymetric output from the principle survey on Arrow Lake. The Raster map was generated using ReefMaster, with depth measurements obtained using a Humminbird 899ci SD HD sonar system.

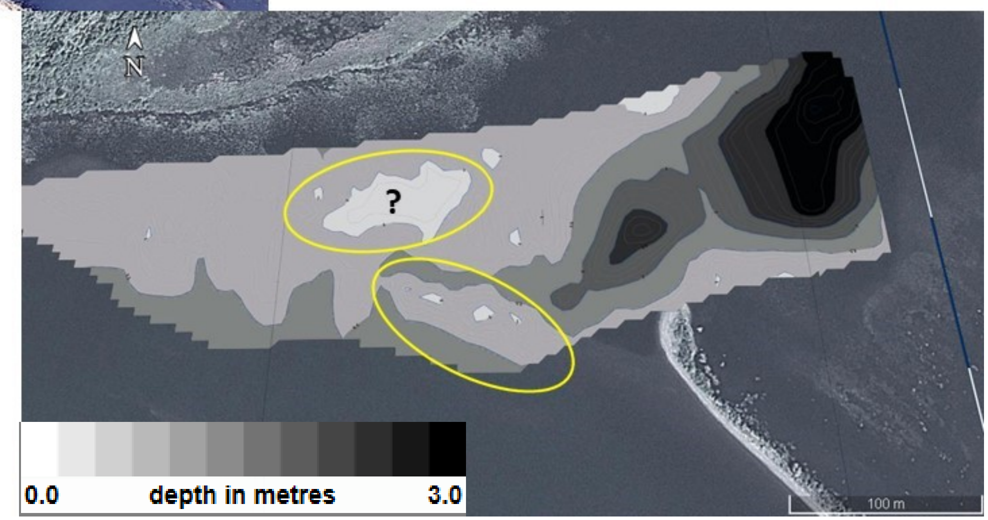


Figure 5.1.1.2. Vector maps comparing bathymetric output from the preliminary (Top) and primary (Bottom) surveys near Frog Portage, Arrow Lake.

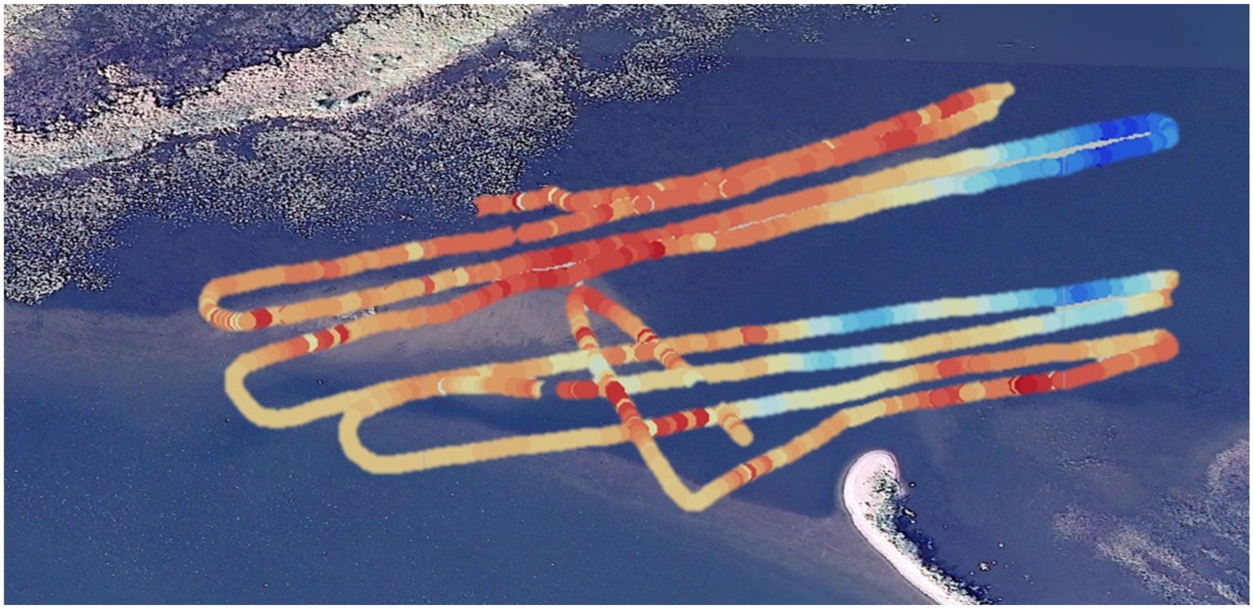


Figure 5.1.1.3.Tracks of data points (depth measurements) collected near the mouth of Frog Portage, on Dog Lake. Colour coding of the data points reflect depth changes (Red reflects a shallower water column, while Blue represent a deeper area).

The case study at Arrow Lake provided insight to the deficiencies often associated with sonar surveys of this level. If similar features need to be recorded in the future, adjustments must be made into how the data is collected and processed.

While out on the water, the primary focus is to ascertain a sufficient number of data points to generate the topographic features that define the bottom. A series of closely spaced transects must be completed to cover the targeted area. Furthermore, concerns regarding continuity and gathering 'too much data' should be disregarded as more data points will result in an accurate bathymetric representation of the lake floor.

Based on these initial results, ReefMaster appears to be proficient at producing spatially accurate bathymetric maps. Limitations in the program's resolution, however, do exist. Subtle features of geomorphological and anthropological origin may be missed, as interpolation will likely smooth over any feature below 12.5cm in height. Based of these findings, further bathymetric charts were interpolated in the *raster* format, as the interpolation provides greater detail.

5.1.2 Dog Lake

With supporting information gleaned through the acquisition of aerial photographs, coring strategies, and ground truth photo-documentation, results of the sonar surveys at Dog Lake offered insight into the accuracy and detail available. In total, 19,434 individual data points were collected across 83 different tracks to acquire the bathymetric data and side scan imagery from both case studies.

Hawk Bay Site (DeJj-2)

Analysis of the bathymetric data collected at the Hawk Bay Site revealed the near-shore relief configuration, some of which is exposed during times of low water levels (**Fig. 5.1.2.1**). According to the bathymetric output, the deepest part of the lake within the survey area (dark blue), is approximately 10 meters deep and is found on the windward side of the Hawk Bay point. On the leeward side of the Hawk Bay point, the maximum depth within the survey area is between 5 and 6 meters deep. Closer to shore, the dark red zone represents depths 1m and less. Between the depths of 0.5-2m, the TIN raster has interpolated a series of artifacts along the near-shore zones of the point. **Figure 5.1.2.2** highlights that some of these artifacts are likely surface undulations that are represented by actual objects such as large boulders, or areas of accumulated sediment.

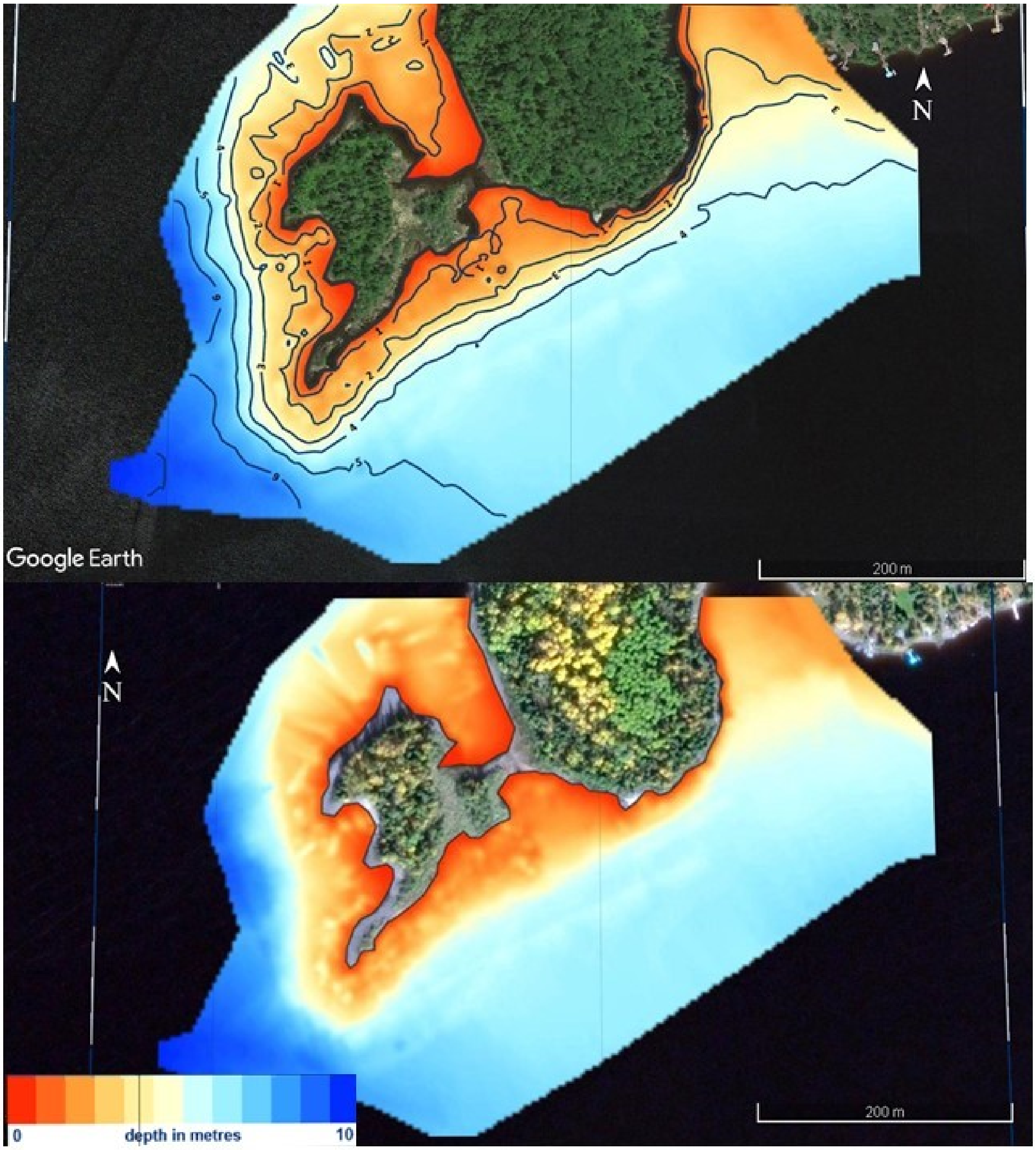


Figure 5.1.2.1. Top) Map 1 ; Bottom) Map 2.

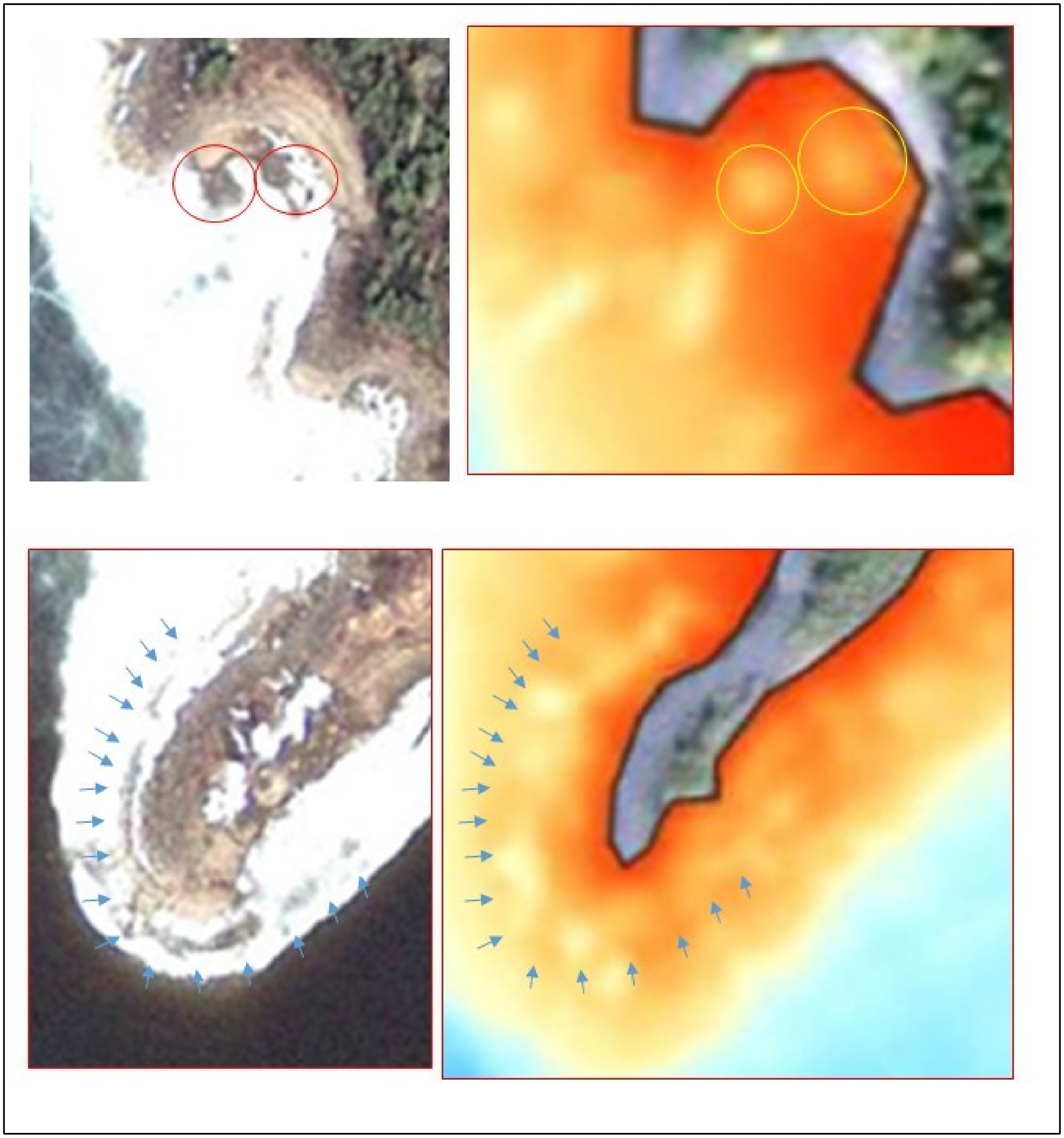


Figure 5.1.2.2. Features represented in the bathymetric data (Right) are evaluated and compared to satellite imageryobtained from Google Earth.

When comparing the bathymetric output to seasonal satellite imagery from ©Goggle Earth Pro (**Fig. 5.1.2.3**), a relationship can be observed between the formations of the cobble shoreline, highlighted by seasonal water levels, and the bathymetric contours. The symilarities between the satalite imagery and the elevation data data suggests that the bathymetric output is likely representing a relatively accurate depiction of the near-shore zone and its elevations. Based on these comparisons alone, it is difficult to determine what isocline likely, if at all, represents the original pre-inundated shoreline.

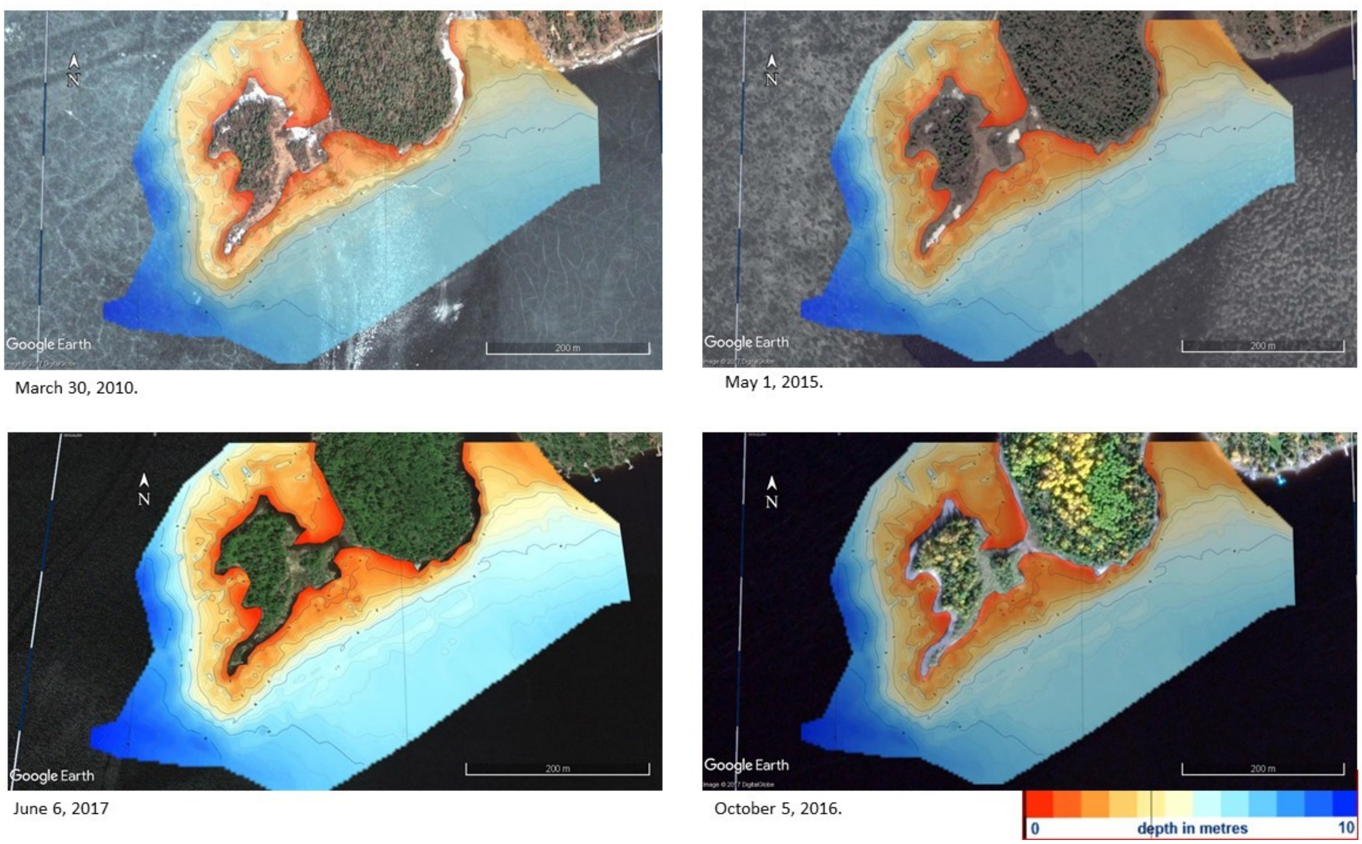


Figure 5.1.2.3. Bathymetric output from the Hawk Bay Site is compared to seasonal imagery obtained from Google Earth.

As discussed previously (Chapter 3), artifacts have been recovered along the shore by amateur and professional archaeologists. Field notes produced by Mike McLeod indicate that archaeological materials can be found at the Hawk Bay site between the elevations of 0m and 3m deep, on the leeward side of the point (**Fig. 5.1.2.4**). At this time it is unclear as to how far out that natural shoreline would have continued, as seasonal fluctuations, including ice formations, have shaped the landscape during a century of use as a hydroelectric reservoir.

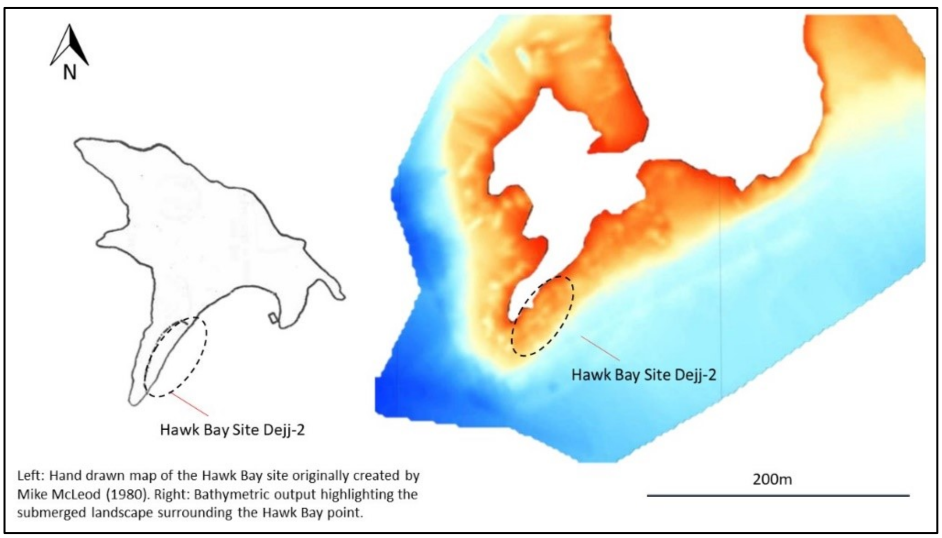


Figure 5.1.2.4. Comparing Mike McLeod's map of the Hawk Bay Site from 1981, with modern Bathymetric data.

The completed mosaic from the *SSS* survey of the Hawk Bay site can be found below in Figure 5.1.2.5. Analysis of the side scan mosaic (**Fig. 5.1.2.6**) revealed that both, the leeward and windward side of Hawk Bay Site, is dominated by hard surfaces (bright areas) composed of boulders, cobble armor, and bedrock features. Approximately 40-50 meters from shore (highlighted by the white dash-marks), the side-scan mosaic reflects a soft bottom (dark areas), likely composed of diverse materials that include sand, silts, and clays. Here depths extend from 2 meters to 5 meters below the surface and are flooded during most of the year.

To test the interpretative accuracy of the data, multiple forms of ground-truthing were employed. First, Scuba equipment was used to swim a series of transects to visually inspect the bottom. Data gathered during the underwater survey (Appendix A, Fig. A1 and Table A1; Appendix B) validated what was observed in the side scan imaging. Information gathered during the dives depicts a series of transition zones (Location# 1141 and 1161), or boundaries, which represented a change from a cobble bottom (Image. 13), to a bed comprised of sands, silts, and clays (Image. 11 and 12). At this time, it is speculated that the cobble-armor observed on the sonar, as well as during the dives, represent 'lag' that is left behind by the intense wave action affecting the shores that are repeatedly eroded as reservoir levels annually fluctuate. Such clasts were likely originally part of the ground moraine, consisting of unsorted sediment and rock of varying sizes that were left behind during deglaciation. The wave action appears to have removed the fine sediment and smaller clasts, leaving behind the heavier rock. Images available in Appendix B (Image 7 and 8) reflect two pieces of debitage (flakes) observed along the bottom near the west side of the point. These percussion flakes, made from quartz and taconite respectively, seem to be large enough to resist erosional displacement.

The finer sediments (clay, silt and sand) that were observed 30-50m away from shore were likely differentially washed away by wave action, which may also carry away the smaller and lighter cultural material.

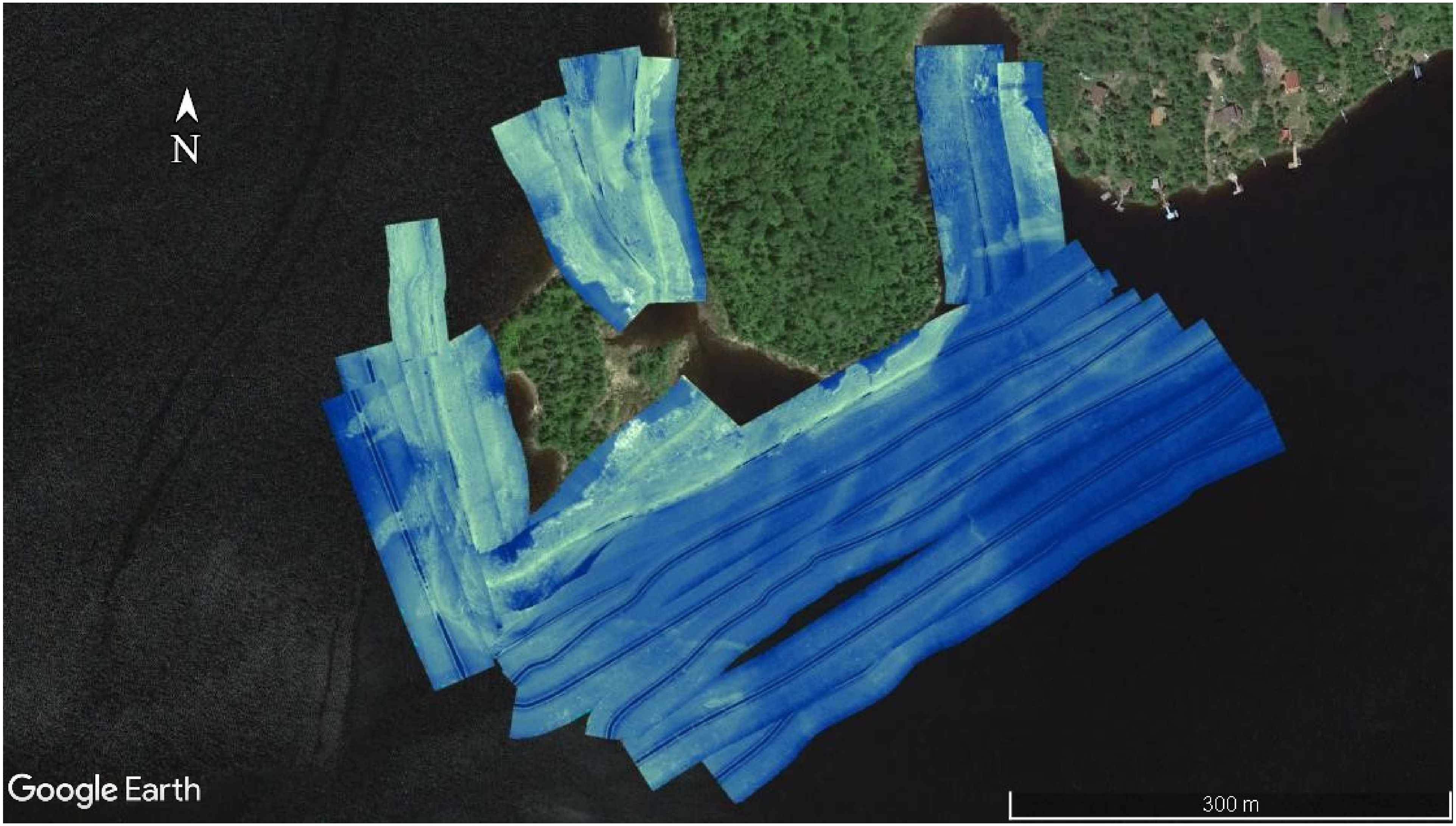


Figure 5.1.2.5. Complete Side Scan Mosaic of the Hawk Bay Site presented in Google Earth Pro.

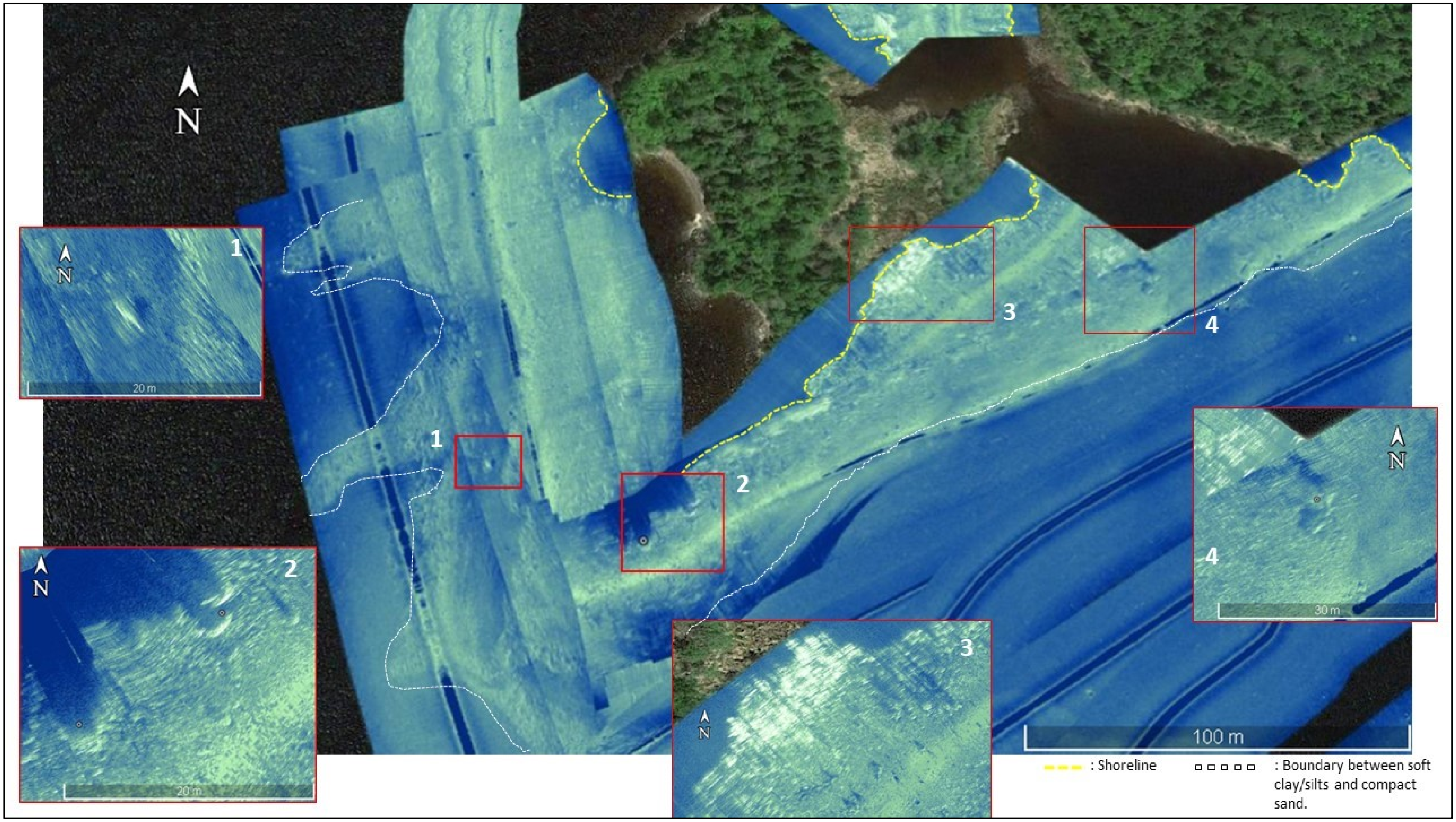


Figure 5.1.2.6: Highlights from the side scan mosaic at the Hawk Bay Site (DeJj-2). 1) Small-Medium Boulder; 2) Large Boulder/Erratic resting against shoreline; 3) Potential bedrock feature or cluster of rocks/cobble; 4) Potential bedrock feature or cluster of rocks/cobble. Yellow dash-marks represent the outline of the shoreline. White dash-marks represent a boundary between the hard surfaces of the near-shore zone and the soft sediments found in the away from shore.

Features detected in the side scan imagery were also corroborated by the 20 cores extracted along the southern shore of the Hawk Bay site (**Fig. 5.1.2.7**). Table 5.1.2.1 confirms that the top-layer sediment found beyond the near-shore 'fluctuation zone' consists of fine sands, clays, and silts (Cores G1b and CF4). In areas amongst the near-shore 'fluctuation zone,' coarse to fine-grained sand can be observed in between the rock features and cobble armor that dominate the area (Cores A2, B2, CF2, CF3). Along the baseline, right on the shore, cores demonstrate that much of the accessible southwest side of the site has been severely eroded by wave action. As the operations moved eastward, away from the point and into the sheltered areas, more organics, silt, and clays were observed. It is unclear at this time whether any of the subsurface organics recovered away from the shore represent intact deposits making up the original terrestrial sediments of the peninsula, or if they have been re-deposited the recent past and have been colonized by aquatic vegetation. The low elevation photomosaic captured with the DJI Phantom provided a means of addressing the spatial accuracy of the side scan sonar. With both mosaics uploaded in Google Earth Pro, 'Place-marks' were added over objects in the side scan mosaic. When the drone image was made visible, a comparison can be made between the place marker (sonar representation) and the same object observed in the aerial mosaic. Analysis of the geo-referenced orthomosaics produced by photogrammetric processing of aerial images from the UAV were first addressed by Hamilton and Stephenson (2016).

Table 5.1.2.1.: Cores extracted from the Hawk Bay Site (DeJj-2) on Dog Lake, Ontario.

			Coring at Hawk Bay Site (DeJj-2)				
Cores	A1	A2	B1	B2	CF1	C1	D1
Assigned #	dlA1a	dlA2a	dlB1	dlB2a	dlCF1	dlC1	dlD1
GPS Lat/Long	48.68881138/-89.5528263	48.68869588/-89.5526181	48.68894482/-89.552644	48.68883393/-89.55241559	48.68907927/-89.55245767	48.6892168/-89.55225592	48.68934103/-89.55207193
Core Type	N/A	N/A	Russian Core	Russian Core	Russian Core	Russian Core	Russian Core
Description	Rocky Foreshore	Open Water	Reedy Foreshore	Open Water	Rocky Foreshore	Rocky Foreshore	Reedy Foreshore
Sediment Type	Cobble	Cobble	0-9cm : Organic Sand/Silt	0-9cm: Browne Medium Grained Sand with Silt. Amongst Cobble	0-5cm: Browne Coarse Sand. Amongst Cobble	0-7cm:Dark Browne Coarse Organic Sand. 7-9cm: Rocks	0-7cm: Browne Coarse Organic Sand with Silt. 7-9cm: Rocks

	D2	E1	F1	G1	H1	H2	I1
Cores	dlD2a	dlE1a	dlF1a	dlg1a	dlH1a	dlH2a	dlI1a
Assigned #	48.68910399/-89.55205525	48.68947196/-89.55187521	48.68959827/-89.55168771	48.6897183/-89.55150221	48.68983758/-89.55132603	48.68973607/-89.55110634	48.68996255/-89.55114137
GPS Lat/Long	Russian Core	Russian Core	Russian Core	Bucket Auger	Bucket Auger	Russian Core	Russian Core
Core Type	Open Water	Reedy Foreshore	Reedy Foreshore	Reedy Foreshore	Reedy Foreshore	Open Water	Reedy Foreshore
Description Sediment Type	0-13cm: Light Browne Fine Sand 13-15cm: Black Organic Silt	0-10cm: Browne Coarse silty Sand. Amongst Cobble	0-2cm: Organic Silt 2 8cm: Light Browne Fine Silty Sand 8- 13cm: Black Organic Silty Sand	0-14cm: Black Organic Sandy Silt. 14- 16cm: Rocks and Roots	0-4cm: Roots and Black Organic. Sand with Some Gravel. 4-13cm: Dark Brown Organics. Coarse Sand with Gravel. 13-20cm: Browne Coarse Silty Sand. large Gravel	0-12cm: Sandy Silt.	0-4cm: Browne Organic Sandy Silt. 4-8cm: Light Browne Sandy Silt 8-11cm: Dark Browne Organic/Muddy Silt 11-20cm: Light Browne Silty Sand.

Date: May 4, 2016. Water levels were approximately 20m below yearly high.

Cores	G1b	CF4	CF3	CF2	D1b	F1b
Address #	diG1b	dlCF4	dlCF3	dlCF2	dlD1b	dlF1b
GPS Lat/Long	N/A	N/A	N/A	N/A	N/A	N/A
Core Type	Universal Core	Universal Core	Universal Core	Universal Core	Universal Core	Universal Core
Situation	below current water level	below current water level	below current water level.	Rocky Foreshore	below current water level.	below current water level.
Sediment Type	0-4cm: Light Brown Silty Sand 4-6cm: Dark Silty Sand 6-11cm: Coarse Sand with Fine Gravel 11-14cm: Wood. Organics	0-8cm: Brown Silty 8-13cm: Dark Coarse Sand with Gravel	0-15cm: Brown Silty Sand. Little Gravel 15-18cm: Dark Brown Coarse Sand. Little Gravel 18-21cm: Dark Organics with Wood	0-2cm: Brown Sand 2-8cm: Dark Coarse Sand. Little Gravel 8-16cm: Dark Silty Clay	0-20cm: Sand Fall out of Core	0-5cm: Corse Sand with Pebbles 5-10cm: Dark Organics with Wood.

Figure 5.1.2.7: Location of cores extracted from the Hawk Bay Site (DeJj-2)

The individual images are geo-tagged using the gps integrated into the UAV (2m-5m accuracy), and this information is integrated into the photogrammetric processing that mosaics the images together using common points in adjacent/overlapping images. They estimate that objects documented in these images might be cartographically registered to within approximately 10-15cm. In contrast the sonar imagery is geo-referenced using GPS signals (± 2.5m accuracy) received by the sonar unit that routinely was placed in the centre of the boat, some 1 to 1.5 meters removed from the transducer attached to the stern. This spatial displacement is an obvious factor affecting the geographic precision of bottom features detected by the sonar. With this cautionary note, the spatial integrity and cartographic precision of the side scan sonar images were evaluated relative to the UAV images. Figure 5.1.2.8. demonstrates that the side scan sonar image reports objects on the bottom in a position somewhat divergent from that evident in the UAV image. In general these displacements are between 2 and 3 meters, with the most significant discrepancy occurring with example C, with a displacement of 355cm. These inaccuracies, while appearing

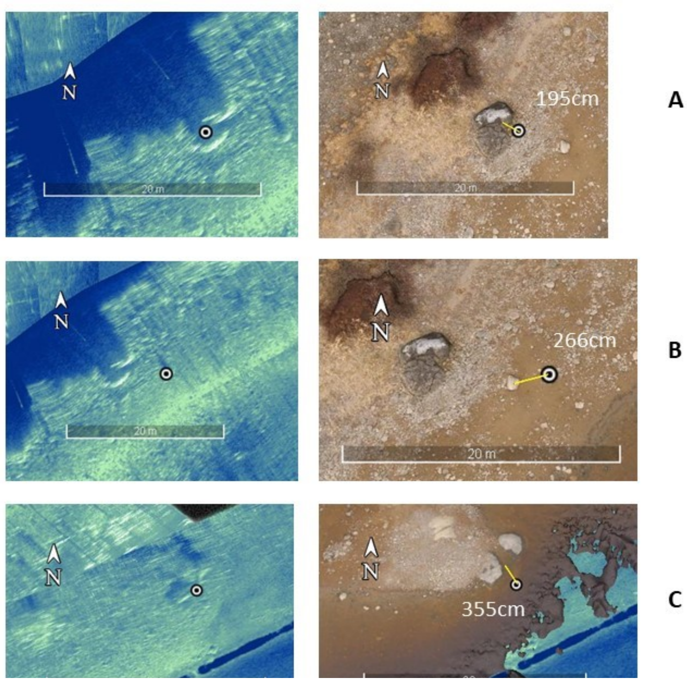


Figure 5.1.2.8. Comparison of spatial accuracy between the side scan sonar, and imagery captured with the UAV at the Hawk Bay Site.

significant, still provide an operationally useful representation of the bottom conditions, and, the spatial distortions likely derive from multiple factors which are addressed more fully in Chapter 6.

5.2.3 Portage Island Site (DeJj-8)

Located 2km to the southeast of the Hawk Bay Site, the Portage Island Site (DeJj-8) exhibited similar features to those observed in the previous case study. The bathymetric output **(Fig. 5.2.3.1**) are consistent with some of the terrestrial geomorphological features that define the eastern side of the island and shoreline. Away from shore, the bathymetric output interprets the deepest section of the survey area (dark blue) as 5m deep. A berm can be detected on the east side of the island, where during seasonal low water levels, the island becomes connected to the mainland. As interpolation gets closer to the mouth of the river, variations in depth (4m, 3m, and 2m) are observed depicting what is either the pre inundated shoreline or features shaped by fluctuating water levels and ice formations (**Fig. 5.2.3.2**)

Consistent to the previous case study, interpolated artifacts are observed in the TIN raster, and are likely associated with natural undulations on the lake bottom. A review of the data points in the sonar viewer suggests that some of the depth measurements within the near-shore zone (0.5-2.5m) are exaggerated and are likely caused by human error. Further information can be found in the following chapter (Chapter 6).

When comparing the bathymetric output to seasonal satellite imagery from ©Goggle Earth Pro (**Fig. 5.2.3.3**), a relationship is observed between the seasonal shoreline configuration and the bathymetric contours. Like the previous case study, this comparison suggests that the bathymetric output is likely representing a relatively accurate depiction of the shoreline. A comparison with documents collected by McLeod (1980) suggests that much of the designated archaeological site is inundated up to 2m during seasonally high water levels (**Fig. 5.2.3.4**). At this time it is unclear as to how far out that natural shoreline would have continued, as seasonal fluctuations, including ice formations, have shaped the landscape during a century of use as a hydroelectric reservoir.

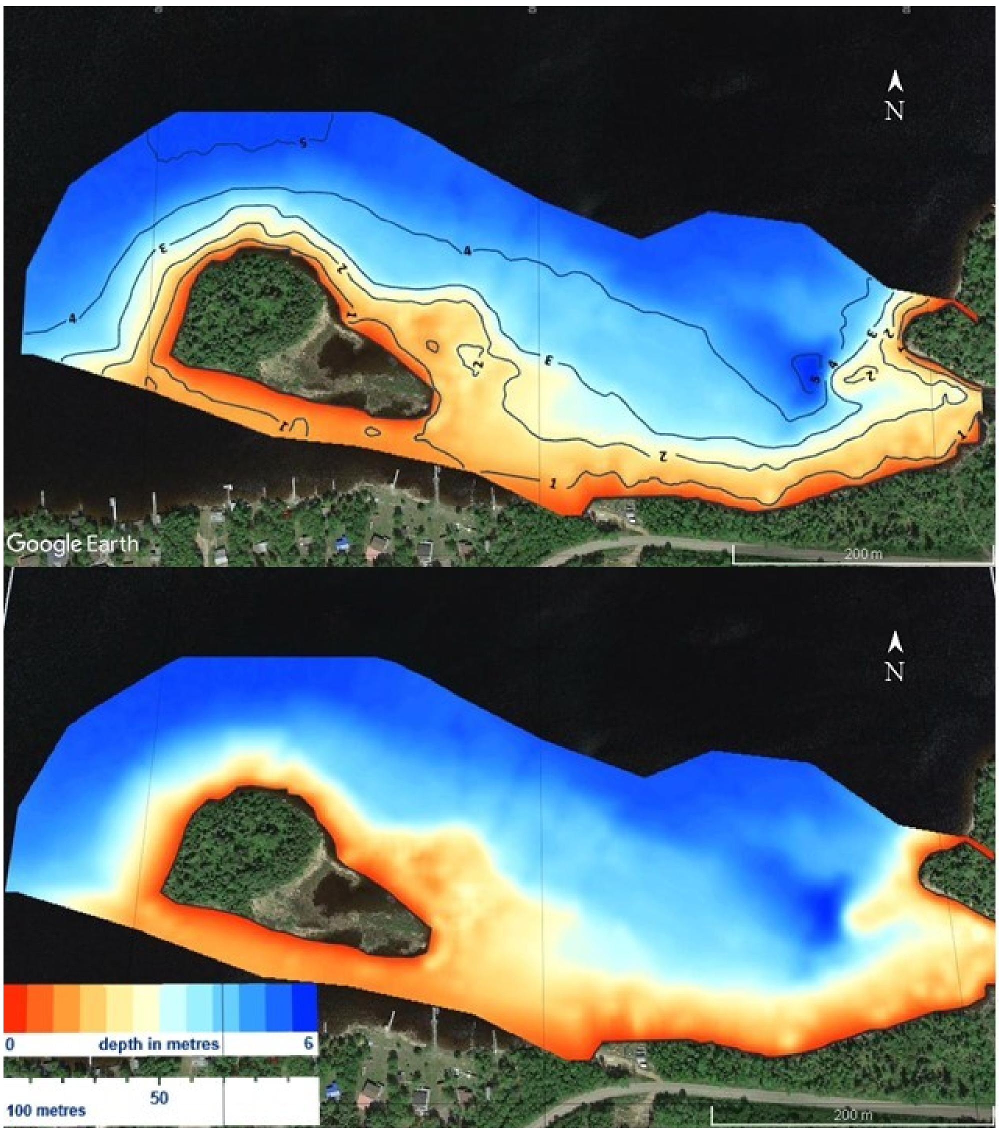
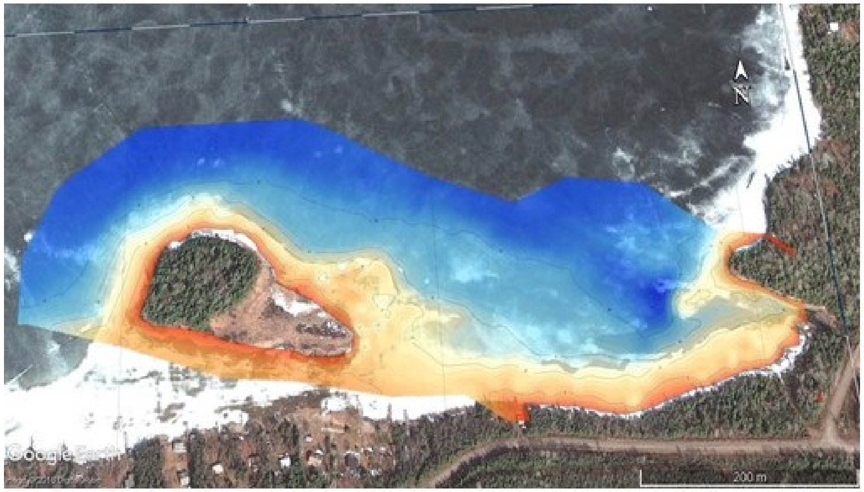
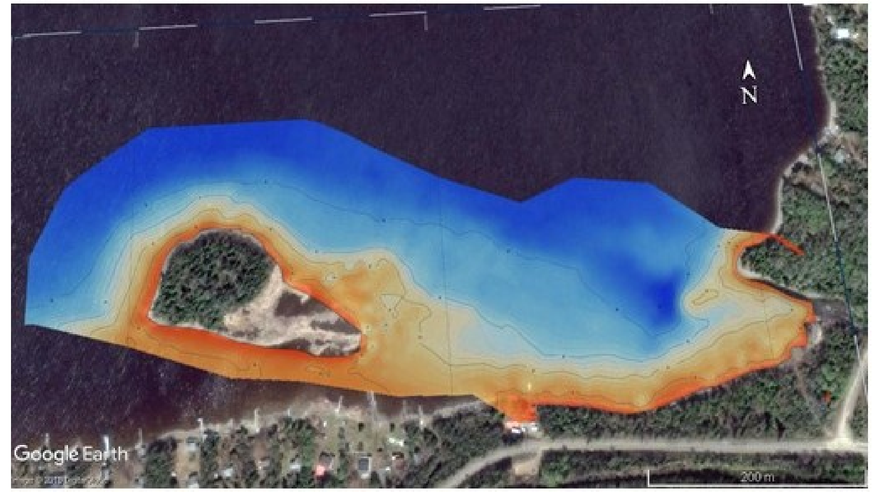


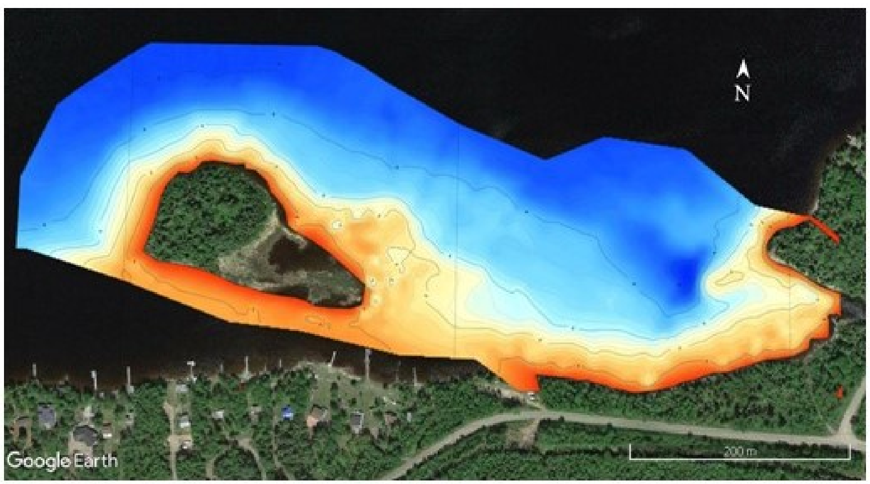
Figure 5.2.3.1: Bathymetric TIN raster of the Portage Island Site and the southeastern near-shore zone of Hawk Bay. Top)Map 1; Bottom) Map 2.



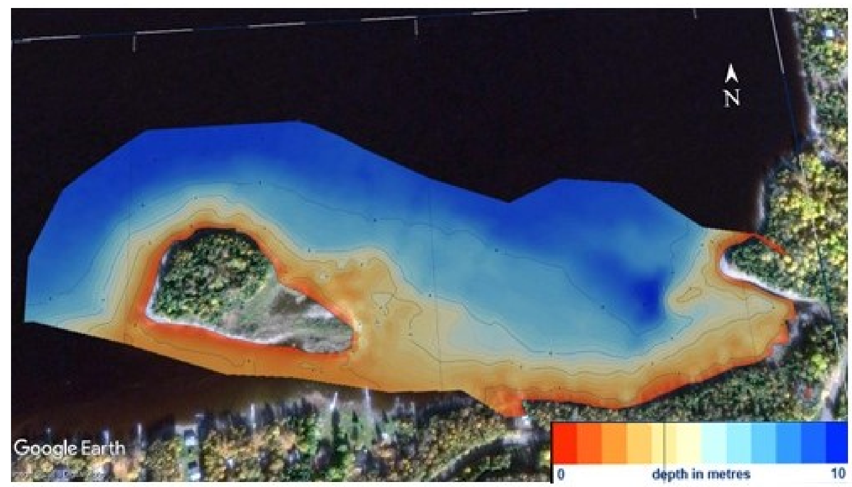
March 30, 2010.



May 1, 2015.

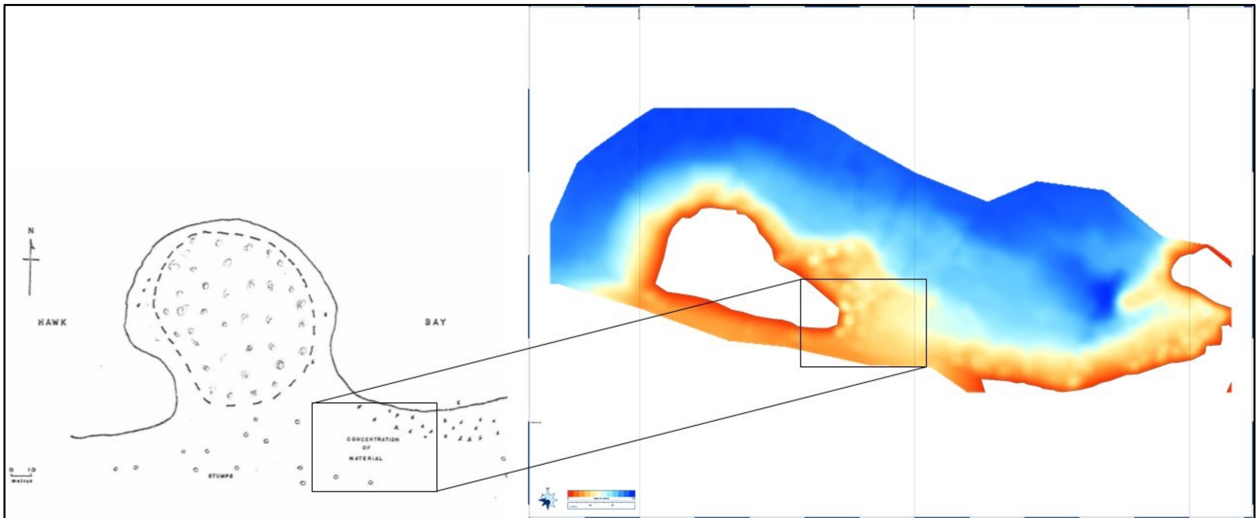


June 6, 2017



October 5, 2016.

Figure 5.2.3.2. Bathymetric output from the Portage Island Site is compared to seasonal imagery obtained from Google Earth.



Left: Hand-drawn map of the Portage Island Site originally created by Mike McLeod (1980). Right: Bathymetric output highlighting the submerged features found around Portage Island.

Figure 5.2.3.3 Comparing Mike McLeod's map of the Portage Island Site from 1981, with modern Bathymetric data.

The side scan imagery captured at the Portage Island Site is presented below in Figure 5.2.3.4, and is composed of 40 different tracks that were compiled in ReefMaster. Analysis of the acoustic mosaic (**Fig. 5.2.3.5 and 5.2.3.6**) reveals that hard surfaces such as cobble lag or bedrock exposures, as well as logs and other forms of debris dominate the underwater circumference of the island, as well as the eastern shoreline. The shoreline, defined by reeds, cattails and other vegetation, is reflected in the imagery as an acoustic shadow. Approximately 55meters away from shore, where depths range from 2.5-5m, the side-scan mosaic once again reflects a soft bottom, likely composed of sand, silts, and clay.

Similar to the Hawk Bay Site, groundtruthing was utilized to address the interpretation and accuracy of the side scan imagery deriving from the Humminbird 899ci HD SI. Data gathered during a series of underwater transects (Appendix A, Fig. A2 and Table A2; Appendix B. Images), confirms what was initially observed on the side scan mosaics. Divers swam along the Portage Island Site encountered transition zones that represented a change from cobble/rocky bottom near the shore (Location # 1321, 1331, 1361, 1371, 1421, and 1451), to a soft bed that is composed of silt and clay (Location #1351 and 1431). One artifact, an old logging boom (Location# 1401, Image 21) likely dating to the early 20th century was encountered during the dives.

A series of cores were extracted from the eastern side of Portage Island (Table. 5.2.3.2 and Figure 5.2.3.7) in order to confirm the side scan mosaic and dive survey interpretations of hard surfaces along the near-shore zone and soft deposits away from shore. While the near-shore zone is predominantly covered in cobbles and boulders, some areas revealed a thin top layer of coarse-grained sand and gravel (Cores 1291, 1281, 1301). Along the shoreline, samples 1331 and 1341 yielded organics from the top layer, indicating vegetation was established on the east side of Portage Island. Only core 1271, was able to penetrate through cobbles and deep into the ground. It revealed some organics and charcoal lying beneath redeposited sands and silts, indicating the dynamic and repeatedly reworked nature of these sediments. Samples confirm that the lake bottom sediment at some distance from the shore were water-saturated silts and clays, likely redeposited from wave action along the shore, or from the river just west of the site.

Similar to the previous case study, place markers were pinned within Google Earth Pro over recognizable objects on the side scan sonar output. The UAV imagery was then imported into Google Earth Pro, with the sonar place markers used to measure spatial displacement compared to where the features are evident in the UAV orthomosaic. Figure 5.2.3.8 may reflect the spatial distortions that occur when comparing the UAV imagery to the sonar imagery. The smallest discrepancy (Object B) is a boulder that is displaced by 130cm, while the largest displacement is 665 cm (6.65 meters).

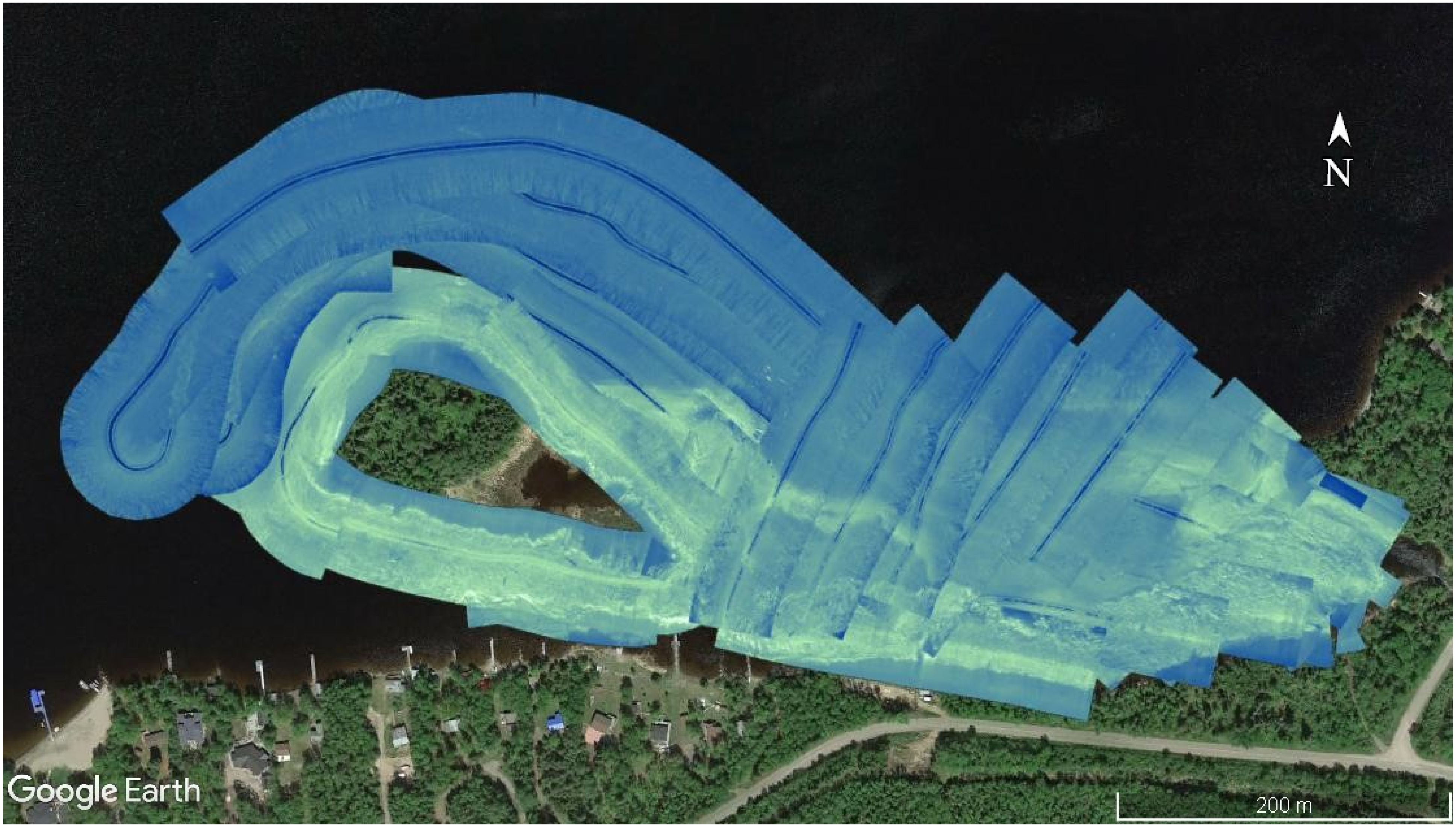


Figure 5.2.3.4. Complete Side Scan Mosaic of the Hawk Bay Site presented in Google Earth Pro.

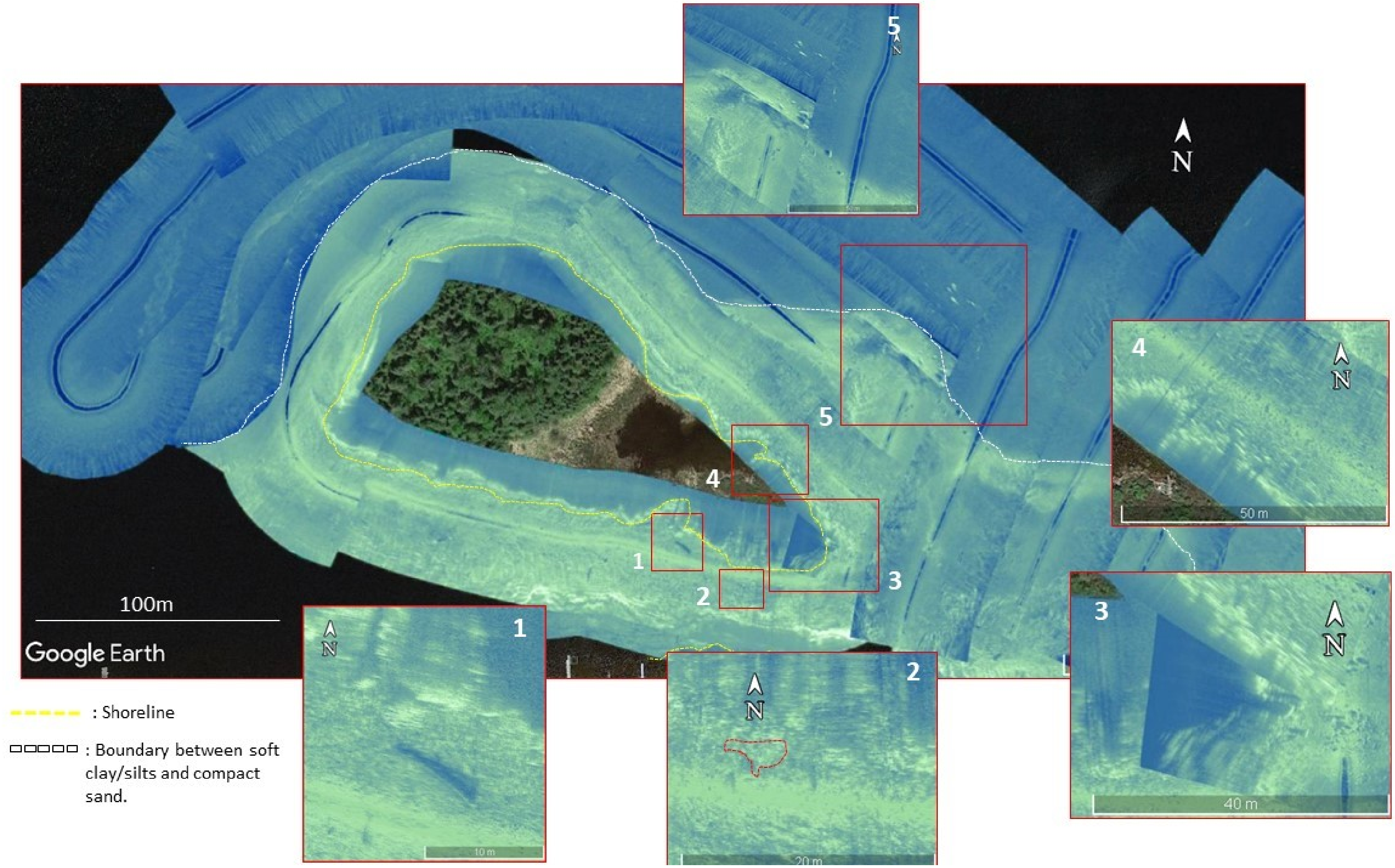


Figure 5.2.3.5. Highlights from the side scan mosaic at the Portage Island Site (DeJj-8). 1) Log, approximately 10m in length ; 2) Patch of rocks and cobble; 3) Large boulder and vegetation; 4) A cluster of rocks, cobble and vegetation; 5) A mix or rocks and hard-packed sediment (sand).. Yellow dash-marks represent the outline of the shoreline. White dash-marks represent a boundary between the hard surfaces of the near-shore zone and the soft sediments found in the away from shore.

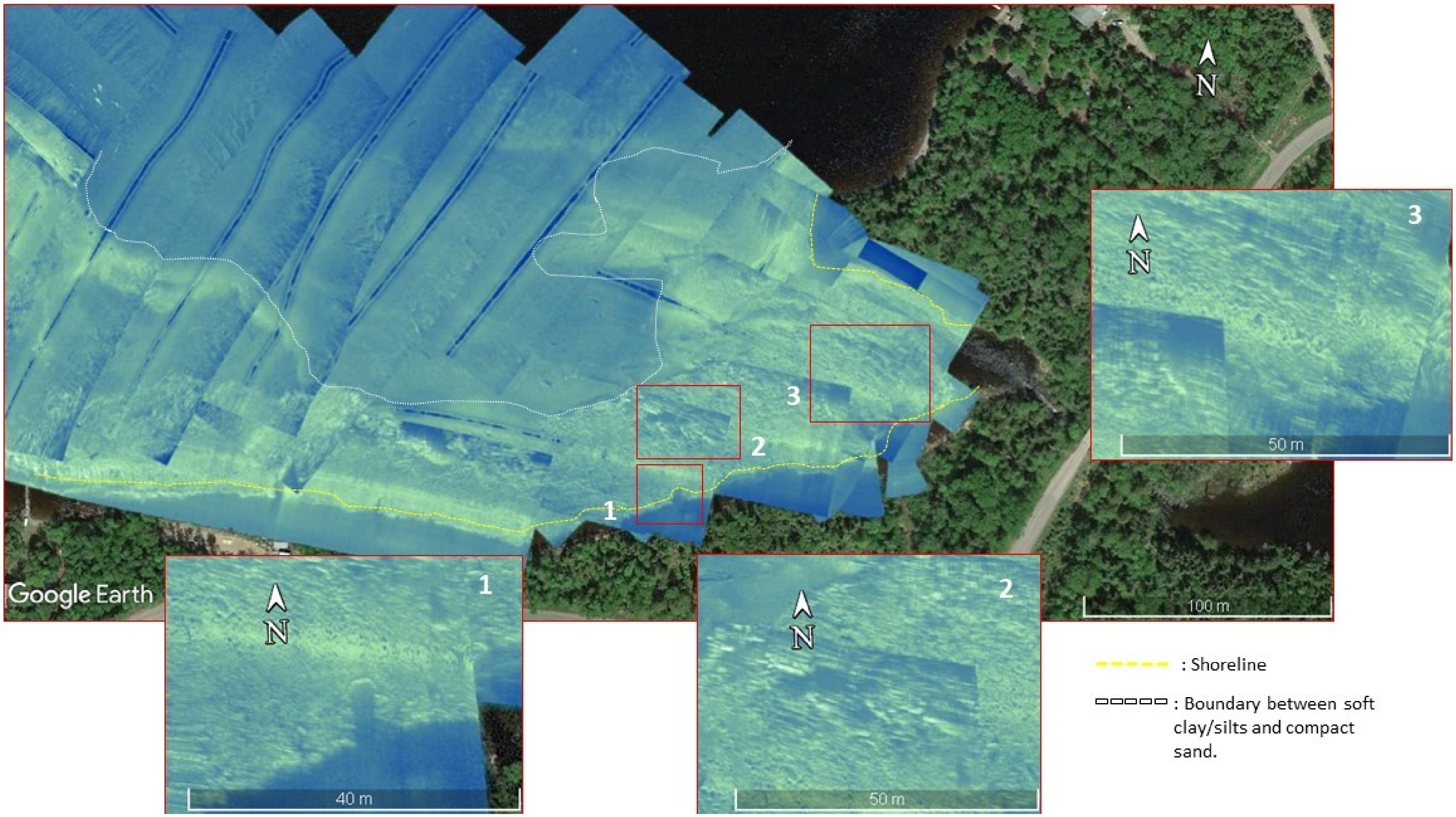


Figure 5.3.2.6. Highlights from the side scan mosaic east of the Portage Island Site (DeJj-8). 1) Large boulder resting amongst a layer of cobble; 2) Patch of rocks and cobble armour; 3) Patch of rocks and cobble armour. Yellow dash-marks represent the outline of the shoreline. White dash-marks represent a boundary between the hard surfaces of the near-shore zone and the soft sediments found in the away from shore.

Table 5.2.3.2. Cores extracted from the Portage Island Site (DeJj-2) on Dog Lake, Ontario

Cores	**A1**	**A2**	**B1**	**C1**
Address #	1271		1281	1291
GPS Lat/Long	48.68086/-89.5272		48.68073/-89.5271	48.68068/-89.52682
Core Type	Russian Core	Russian	Bucket Auger	Bucket Auger
Situation	Sandy Foreshore	Open Water	Reedy Foreshore	Sandy Foreshore
Sediment Type	0-24cm: Coarse Sand and Little Silt. 24-38cm: Coarse Sand and Silt. 38-44cm: Black Organics with Charcoal. 48-59cm: Coarse Sand. 59-70cm: Water Saturated Coarse Sand.	N/A	0-10cm: Organic Coarse Sand. 10-20cm: Coarse Sand	0-14cm: Water Saturated Peaty Silt. 14-16cm: Gravel Layer
Cores	1	**2**	**3**	**4**
Address #	C2016 A	C2016 B	C2016 C	C2016D
GPS Lat/Long	16 U E0314037/N5395085	16 U E0314054/N5395111	16 U E0314074/N5395137	16 U E0314139/N5395103
Core Type	Russian Core	Russian/Universal Core	Universal Core	Universal Core
Situation	Away from shore, through ice.	Away from shore, through ice.	Away from shore, through ice.	Away from shore, through ice.
Sediment Type	0- 10cm: Unknown. Soft bottom, no core	0-17cm: Water Saturated Silt 17-23cm: Medium - Coarse Sand 23-24cm: Organic Carbonized Wood 24-29cm: Coarse Silt	0-3cm: Organics 3-33cm: Sandy Silt	0-8cm: Fine Silt 8-22cm: Fine Sand 22-28cm: Organic Flex 28cm-40: Silty Sand

Cores	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Address #	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
GPS Lat/Long	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Core Type	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Situation	[redacted]	[redacted]	Marsh Wetland	[redacted]	[redacted]
Sediment Type	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Cores	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Address #	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
GPS Lat/Long	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Core Type	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Situation	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Sediment Type	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

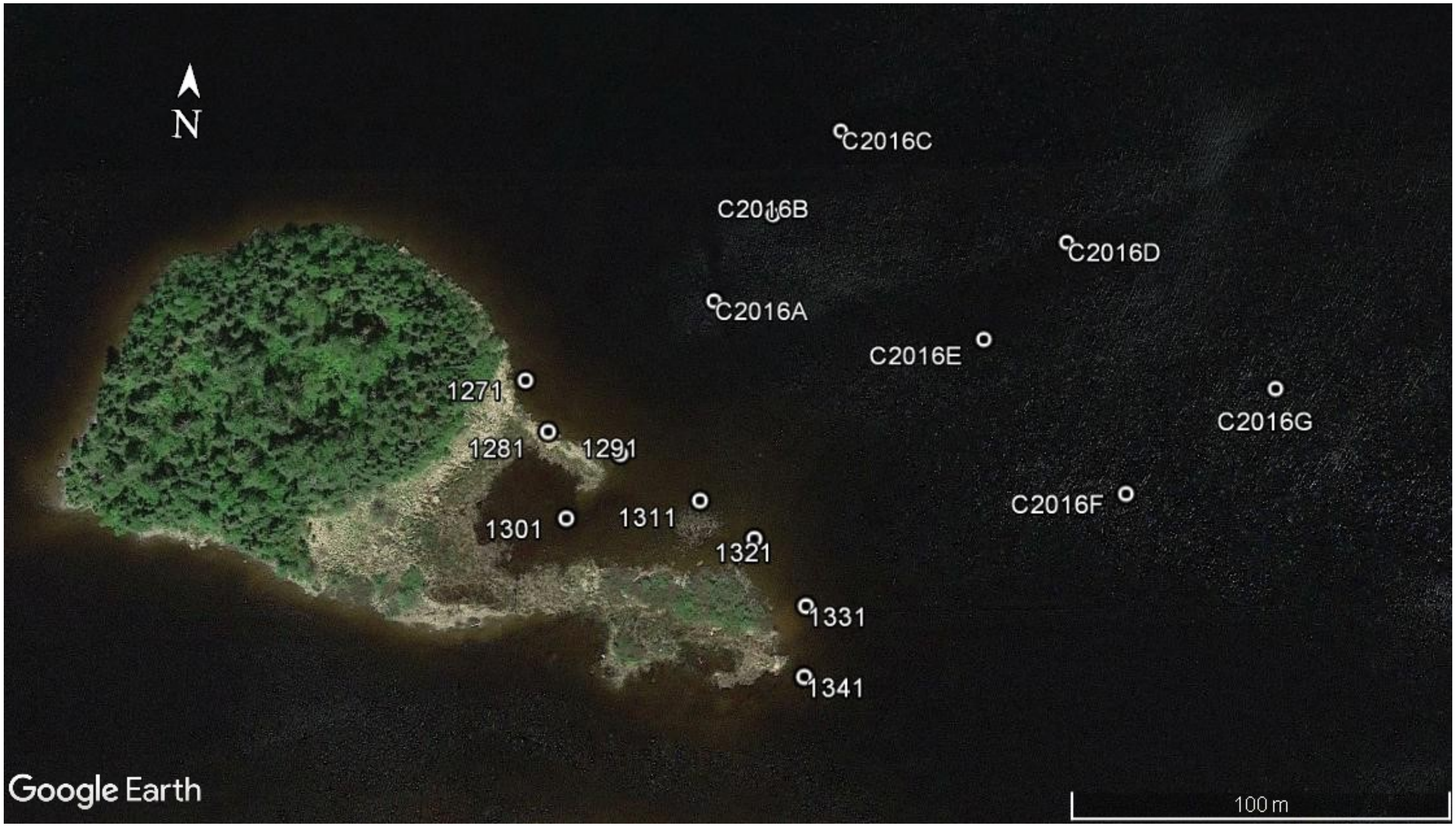


Figure 5.3.2.7. Location of cores extracted from the Portage Island Site (DeJj-2)

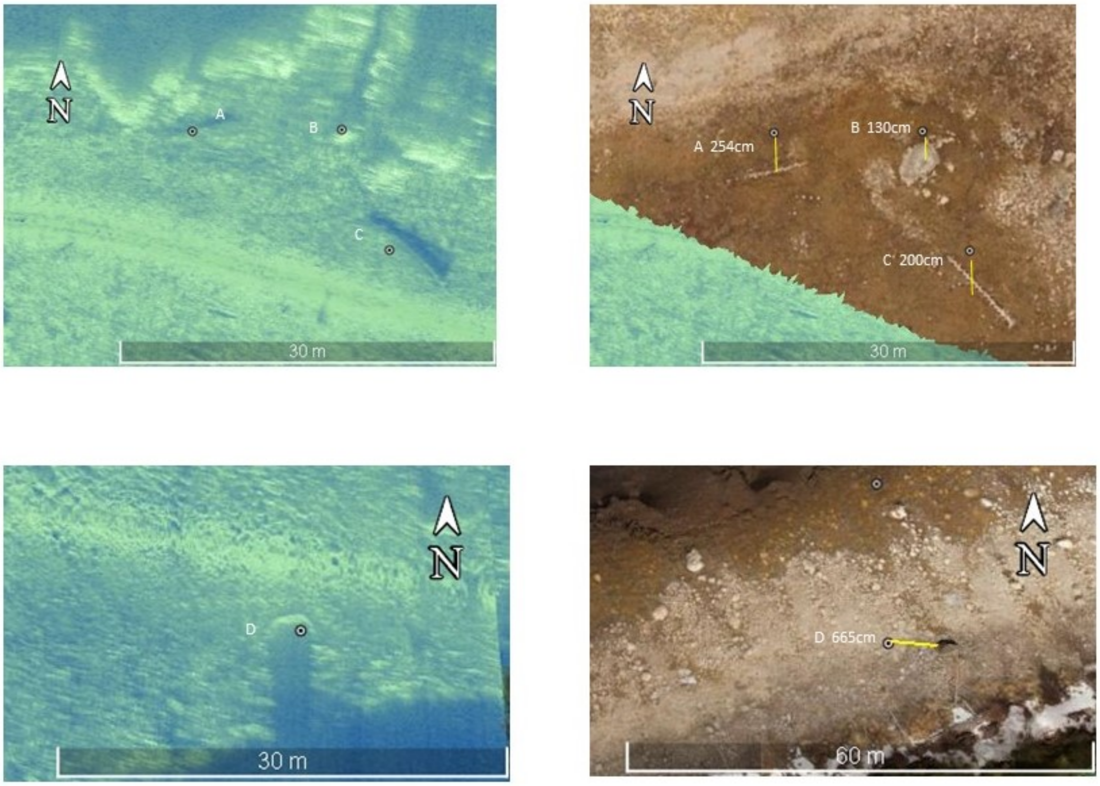


Figure 5.2.3.8. Comparison of spatial accuracy between the side scan sonar, and imagery captured with the UAV at the Portage Island Site.

5.1.4 Boulevard Lake Rock Circle (DcJh-72)

The Boulevard Lake Rock Circle case study sought to test the abilities of the Humminbird sonar in collecting side scan images from very subtle rock features that are well documented using the UAV. The 30m wide rocky anomaly is likely anthropogenic in origin and is submerged underwater during the summer months (**Fig. 5.1.4.1**). Utilizing the methods described in the previous chapter, multiple attempts to scan the arrangement resulted in the partial documentation of the target. In total, four scans were completed with varying levels of success (Individual sonograms available in **Appendix A** (**Fig**. A3-A6). Due to regulatory requirements, permission from the Thunder Bay City Council was required to gain access to Boulevard Lake, which resulted in the study being pushed back to early November when water levels are approximately 1.5 meters deep at the site of the anomaly. Sonograms *R00144*, *R00147, R00150*, and *R00151* (**Fig. 5.1.4.2**), failed to capture the entire anomaly since water levels were too low, thereby obstructing the acoustic signal from reaching the target. Based on these results, the side scan sonar is limited in depths below 2 meters, as the angle of the acoustic signal (455 kHz at 86º) is impeded by that lack of depth.

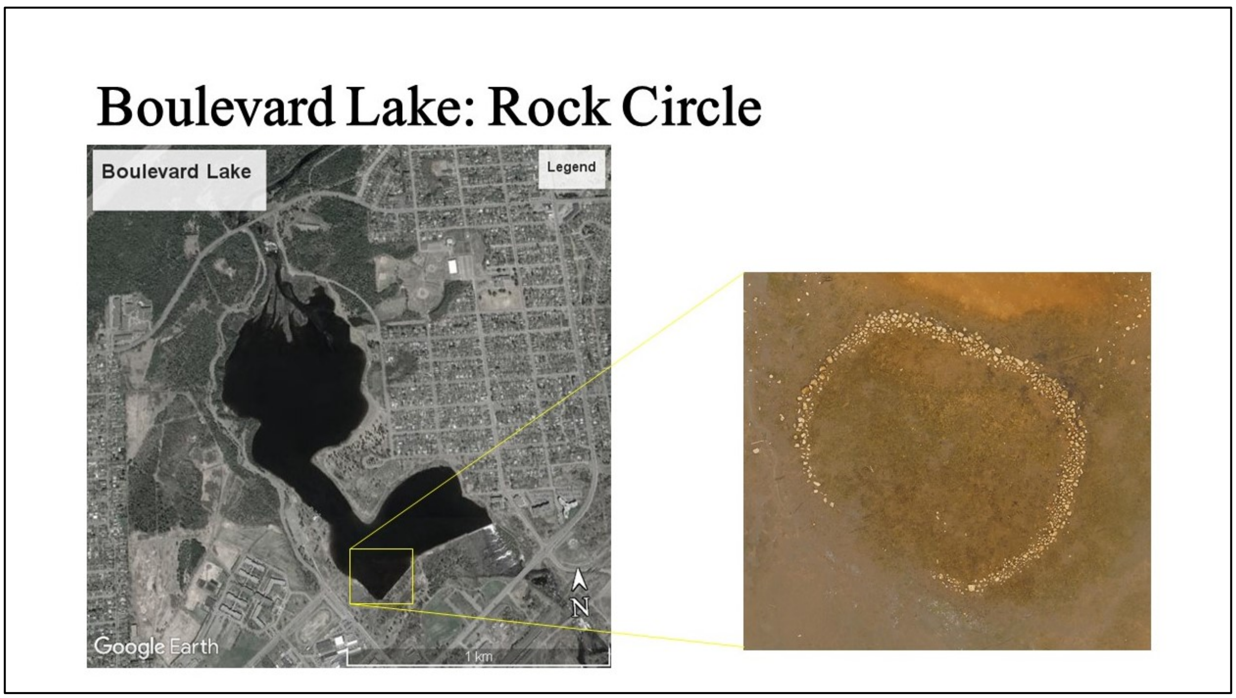


Figure 5.2..4.1. Location of the Rock Circle at Boulevard Lake.

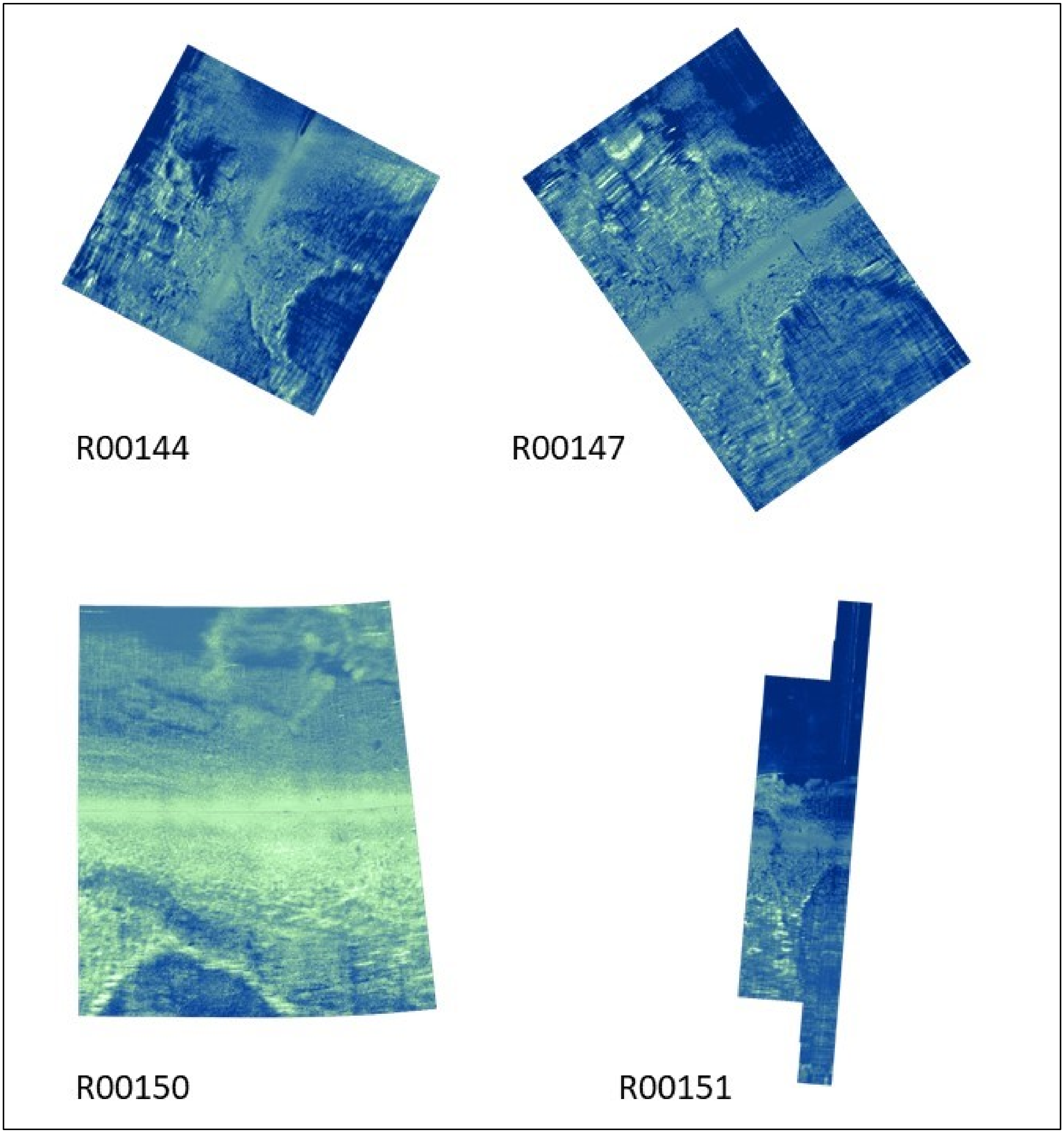


Figure 5.2.4.2. Recorded sonograms of the Boulevard Lake Rock Circle.

Side scan sonar imagery is useful as an archaeological remote sensing tool through identification of patterns of contrasting light and shadows that characterize objects lying on the bottom. The ability of the acoustic signal to detect features of natural or anthropogenic origin depends on series of variables including the boat's rate of travel and stability in the water, the signal's angle of approach, signal frequency, the distance between objects, and water depth. Each sonogram acquired during the case study (**Fig. 5.2.4.2.**) provided a somewhat distinct although hazy view of the rock circle, with features around the structure also being recorded. Both recordings *R00144* and *R00147*, reflected the left-half of the rock structure (bottom right), while the bright signals and acoustic shadows that compose the western portion of the image reflect debris and rocks.

According to the Digital Elevation Models created by Hamilton (2017), the rock circle is on a slightly lower elevation than that of the rocky knoll seen in both Figure 5.2.4.3. and 5.2.4.4. Sonogram *R00150* captured the higher northwest side of the rocky feature, along with the potential remains of the original Current River bank. Observed in both Figure 5.2.4.3. and 5.2.4.4. there is a clear contrast between the hard bottom that compiles the 'Point Bar' and the soft sediments that may reflect the old, pre-dam, the channel of the Current River. The final sonogram *R00151*, reveals similar features with the left portion of the Boulevard Lake rock circle being documented, along with the Current River channel to the north and rocky debris to the west (**Fig 5.2.4.4**).

The sections of the rock circle that were recorded provide valuable information regarding the accuracy and resolution of the side scan sonar. When comparing the sonograms of the rock circle to the imagery captured by a UAV, the distortions in the shape and spatial accuracy of the structure are noticeable. The yellow dashes highlighted in Figure. 5.2.4.4 represent the re-scaled outline of the structure acquired from the UAV imagery.   In some form or another, all four sonograms seem to reflect a distorted view of the rock structure.

The most apparent inaccuracy is seen in recording *R00147* where both the position and shape of the cobble arraignment are distorted. The spatial inaccuracy, approximately 3 meters, is likely caused by a combination of factors. These include the location of the GPS receiver relative to the transducer, the precision of the GPS, and distortions that naturally occur with side scan imaging. Such distortions are highlighted and discussed in the following chapter.

The overall shape captured by the acoustic signal seems to 'smooth' over the point observed near the northern part of the rock structure. Sonograms *R00144, R00150,* and *R00151* appear to be the most accurate, at least regarding their shape and image resolution.   Both sonograms, *R00144* and *R00150,* capture the distinct point atop the assemblage, while with image *R00151*, also reflecting the curved edge along the western section of the sonogram.   All three images provide enough detail to differentiate some of the cobbles that comprise the feature found along the southern shore of Boulevard Lake.

Though the exact size of the structure is not known, the utilization of a digital elevation model (DEM), can provide a relative height to the rocks observed in the acoustic images. Figure 5.2.4.5 represents a juxtaposed DEM over the *R00144* sonogram, where contour intervals of 5cm are compared to the shadow measurements established by ReefMaster. Based off of Figure. 5.2.4.5, one can infer that the rocks range from 10-35cm in height, when comparing the colored contours with one another. While the individual shadow measurements, on the other hand, infer cobble size range of 10-50cm in height. Though both methods are not exact, the height data collected on sonogram *R00144* suggests that the side scan sonar can distinguish objects that are at least 10-50cm in size, depending on the surrounding composition and backscatter.

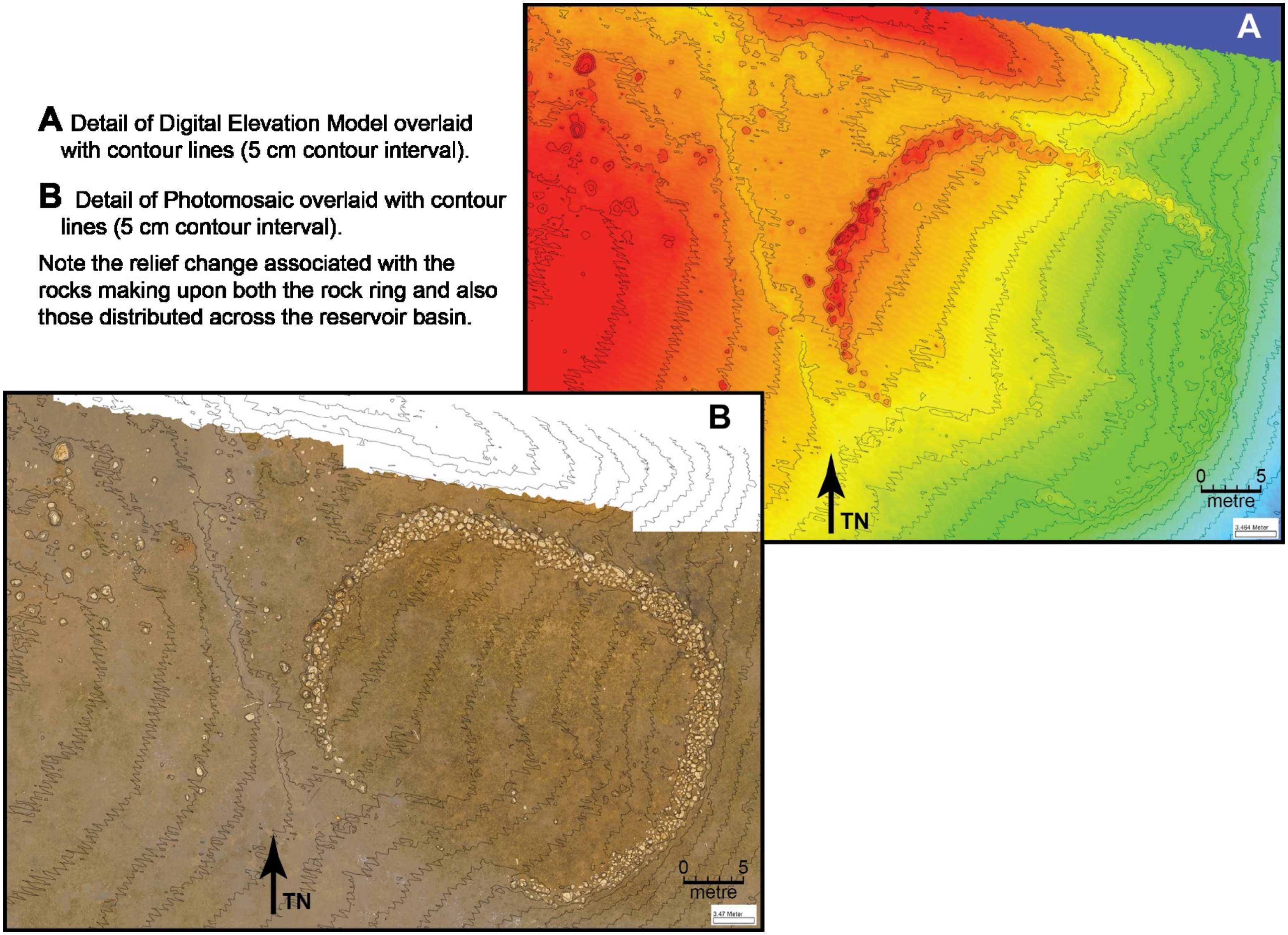


Figure 5.2.4.3. Elevation models of the rock circle and surrounding terrain with 5cm contour resolution (from Hamilton, 2017). Elevation data is relative and not tied to ASL.

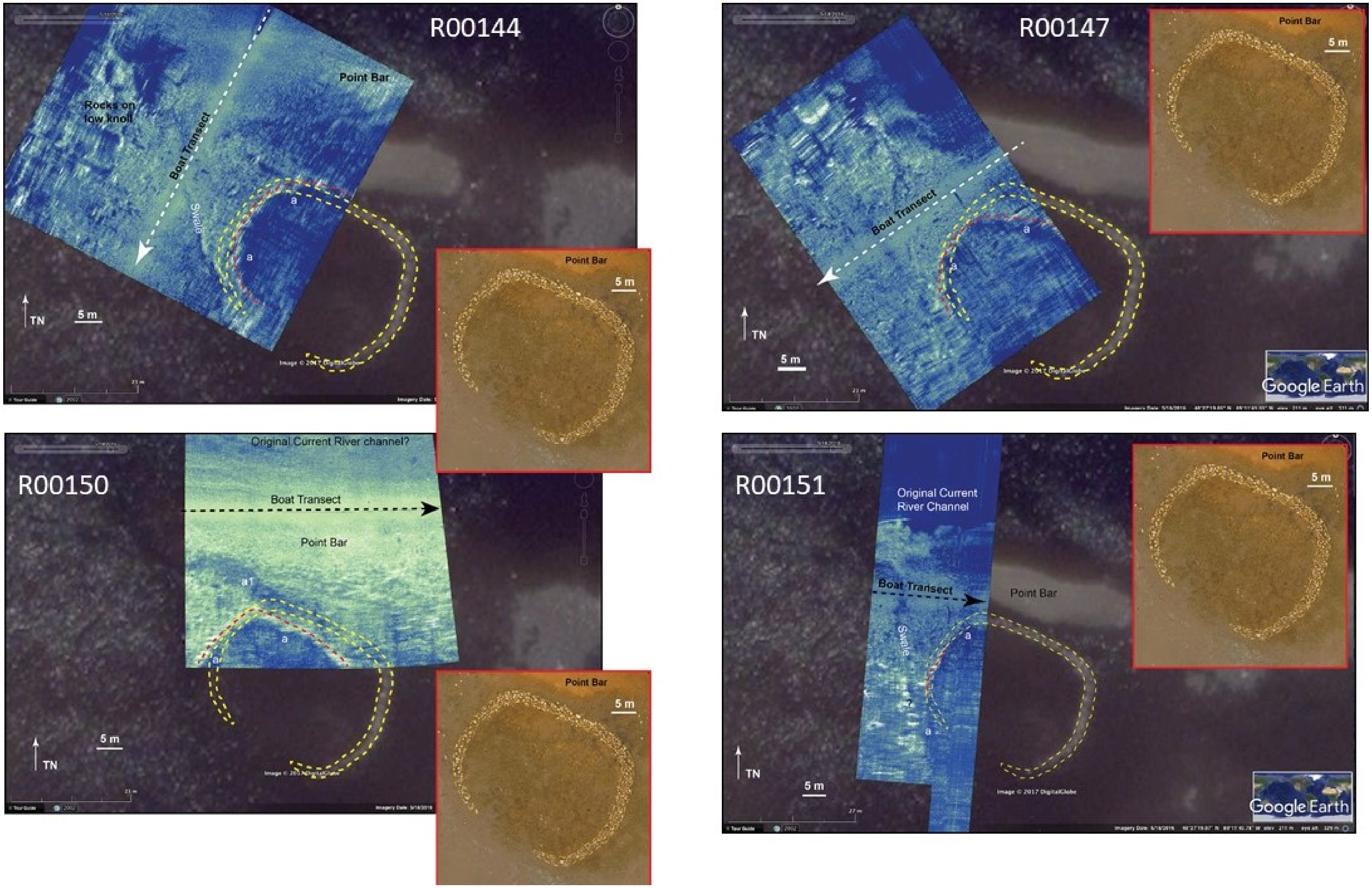


Figure 5.2.4.4. All four sonograms of the Boulevard Lake Rock Circle are compared to the drone imagery from Stephenson and Hamilton, 2016 (From Hamilton, 2017).

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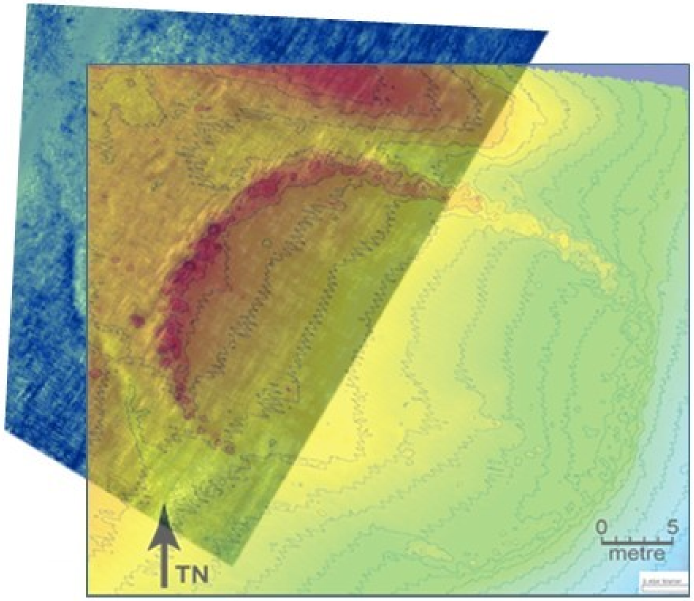
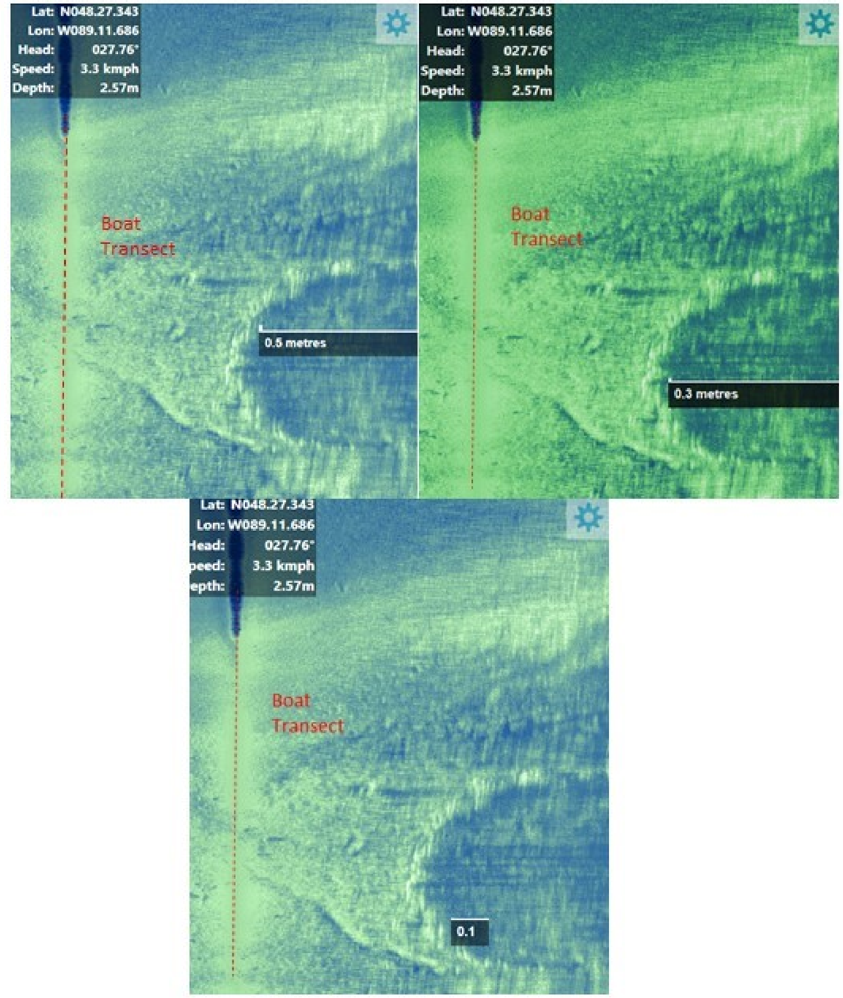




Top: 5cm contour DEM juxtaposed over sonogram R00144.

Right: Heights of the cobbles estimated by measuring the individual shadows.

Figure 5.2.4.5. Elevation data that reflects the size of the rocks that compose the Boulevard Lake Rock Circle.

5.3 Summary

The preliminary sonar investigations (validated by underwater inspection and coring operations) suggest that such a remote sensing approach offers an effective means of evaluating the condition of inundated surfaces containing archaeological deposits, even within active hydro-electric reservoirs. Results from the four case studies offered insight into the complexities associated with using consumer-grade sonar and programming for the acquisition of acoustic imaging and bathymetric data. Data was acquired with the user-friendly Humminbird 899ci HD SI sonar system, while ReefMaster provided an effective means of processing data that was accessible and easy to learn compared to other processing systems such ArcGIS. However, issues did arise as numerous artifacts (errors in depth measurement) appeared in most of the case studies. The Arrow Lake provided lessons how to accurately collect bathymetric data, and revealed that sufficient data points must be collected in order to effectively and accurately map the geomorphological feature (sand-bar). In all three of the other examples, discrepancies were observed between the down imaging and the calculated depth within ReefMaster's 'Sonar Viewer.' In some cases, where isolated data points were off by more than a meter, the information was considered as 'bad data' and edited or deleted. At the Hawk Bay Site, these discrepancies are likely associated with objects on the bottom that vary in size, shape, material, and depth, as any combination of these may distort the acoustic signal, and misrepresent the actual depth. Despite this issue, the representation of the geomorphological features at the Hawk Bay Site, when compared to satellite imagery, seemed to be representing true-to-life features. At the Portage Island Site, errors were observed just off of the eastern shore of the island. Analysis of the side scan sonar suggests that the depth errors were likely caused by the boat (and transducer) colliding with rocks and boulders, as the side imaging reveals multiple deformations in the same areas. The depths in such areas were less than 2 meters.

The use of consumer-grade sonar offered a practical and time-efficient method for documenting submerged archaeological landscapes in northwestern Ontario. Though there are issues with the image quality and resolution, the information gleaned from the case studies suggests that such remote-sensing approach offers an effective means of evaluating the condition of inundated archaeological deposits. The data gathered from the Hawk Bay site (DeJj-2), as well as the Portage Island site (Dejj-8), exhibit evidence that each site has been repeatedly eroded, with the sedimentary matrix of the near-shore zone being redeposited in deeper water. The bright surfaces (hard acoustic rebound) depicted in the sonograms reflect the cobble armour often found on the shores of hydroelectric reservoirs (Ward, 2013), where sediment that once surrounded the 'lag' is mechanically removed through wave action, and redeposited elsewhere (darker colours represent soft acoustic returns).

The Boulevard Lake Rock Circle provided an opportunity to test the side scan sonar in a scenario where a known object, of anthropogenic origin, could be evaluated. The case study proved, that in a real-world situation the Humminbird 899ci HD SI fishfinder could provide sufficient imaging for the documentation of inundated stone structures. Discrepancies in spatial accuracy were noticed in all three case studies, as the objects observed on the sonograms were displaced when compared to drone imaging. Further information is detailed in the following chapter.

Chapter 6

Discussion

6.0 Introduction

The results of the sonar survey and all the supporting tests show that the methodologies employed provided sufficient data for the preliminary documentation of submerged archaeological sites within northern Ontario lakes. Though there are some issues with depth accuracy in shallow water, the findings suggest that the Humminbird 899ci HD SI sonar system and ReefMaster processing software, are useful tools for shallow water documentation of inundated deposits, especially in areas that are confined, and cluttered with debris. In this chapter, the pros and cons of the sonar system and processing software will be examined to determine what issues could be addressed for future research. Also discussed in this chapter is a series of recommendations to address concerns, as well as and plans for future research.

6.1 Humminbird 899ci SDHD

The Hummingbird system provided a suitable method for acquiring depth measurements for the creation of bathymetric charts. The hull-mounted transducer demonstrated that a single eam echo sounder can acquire sufficient data along shallow water sites, where obstructions would impede a traditional towed array sonar in obtaining the necessary information. The case study at Boulevard Lake exemplifies the capabilities of using the Humminbird sonar system for SSS, as water levels were only 1.5m high. In waters greater than 1.5m deep, however, some discrepancies were observed in the bathymetric output and data points.

Depth Errors

Before one can address the discrepancies in depth determination a brief explanation of how single beam echo sounder works is first required. As discussed in Chapter 4, SBES's send a cone-shaped pulse of sound (ping) at a predetermined frequency that reflects off of the lakebed, whereupon the transducer detects the rebounding echo. To calculate depth, the sonar system utilizes a formula that takes into account the velocity of the sound in water, and travel time to provide a measurement (**Fig. 6.1.1.1**). Since a single beam echo sounder only distributes one 'ping,' only a single value is recorded from the footprint of the acoustic pulse.

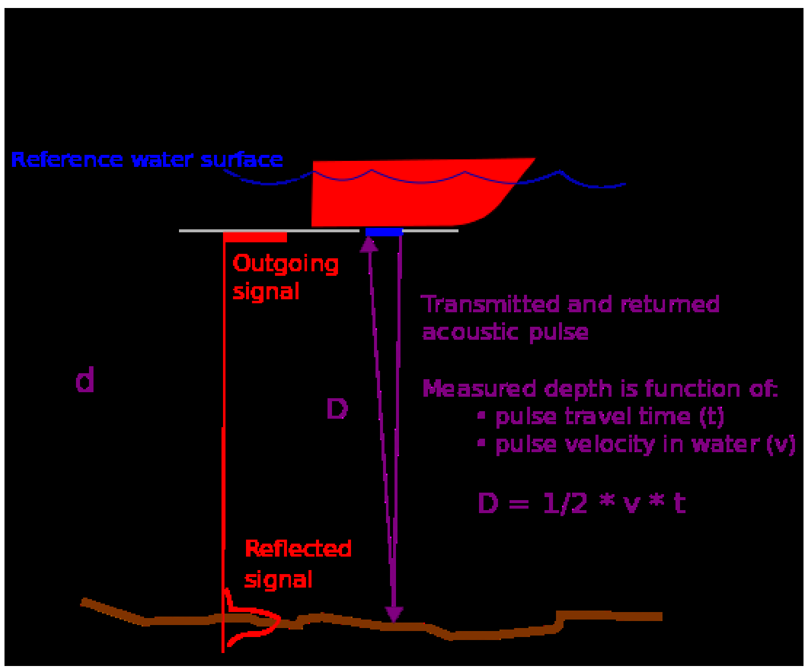


Figure 6.1.1.1. : Schematic of how depth is calculated using a single beam echo sounder (from Army Core of Engineers).

After the survey, data are imported into the processing software, where the sonar return (echogram) can be assessed. Figure 6.1.1.2**.** characterizes a typical sonar return (echogram) that provides multiple pieces of information. The first echo return (E1) represents the first acoustic rebound from the bottom, and it is here where the depth measurement is calculated. According to ReefMaster, the E1 can also provide a value of roughness of the lake bottom. As the name suggests, the second echo return (E2) represents the second rebound of the acoustic signal, where values of bottom hardness are given (ReefMaster Reference Manual, Ocean Ecology, 2015). The depth measurements, represented in ReefMaster as colorized dots, should fall along the same plane as the first echo return (E1).

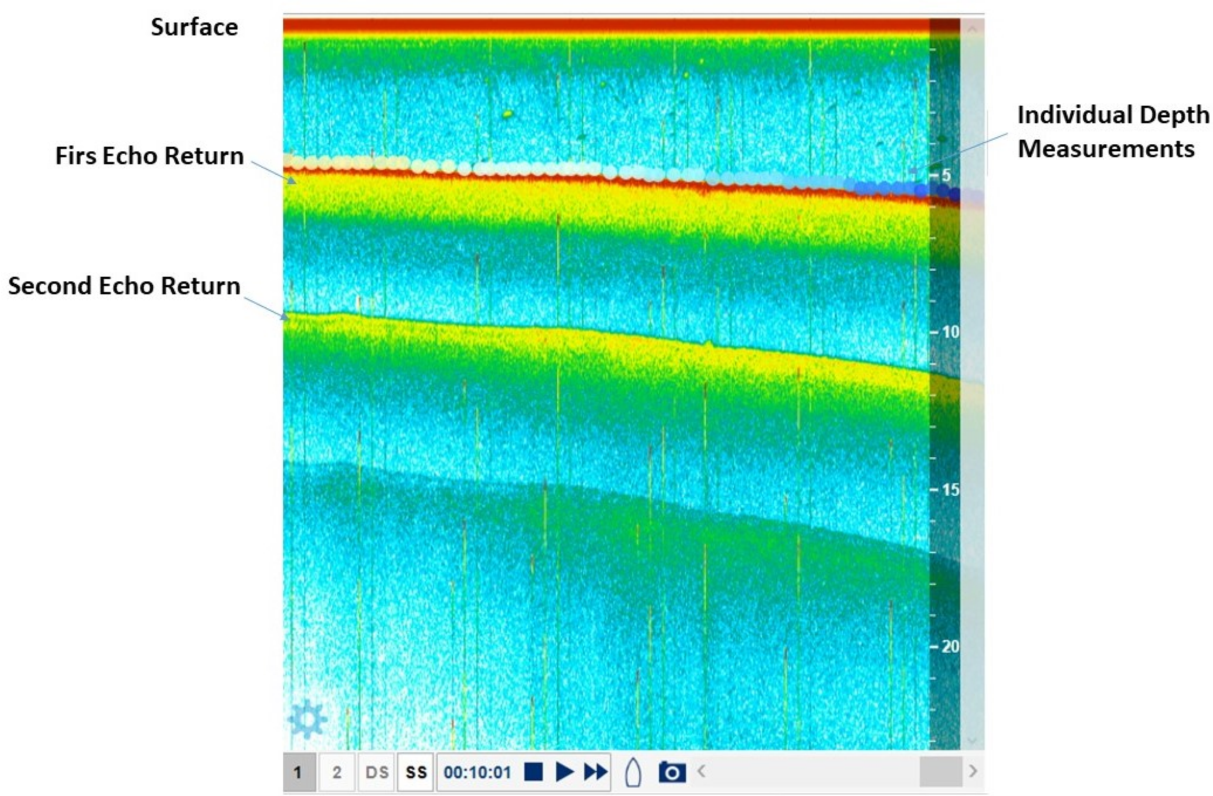


Figure 6.1.1.2. Schematic representing the different traits of an echogram.

Further assessment of the depth measurements along the near-shore zone of the Dog Lake case studies, however, reveal discrepancies between the *E1* return and the plotted depth measurements (**Fig.** 6.1.1.3.). Examination of the individual data points across the all the tracks revealed that such phenomenon occurred only in shallow waters (>1.5m), where objects of varying size, shape, and composition, may impact the acoustic return, and thus the accuracy of the depth measurements. Previous research by Sonnenbug and Boyce (2008), suggests that without the use of additional filters, vegetation can also impact the acoustic return. However, little to no vegetation was observed along the nearshore zone of Dog Lake.

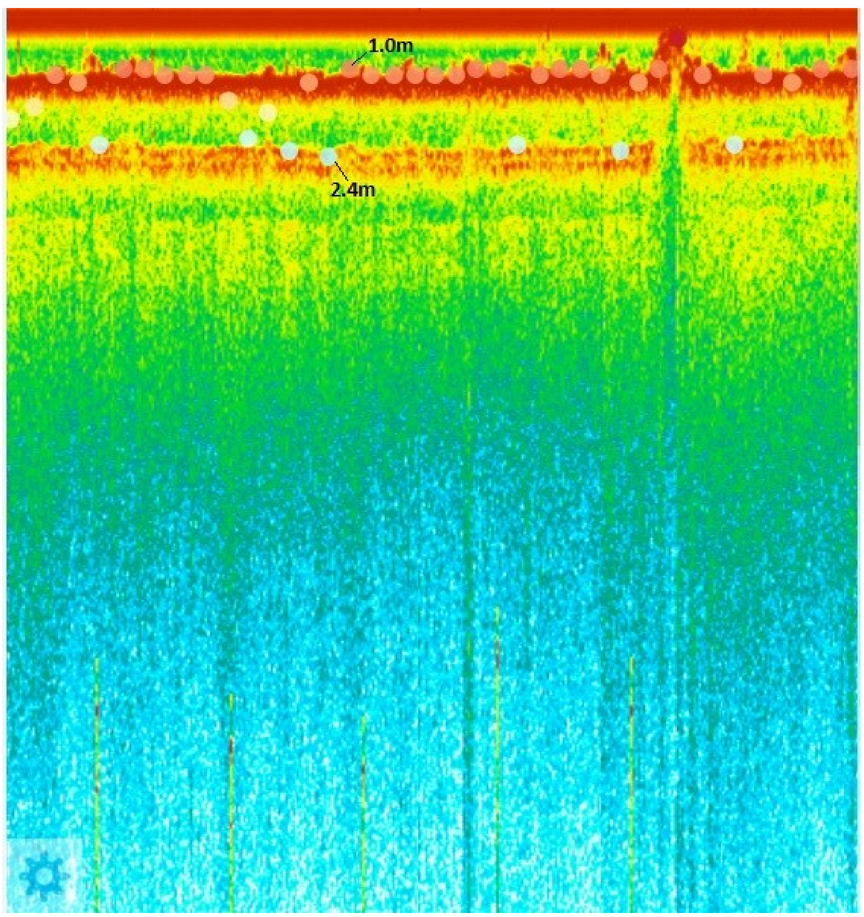


Figure 6.1.1.3. Echogram reflecting the errors in depth, as some of the data points are falling below the first echo return (E1).

The exact reason for the depth discrepancies observed in some of the SBES data is not entirely clear, as a combination of variabilities can impact the accuracy of acoustic depth measurement. According to Penrose et al. (2005) and Handley (2007), multiple factors (**Fig. 6.1.1.4**) can all increase the vertical and horizontal uncertainty of the acoustic measurements. Vessel motion is one of the most common factors as weather can easily impact a boat and its stability on the water. Increased wave action will result in the boat, and thus the transducer, changing elevations (above or beneath the wave) or swaying and rolling on its side (**Fig. 6.1.1.3, A**). The footprint (sonified area) of the acoustic pulse can also impact the accuracy of measurements, and increase the horizontal uncertainty (**Fig. 6.1.1.3, B**). With an acoustic pulse that is cone-shaped, the size of the footprint will increase with depth, which will also increase the area that is being measured. According to Handley (2007), "there is a difference between the recorded depth, which is a slant range to the nearest obstruction, and the true perpendicular depth over that point." The final factor that can lead to discrepancies in the data is the composition of the bottom (**Fig. 6.1.1.3, C**). According to Penrose *et al.,* (2005) and Handley (2007), the composition of any object on the bottom (hardness, size, shape, and angle) can impact how the acoustic signal returns to the transducer.

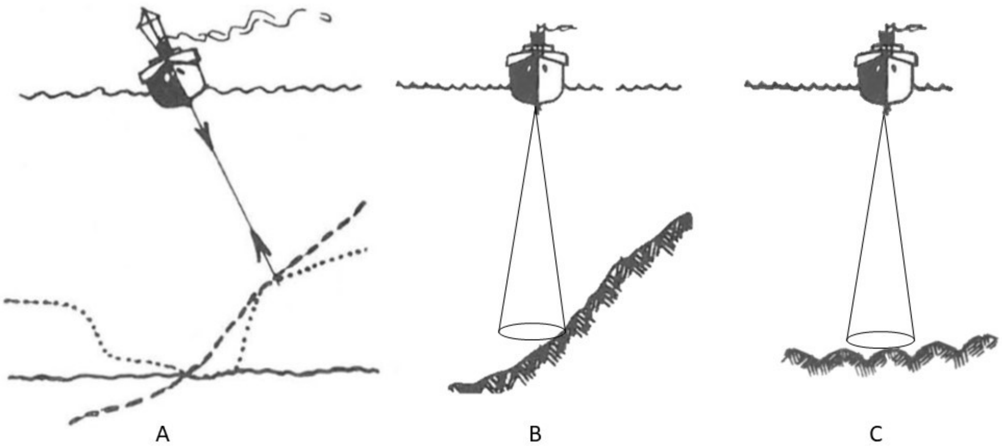


Figure 6.1.1.4. Common variables that can affect the vertical accuracy of a Single Beam Echo Sounder include: A) Vessel motion such as yaw, pitch and roll; B) Size of the acoustic footprint on a severe slope; C) The composition of the bottom (i.e. hardness, size, and shape) (after Honeywell Elac Brochure).

Discrepancies in depth measurement at the Hawk Bay site **(Fig. 6.1.1.5**.) likely created the digital artifacts being observed along the near-shore zone in the bathymetric output. Analysis of the side scan imaging confirms that the red spikes observed on the echogram (**Fig. 6.1.1.5**) are intense acoustic reflections off of cobble and rocks that define the shallow near-shore zone. Neither the motion of the vessel or the acoustic footprint of the sonar are likely attributed to the errors in depth. Instead, the lack of water depth over an area composed of rocky features likely overwhelmed the transducer, as little to no errors are observed in waters 1.5m >.

According to International Hydrological Organization errors in depth measurements (spikes and blunders) are typically removed before further analysis. However, the discrepancies at the Hawk Bay site do reflect genuine surfaces (see Chapter 5, **Fig. 5.1.2.2.**) and aren't considered as "bad data." Due to the anomalies reflection of real surfaces, no editing or removal of data points occurred for the final bathymetric chart.

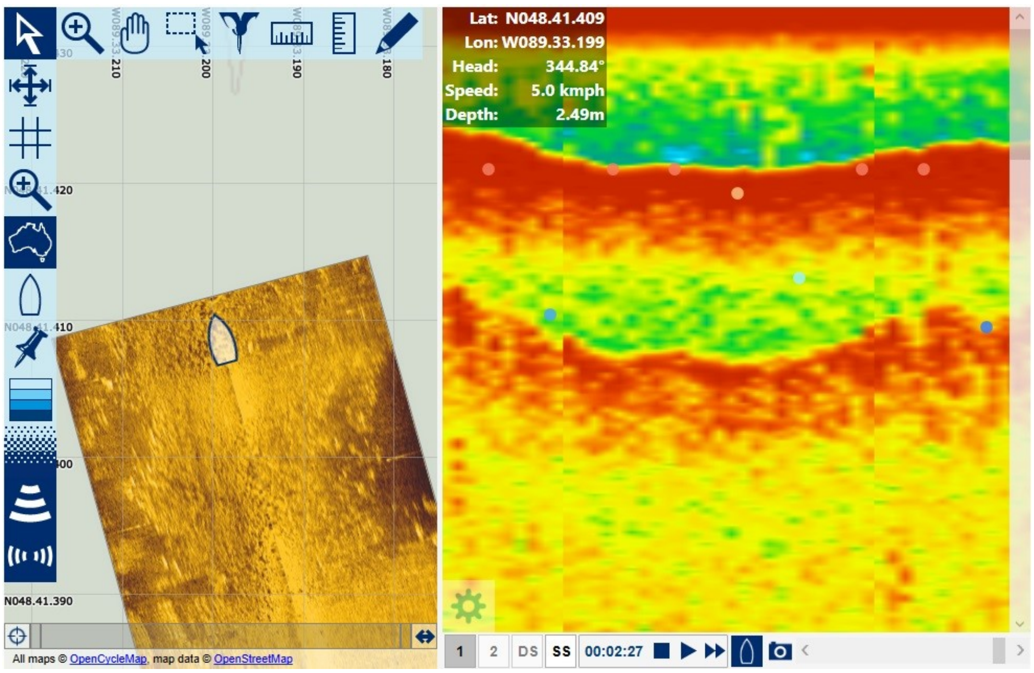


Figure 6.1.1.5. Right) Echogram of track R0091 shows that some of the depth returns are at odds with the bottom profile. Left) Side scan image (sonogram) of the R0091 track detecting the field of rocks and cobble below the transducer.

At the Portage Island site, analysis of the echogram in ReefMaster suggests that errors in depth measurement along the near-shore zone are likely associated with human error, as the examination of the side scan imaging reveal problems with data acquisition. Figure. 6.1.1.6 reflects two areas (A and B) where errors in depth measurement (3.8m and 5m respectively) coincide with anomalies observed on the side scan sonar. Notes recorded in a field book suggest that these 'anomalies' might have occurred when the watercraft made contact with objects on the bottom. As such, these particular data points were deleted from the survey, as they were caused by human error, and not reflect true to life geomorphic features.

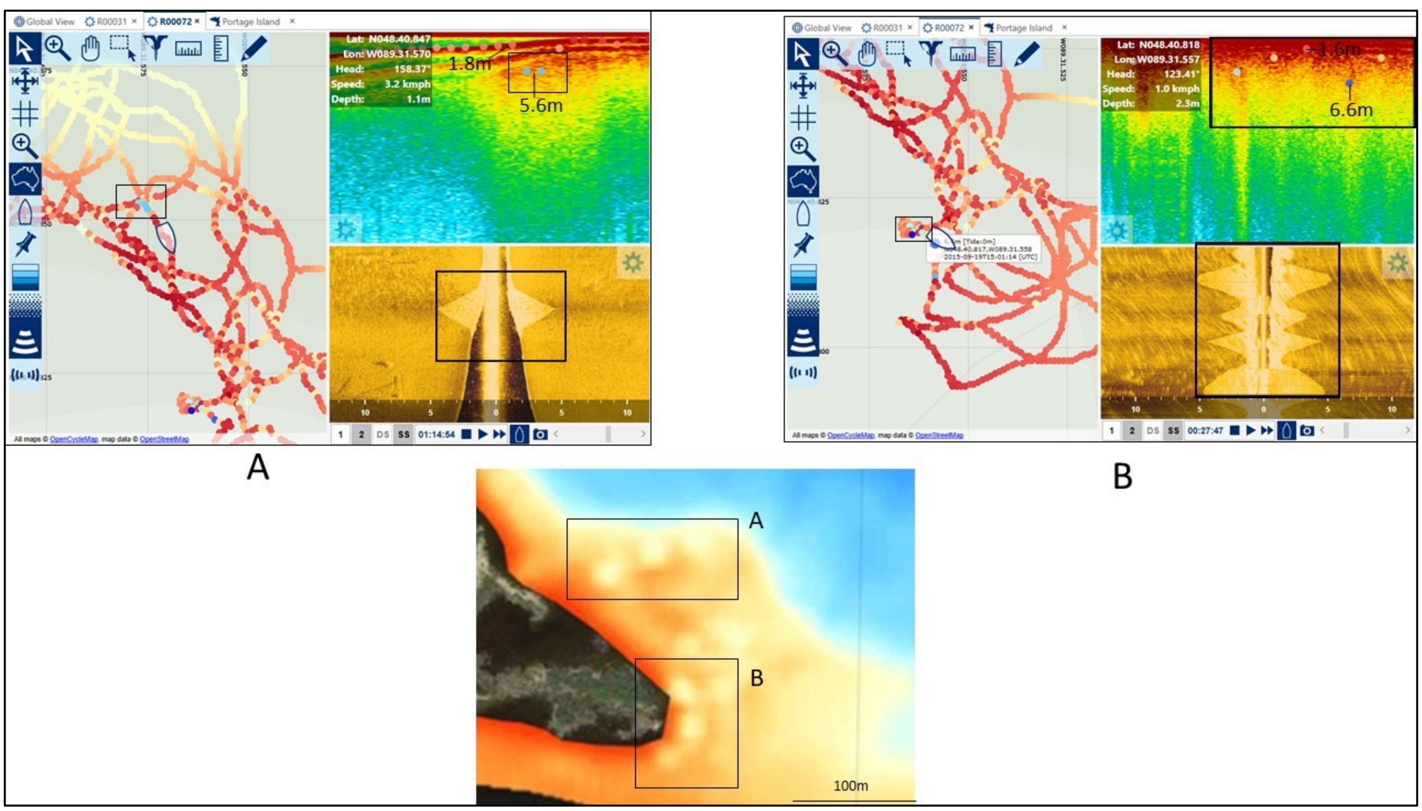


Figure 6.1.1.6. Anomalies in the bathymetric output (areas A and B) are compared to the sonograms taken from the same area. Evidence suggests human error caused the anomalies.

Side Scan Sonar

Similar to the SBES functions of the Humminbird sonar system, the accessibility of the SSS provided an excellent opportunity to acquire imaging of multiple sites within northern Ontario. Data gathered from the sites, however, can be improved as the resolution and spatial accuracy of the images lack the ability to differentiate between some objects. This is especially evident in the Boulevard Lake case study, where the SSS had difficulties distinguishing the boulders that made up the rock circle. According to multiple sources (Handley, 2007; Kearns and Breman), the acoustic reflectivity of a target (size, shape, the hardness of material, and orientation) can cause the sound waves to be irregular, which intern can create uncertainty in an acoustic image. Speed is a common factor that can also impact the quality and resolution of acoustic imaging. Though analysis of the Boulevard Lake rock circle shows that the vessel did not go over 4km/h, which is in the realm of acceptable speed for SSS, image quality still suffered. According to Fisher and Car (1990), there are multiple factors that affected the resolving power of a sonar system during surveys highlighted in this thesis. Two of the most common types of resolution are *Transverse Resolution* and *Range Resolution*.

Defined as the ability of the sonar to differentiate similar objects that sit in a line that is parallel to the transducer, *Transverse Resolution* is a function of a vessels speed, the horizontal beam, and the ping rate. *Range Resolution*, determined by the pulse length and the insonified footprint, is the minimum distance between two objects that are perpendicular to the line of travel. As Kaeser et al (2012) explain, “at a fixed frequency (e.g.455 kHz), increasing sonar ranges leads to decreasing transverse resolution due to horizontal beam spreading, an effect that is magnified in the far-field or near-edge portions of the sonar image”.

According to Cervenka *et al.,* (1993) multiple factors likely impact the spatial accuracy of the side scan imaging. According to their research, factors such as the geometry of the acoustic signal, performance of the processing, altitude and angle of the transducer, and vessel motion (yay, pitch, roll, and sway) can affect a sonars ability to accurately display objects off the bottom. To address these issues, a more complex study is required, as additional programs are required. Additionally, the location of the GPS, relative to the transducer, can also hinder the accuracy of a SSS, as the console that holds the GPS sits with the user in the middle of the boat (approximately 1.5m away). It is unclear what impact this has on the spatial accuracy of the side imaging, as ReefMaster does adjust for this in the Global Settings.

The Humminbird 899ci HD SI sonar system provided valuable information regarding the integrity and condition of the sites presented in the case studies. Precision and accuracy in both depth measurements and within the side imaging, however, do highlight that this device is still a consumer-grade system, and that title brings with it some flaws. To address some of the discrepancies caused by the unit, future research should experiment with an updated transducer. The transducer provided with the 899ci HD SI system (XNT 9 SI 180 T) is at this time, considered outdated. Consideration towards upgrading to the XHS 9 HDSI 180 T transom transducer should occur, as it provides an increase in kilohertz for the side scan sonar (Table 6.2). This, in theory, may provide an upgrade in the resolution and accuracy of the Hummingibrdt 899ci HD SI system.

Table 6.1.1. Comparison of the transducers available to purchase.

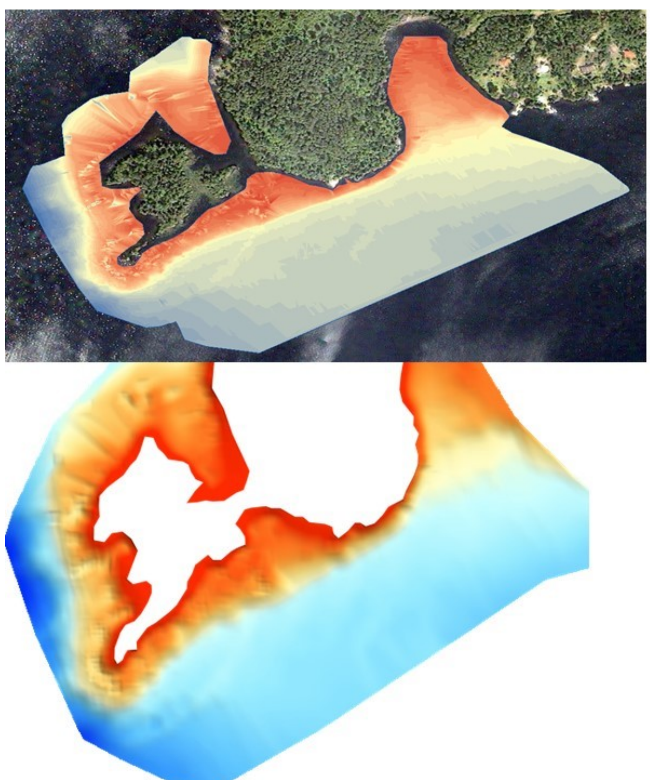
Sonar	XNT 9 SI 180 T	XHS 9 HDSI 180 T
Degree of Signal	20/60/180 Degree	20/60/180 Degree
Imaging Frequency	200/83/455	200/83/455/800

6.2 Software

The use of ‘entry-level’ software for the creation and analysis of the acoustic data (side scan images and bathymetry) allowed researchers the opportunity to interpret and learn about the complexities of such research. A recent publication by Buscombe (2017) however, emphasizes how important transparency is when utilizing software for scientific research, and that such automated programs like ReefMaster lack the ability to be freely adapted to a specific researchers needs. Even though a comparison between ReefMaster and ArcGIS showed that the bathymetric output generated similar charts (**Fig. 6.2.1**), the use of ReefMaster and Google Earth Pro did not allow for more complex analysis to occur. Editing tasks such as ‘*Slant Range Correction*’ (removal of the water column) and ‘*Automatic Gain Correction*’ (equalization of the signal to improve image quality) are available within ReefMaster, though the former is done automatically during the creation of the side scan mosaics. Further abilities such as ‘*Radiometric Corrections*,’ ‘*Georectification*,’ and the removal of acoustic shadows (Buscombe, 2017), are not possible utilizing the program, and as such, is limited in comparison to software like PyHume that has these capabilities. The creation of the side scan mosaic within ReefMaster is also a muddled process, as all the tracks used in the mosaic are simply placed on the screen in their spatially correct position. This requires the user to review each track and determine how they overlap, rather than the computer stitching them together as a “proper” mosaic.

The results show that ReefMaster produces bathymetric information that is spatially accurate, though there is a limit to the software’s resolution. As observed in Case Study 1 (Arrow Lake), the isoclines of a Vector interpolated map have a maximum resolution of 12.5cm. This means that any feature, of anthropogenic or natural origin, won’t be reflected in the interpolation.

Popular GIS programs such as ArcGIS and QGIS do provide users with the ability to draw-out further details, as the resolution capabilities of such programs are nearly unlimited. A comparison between the bathymetric output (**Fig. 6.1.3.1**) does suggest, however, that ReefMaster can generate a similar output to that of ArcGIS, as each captured and displayed the anomalies found along the near-shore zone. This, however, might also reflect the use of TINs (Triangular Irregular Network) to interpolate the data, as this form of algorithm seems to exaggerate the size and shape of artifacts (McGrath *et al.,* 2007). The use of more sophisticated software, such as ArcGIS, will allow for other forms of elevation mapping to be used. Digital Elevation Models (rather than a TIN) can be employed using interpolation techniques such as Inverse Distance Weighting (IDW), Kriging, or Spline to estimate the elevation values with minimal errors (Chang, 2012).



A: ArcGIS

B: ReefMaster

Figure 6.2.1. Comparison of the ArcGIS and ReefMaster bathymetric rendering of the Hawk Bay site.

The use of Google Earth Pro to display and assess the charts also came at a cost. Other than placing each form of output in its spatially accurate location, Google Earth Pro does not provide any other form of analysis to the bathymetric data or side scan mosaics. Programs such as ArcGIS for instance, have multiple investiture tools that may extrapolate further information, such as statistical analysis.

6.3 Future Research

6.3.1 Lake Superior

In 2011 and 2012, archaeological and paleoenvironmental investigations took place along a submerged landscape known as the Alpena-Amberley Ridge. Located beneath the surface of modern-day Lake Huron (Fig. 6.2), the Alpena-Amberley Ridge is associated with the Lake Stanley low stand event, where water levels approximately 10-8ka were much lower (over 100m) than modern times do to deglaciation events (Sonnenburg and O'Shea, 2016). With a multidisciplinary approach, researchers were able to examine multiple archaeological sites, including the 'Funnel Drive structure,' and determined they were likely associated with seasonal hunting structures of the Late Paleo-Indian or Early Archaic periods (O'Shea *et al*., 2013).

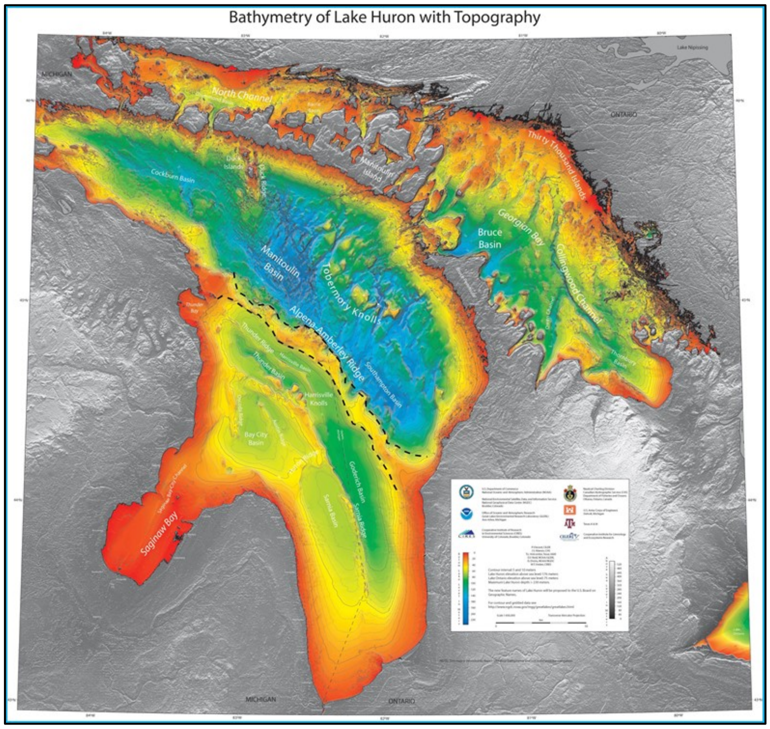


Figure 6.3.1.1. Bathymetry of Lake Huron (from National Geographic).

At ~9,000 cal BP, the Lake Superior basin was experiencing low-water levels caused by a reduced hydrological budget. Known as the Houghton phase, this low stand event coincides with the diversion of glacial Lake Agassiz into the Hudson Bay lowlands during the early Holocene (Farrand and Drexler, 1985; Boyd *et a*l., 2010). With the water levels dropping to approximately 600 feet (182.88m) ASL, some of the shorelines that weren't affected by differential isostatic rebound may be submerged beneath modern Lake Superior levels (Hamilton, 1996). Some have hinted in the past that the drowned beaches of the Houghton Low would have been attractive to the early Archaic people, which explains the rarity of early Archaic sites throughout the Lake Superior basin (Mason, 1981).

In the 1970's, William Fox received a series of copper gaffs (fish hooks) from local fisherman that were likely retrieved just offshore from either the Black Bay or Sibley Peninsulas (per comms, Fox, 2017). It has been speculated by Fox, whether such finds might represent early Archaic deposits similar to what was discovered along the Alpena-Amberly Ridge in Lake Huron. To address the finds that may have been recovered off a series of islands along the southern end of the Black Bay and Sibley Peninsulas, a research question is proposed: The hypothesis, can consumer-grade sonar (both SBES and SSS), with its capabilities in shallow and confined waters, be used to map, document and record potential Houghton beaches and associated archaeological deposits on Lake Superior?

6.3.2 Future archaeological examination of DeJj-2 and DeJj-8

The underwater documentation and analysis at Dog Lake provided only a glimpse into the site history of each case study. To further address how erosion has impacted and displaced the sites, additional research is required. For one, cores obtained from both DeJj-2 and DeJj-8 did have some organics and soils found below layers of surface sediment. To address whether these subsurface soils and organics are representative of the pre-inundated terrestrial shoreline, a more comprehensive coring strategy is recommended. The use of a bucket auger and russion corer resulted in extractions where sediment fell out during removal. For the removal of the sediments observed at Dog Lake, a vibracore may be required. If additional subsurface organics are encountered, radiocarbon dating may be used to further address the existence of a pre-inundated shoreline.

6.4 Cost

With the objective of this thesis being focused on cost-effectiveness, it is essential to detail the number of funds used in this project. The total cost of the project can be found below in Table 6.3. Not included in the analysis are the human resources utilized during this project as the amount can very from project to project. These resources include gas money and travel time to and from the case studies, boat operation fees, post-processing of data, and research and fieldwork employed. Other items not accounted for in the budget include coring devices, survey equipment such as flagging tape and poles, and boat costs as this is equipment is already owned by Dr. Scott Hamilton. or the Department of Anthropology.

6.4.1 Hardware

To some, the use of a $1,200 sonar system and transducer set might seem lavish and quite expensive. However, when compared to large-scale acoustic surveys, having a budget that is less than $10,000 is advantageous to small research facilities with a minimum budget and funding. Though most projects do not make their budgets available to the public, sonar system that can provide both bathymetric measurements and side imaging can cost anywhere between tens of thousands to millions of dollars.

Other important equipment includes the boat utilized in this study, the outboard motor, and the use of a Garmin GPS. Multiple cameras were used in this study, including a GoPro Hero 3

(Black) for underwater documentation, as well as a Nikon PowerShot for surface photos. These cameras are now standard issues in any field study across multiple disciplines.

The drone (DJI Phantom 3 Pro) is a standard consumer-grade UAV that is available to most people. The Pro model does, however, cost a bit more than the base model. Not tallied in the cost of the drone is the various 'extras' need for this kind of project. Items such as filters, batteries, and better propellers can easily add to a budget.

6.4.2 Software

Though there are more accurate and sufficient processing and mapping systems available, like ArcGIS, most of these programs cost too much for small programs or independent researchers, as such programs outside an academic institution can exceed thirty-thousand dollars. ReefMaster was purchased for $250 to provide multiple functions. 1) it was used to assess depth profiles for the bathymetric output; 2) generate bathymetric charts; 3) assess and create side scan mosaics from collected from the case studies. Issues did arise with ReefMaster's accuracy and resolution (mentioned above), however it did prove to be an inexpensive and reliable alternative.

Google Earth Pro was used to present and assess the information for this project. Bathymetric maps, coring data and picture, UAV imagery, and side scan mosaics were imported into the program to spatially compare one another. Like the regular version of Google Earth, Google Earth Pro is free.

6.4.3 Transportation

Boat fuel and maintenance were purchased by Dr. Hamilton (thesis adviser), for this thesis. To compensate him for his generosity, the author of this thesis volunteered on various archaeological and projects.

Table 6.4.1. Project budget.

Hardware	Manufacturer	Model	Cost	Note
Fish finder Transducer	Humminbird Humminbird	899ci HD SI XNT 9 SI 180 T	$1,200 Included	
GPS	Garmin	64S	$300	
Camera	Pentax	Optio Wg-2	$400	
Boat Motor	Crestliner	16 foot Sportsmans	$4,500	
Drone	DJI	Phantom 3 Advanced	$1,300	
SUBTOTAL			*$7,700*	
SOFTWARE				
Sonar Processing	ReefMaster	ReefMaster Pro	$250	
Spatial Analysis	Google Earth	Google Earth Pro	Free	
SUBTOTAL			*$250*	
TRANSPORTATION				
Boat Fuel			$500	
SUBTOTAL			$500	

PROJECT COSTS	Cost
HARDWARE	$7,700
Software	$250
Transportation	$700
TOTAL	***$8,650***

6.4.4 Cost-Effective?

With a budget of $8,650, one could speculate at how effective these consumer-grade methods were in acquiring, analyzing, and presenting data of archaeological interest. For a fraction of what a traditional "towed array" sonar would cost (anywhere between $15,000 to $100,000 and beyond) the Humminbird 899CI HD SI fish finder ($1,200) provided researchers with data that is adequate enough for finding, documenting, and monitoring archaeological deposits. Similarly, the use of consumer software provided an inexpensive option for the creation of multiple forms of output that can be used to assess areas of interest.

To answer the question, "is the use of these consumer-grade equipment and software cost-effective"? Based on of this thesis, and other research projects like it, the answer is yes. Though there are some issues that reflect how inexpensive the equipment is, the use of such "cheap" methods provides an opportunity for researchers with a limited budget, to conduct underwater studies of any kind.

Chapter 7
Conclusion

Fluctuating water levels caused by anthropogenic development, have made archaeological investigations in northwestern Ontario challenging. With the inability to access culturally significant sites during the primary field season (summer), as water levels are at their highest, archaeological sites are left to the elements where they are eroded and displaced from their primary (*in situ*) context. To confront this issue, researchers have sought diverse ways to collect information from inundated landscapes. Traditionally, such investigations require the use of non-invasive marine archaeological techniques to survey the drowned archaeological deposits. As stated in this thesis and in other studies (Quinn *et al.*, 2000; Westley *et al*., 2010; Westley and McNeary, 2016), conventional methods for attaining and processing sonar data (either bathymetric of imaging) requires the use of expensive equipment that is clumsy to use in restricted shallow bodies of water.

In the case studies presented in this thesis, four sites (three archaeological) were examined using a hull-mounted consumer-grade sonar system, and cost-effective processing software, to acquire and present both depth measurements and acoustic images. The aim of this research allowed potential insights into the pros and cons of sonar surveys in shallow and restricted environments.

The collection of bathymetric data for the creation of accurate elevation models was used across three case studies around the Thunder Bay area. In three tests, the Humminbird© sonar system adequately collected depth measurements that were later interpolated with the ReefMaster© processing system. Bathymetric charts in all three cases revealed subtle elevation changes that reflect the geomorphological features at each site. Despite these findings, an early examination of the data revealed a series of discrepancies in the depth accuracy of a small portion of the depth measurements. Multiple data points were removed from each case study, as depths were inconsistent with the first echo return (image representation of depth). Though the acquisition of false data is not new to these kinds of surveys, it is apparent that Humminbird 899cii HDSD sonar system is susceptible to such inaccuracies. The solution to this dilemma is twofold. First researchers must collect the data as slowly, and meticulously as possible, to ensure that distortions caused by boat movement, and human error are eliminated. Second, evaluation of the data for errors must occur as soon as possible, so that any discrepancies can be fixed and recollected as soon as possible.

In the case studies where acoustic imaging was used, the side scan sonar (validated by underwater inspection) successfully characterized the lake bottom and some of its features. Areas of hardness versus soft were easily distinguishable on the side scan sonar, while more detailed features, such as rocks and logs, were challenging to capture with the acoustic image. This was never more apparent than at the two case studies at Dog Lake, where weather, signal frequency, human error, and the angle of attack limited the sonar in capturing high-resolution imagery.

This is caused by various types of distortions that can plague an acoustic survey. Limitations in the resolution are often associated with one or many factors. These include the speed of the boat, the ping rate used, and the beam spread relative to the position of the boat.

The use of consumer-grade sonar and processing programs highlighted the many challenges underwater archaeologists face when implementing these kinds of methods. On the one hand, the use of cost-effective methods provides researchers with an affordable and accessible means to acquire information from a submerged site. While on the other hand, these affordable methods come at a slight cost to accuracy and resolution.

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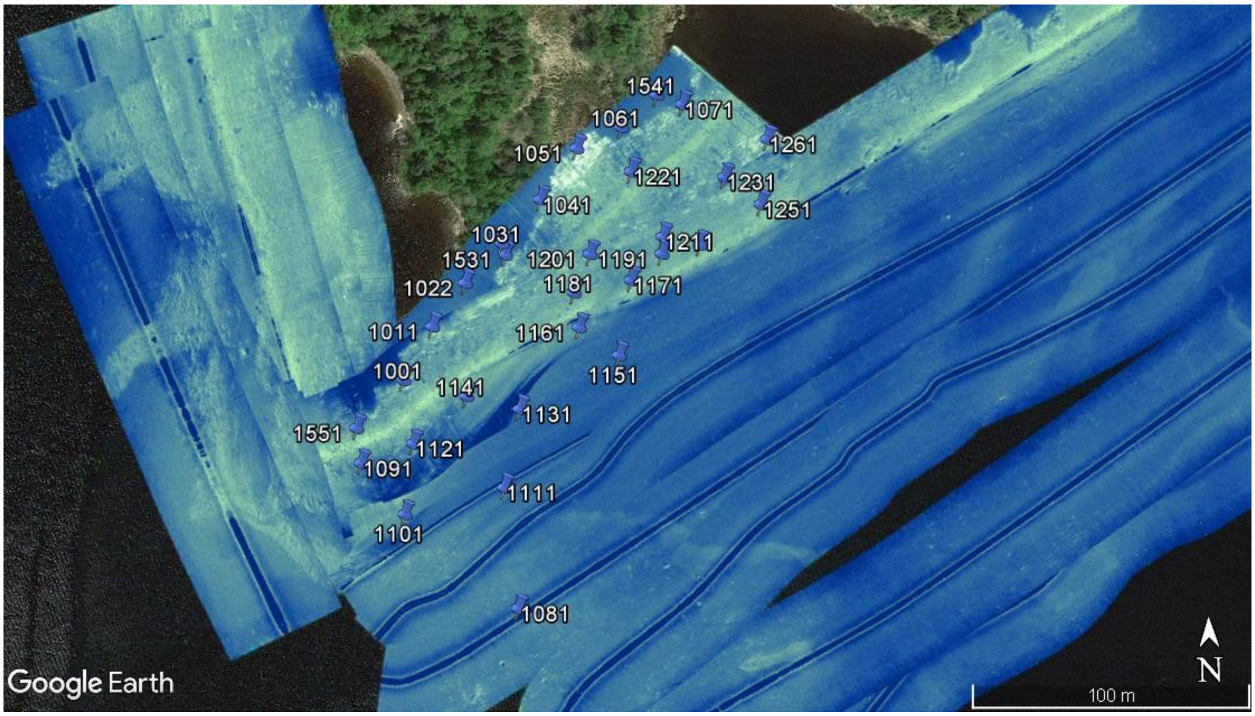
Appendix A: Figures and Tables



Tope: Fig. A 1. Map showing the geo-tagged points of interest during the underwater (SCUBA) survey at the Hawk Bay Site.

Baseline at the Hawk Bay Site

Assigned #	**1551**	**1001**	**1011**	**1022**	**1031**	**1041**	**1051**	**1061**	**1071**
Lat	48.68881138	48.689009	48.68918	48.68932	48.68944	48.68958	48.68974	48.68981	48.68987
Long	-89.552826	-89.5525	-89.5524	-89.5522	-89.552	-89.5518	-89.5516	-89.5514	-89.5511
Description	Rocky Foreshore	Rocky Foreshore with Reeds	Rocky Fore-Shore	Reedy Foreshore	Reedy Foreshore	Reedy Foreshore	Reedy Foreshore	Reedy Foreshore	Reedy Foreshore
Image #	1,2	N/A	N/A	4	N/A	N/A	N/A	5	N/A

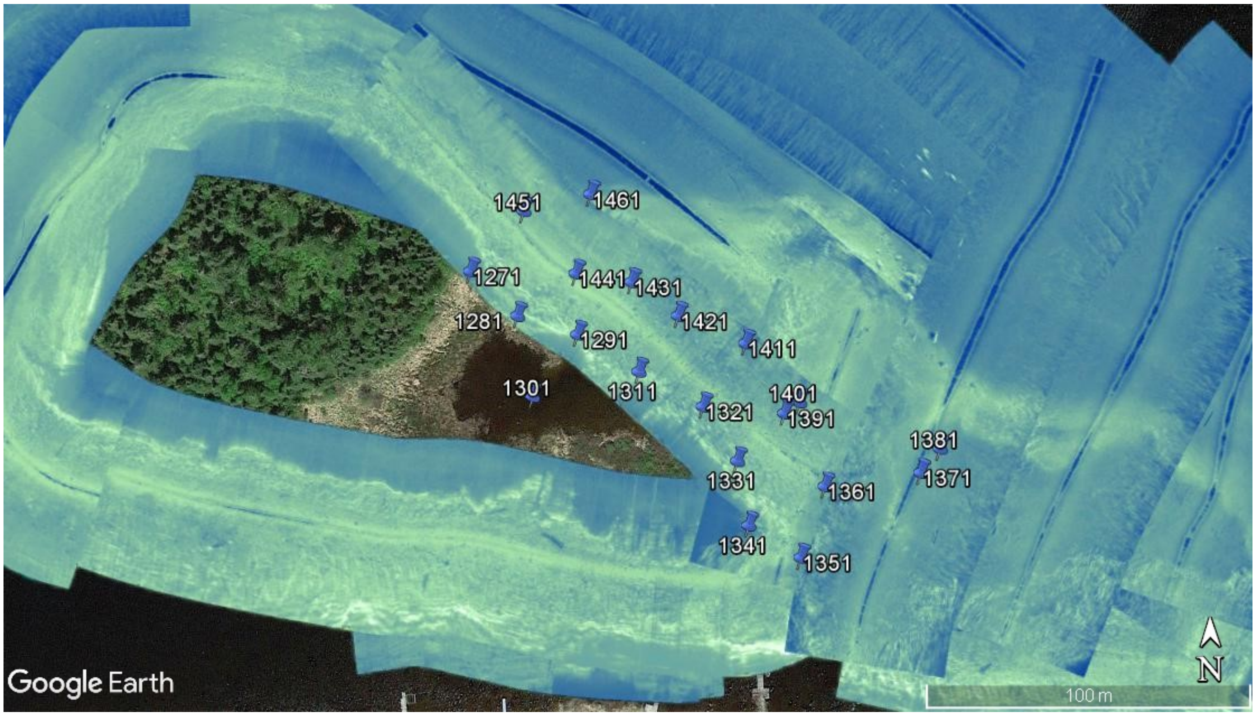
Features Found

Assigned #	**1081**	**1091**	**1101**	**1111**	**1121**	**1131**	**1141**	**1151**	**1161**	**1171**
Lat	48.68826	48.68874	48.68857	48.68865	48.6888	48.6889	48.68895	48.68907	48.689161	48.68931
Long	-89.552	-89.5527	-89.5525	-89.552	-89.5525	-89.552	-89.5522	-89.5515	-89.5517	-89.5514
Observations	Silt and Clay Bottom	Large Quartz and Taconite Flakes	Boundary Between Cobble and Silt/Clay Bottom	Boat Position	Organics Amongst Rocky Bottom	Boat Position	Cobble Bottom Boundary	Boat Position	Boundary Between Cobble and Silts/Clays	Boat Position
Depth	5 m	1.1 m	2.9 m	4.3 m	2 m	3.7 m	1.2 m	4 m	2 m	2.2 m
Image #	N/A	7, 8	9	N/A	10	N/A	N/A	N/A	11	N/A

Features Found (cont'd)

Assigned #	**1181**	**1191**	**1201**	**1211**	**1221**	**1231**	**1241**	**1251**	**1261**
Lat	48.68927	48.68939	48.6894	48.68945	48.68966	48.68963	48.68942	48.68954	48.68975
Long	-89.5517	-89.5512	-89.5516	-89.5512	-89.5514	-89.5509	-89.551	-89.5507	-89.5507
Observations	Boulders Surrounded by Silts/Clays	Boat Position	Potential Quartz Flake	Boat Position	Organic Sediment Boundry	Boat Position	Cobble Bottom	Boat Position	Exposed Bedrock
Depth	1.4 m	2.2 m	1.5 m	1.8 m	1.5 m	1.0 m		1.8 m	1.5 m
Image #	12	N/A	N/A	N/A	N/A	N/A	13	N/A	N/A

Left: Table A 1. Data gathered during the underwater (SCUBA) survey at the Hawk Bay Site.



Baseline at the Hawk Bay Site

Assigned #	**1551**	**1001**	**1011**	**1022**	**1031**	**1041**	**1051**	**1061**	**1071**
Lat	48.6888113 8	48.689009	48.68918	48.68932	48.68944	48.68958	48.68974	48.68981	48.68987
Long	-89.552826	-89.5525	-89.5524	-89.5522	-89.552	-89.5518	-89.5516	-89.5514	-89.5511
Description	Rocky Foreshore	Rocky Foreshore with Reeds	Rocky Fore-Shore	Reedy Foreshore	Reedy Foreshore	Reedy Foreshore	Reedy Foreshore	Reedy Foreshore	Reedy Foreshore
Image #	1,2	N/A	N/A	4	N/A	N/A	N/A	5	N/A

Features Found

Assigned #	**1081**	**1091**	**1101**	**1111**	**1121**	**1131**	**1141**	**1151**	**1161**	**1171**
Lat	48.68826	48.68874	48.68857	48.68865	48.6888	48.6889	48.68895	48.68907	48.689161	48.68931
Long	-89.552	-89.5527	-89.5525	-89.552	-89.5525	-89.552	-89.5522	-89.5515	-89.5517	-89.5514
Observations	Silt and Clay Bottom	Large Quartz and Taconite Flakes	Boundary Between Cobble and Silt/Clay Bottom	Boat Position	Organics Amongst Rocky Bottom	Boat Position	Cobble Bottom Boundary	Boat Position	Boundary Between Cobble and Silts/Clays	Boat Position
Depth	5 m	1.1 m	2.9 m	4.3 m	2 m	3.7 m	1.2 m	4 m	2 m	2.2 m
Image #	N/A	7, 8	9	N/A	10	N/A	N/A	N/A	11	N/A

Features Found (cont'd)

Assigned #	**1181**	**1191**	**1201**	**1211**	**1221**	**1231**	**1241**	**1251**	**1261**
Lat	48.68927	48.68939	48.6894	48.68945	48.68966	48.68963	48.68942	48.68954	48.68975
Long	-89.5517	-89.5512	-89.5516	-89.5512	-89.5514	-89.5509	-89.551	-89.5507	-89.5507
Observations	Boulders Surrounded by Silts/Clays	Boat Position	Potential Quartz Flake	Boat Position	Organic Sediment Boundry	Boat Position	Cobble Bottom	Boat Position	Exposed Bedrock
Depth	1.4 m	2.2 m	1.5 m	1.8 m	1.5 m	1.0 m		1.8 m	1.5 m
Image #	12	N/A	N/A	N/A	N/A	N/A	13	N/A	N/A

Tope: Fig. A 1. Map showing the points of interest during the underwater (SCUBA) survey at the Portage Island Site. .

Bottom: Table A 1. Data gathered during the underwater (SCUBA) survey. At the Portage Island Site.

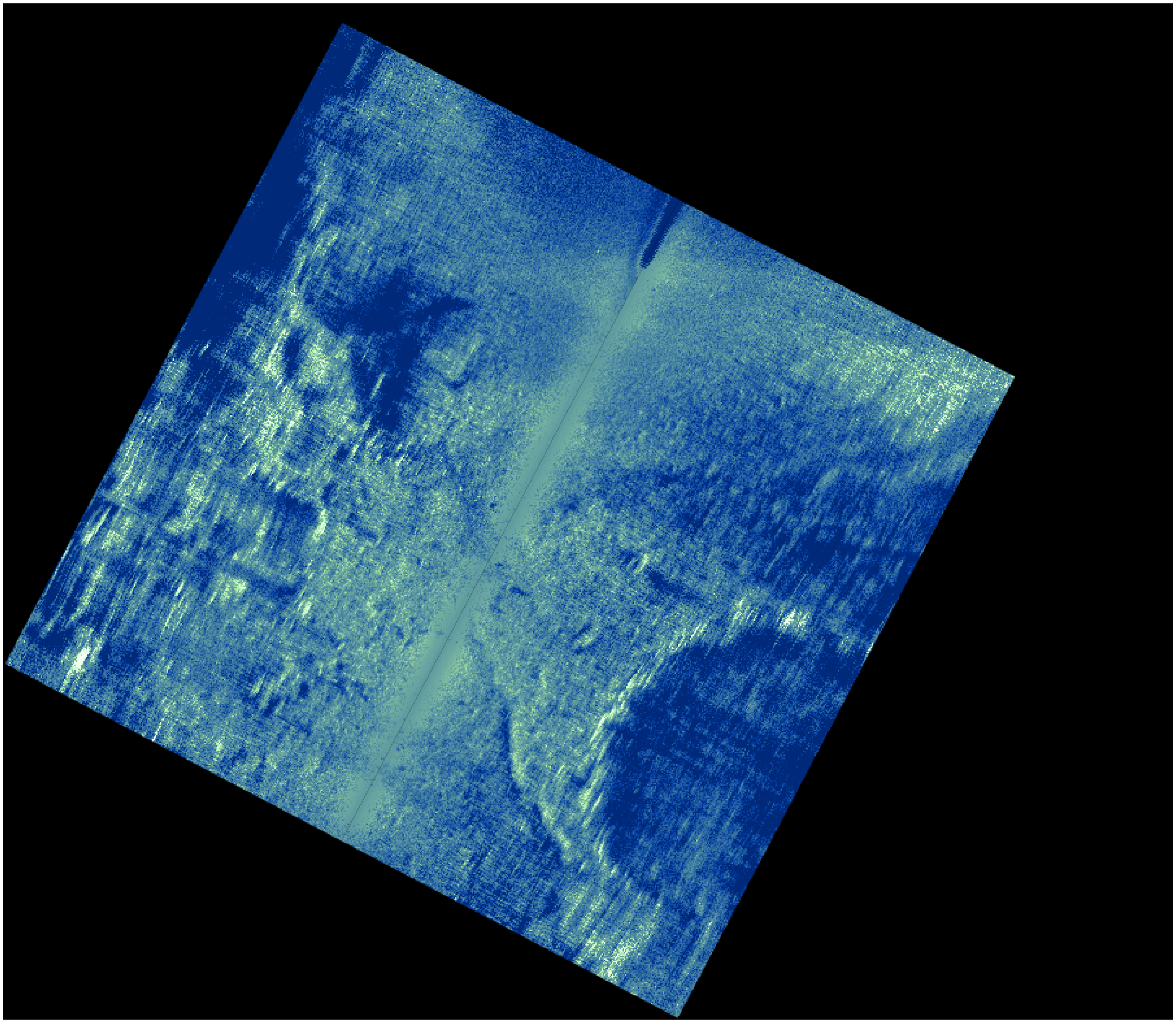


Figure A3: Sonogram R00144 of the Boulevard Lake Rock Circle

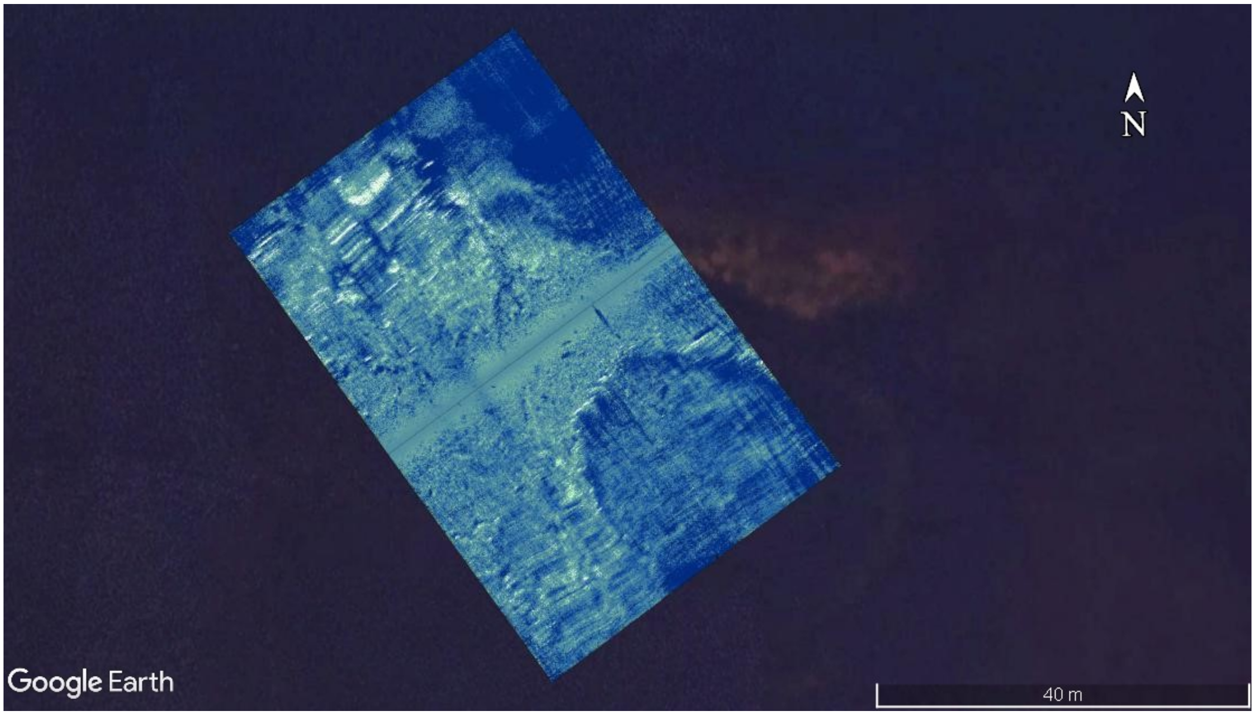
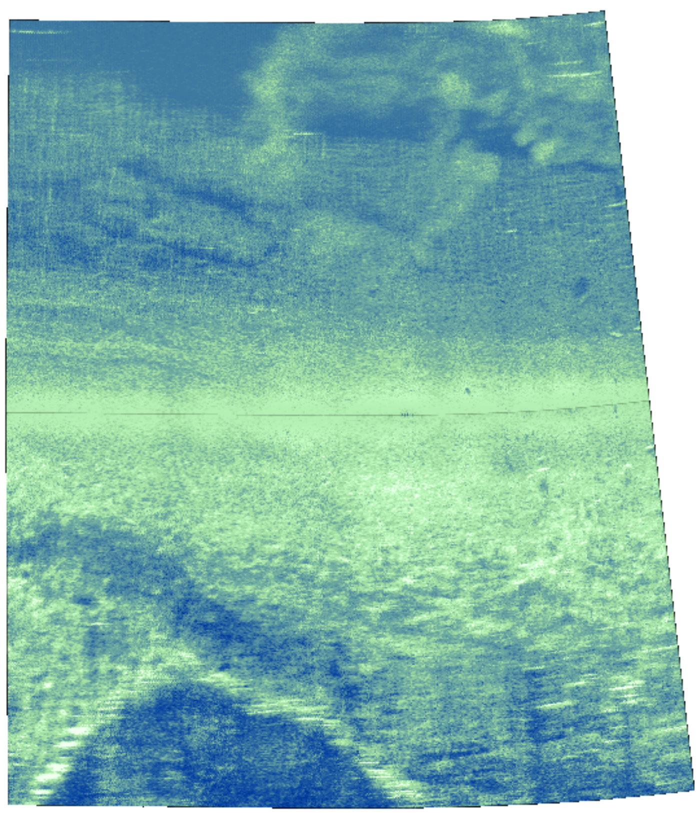


Figure A4: Sonogram R00147 of the Boulevard Lake Rock Circle

Figure A5: Sonogram R00 150 of the Boulevard Lake Rock Circle



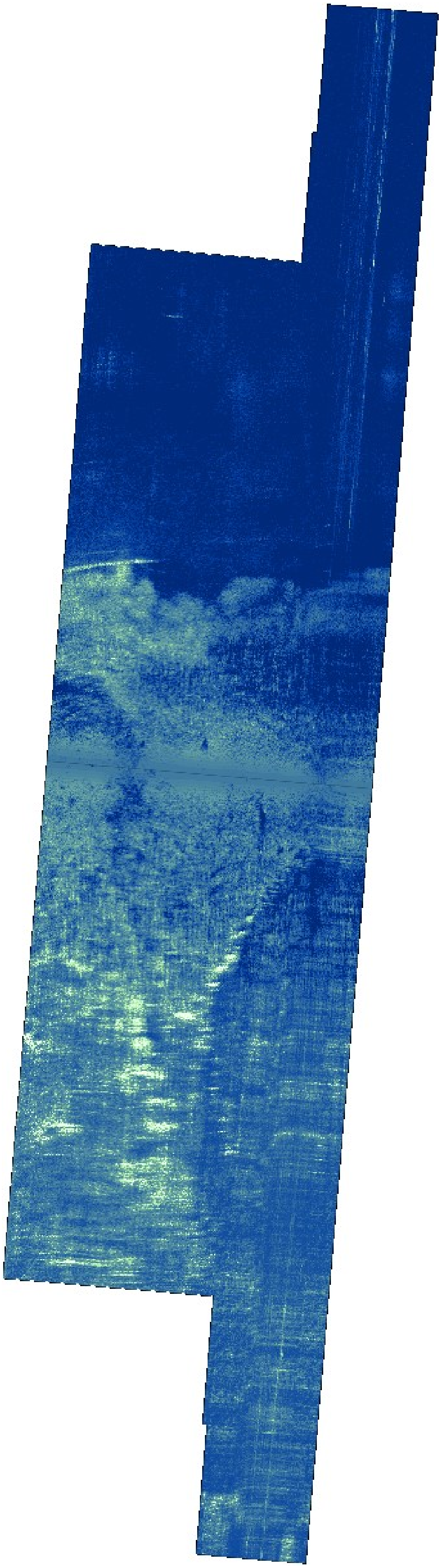


Figure A6: Sonogram R00151 of the Boulevard Lake Rock Circle

Appendix: B Images

Image 1: Photograph taken of the rocky point that comprises the Hawk Bay Site (DeJj-2). Photograph taken at the 1551 (Fig .A1 and Table A 1) location, facing north.

Image 2: Photograph taken of the cobble and rocky point that comprises the Hawk Bay Site (DeJj-2). Photograph taken at the 1551 location, facing northeast.

Image 3: Large erratic found at the Hawk Bay Site. Photograph taken facing northwest.

Image 4: The shoreline of the Hawk Bay Site is dominated by reeds and cattails. Photograph taken at 1022 location, facing northeast.

Image 5: Another photograph showing the vegetation of the Hawk Bay Site. Photograph taken at 1061 location, facing southwest.

Image 6: Shoreline of the Portage Island Site (DeJj-8).   Photograph was taken from a boat, looking south.

Image 7: Quartz flake observed beneath the waves at the Hawk Bay Site (Location 1091 Fig. A1 and Table A1).

Image 8: Taconite flake observed beneath the waves at the Hawk Bay Site (Location 1091 Fig. A1 and Table A1)

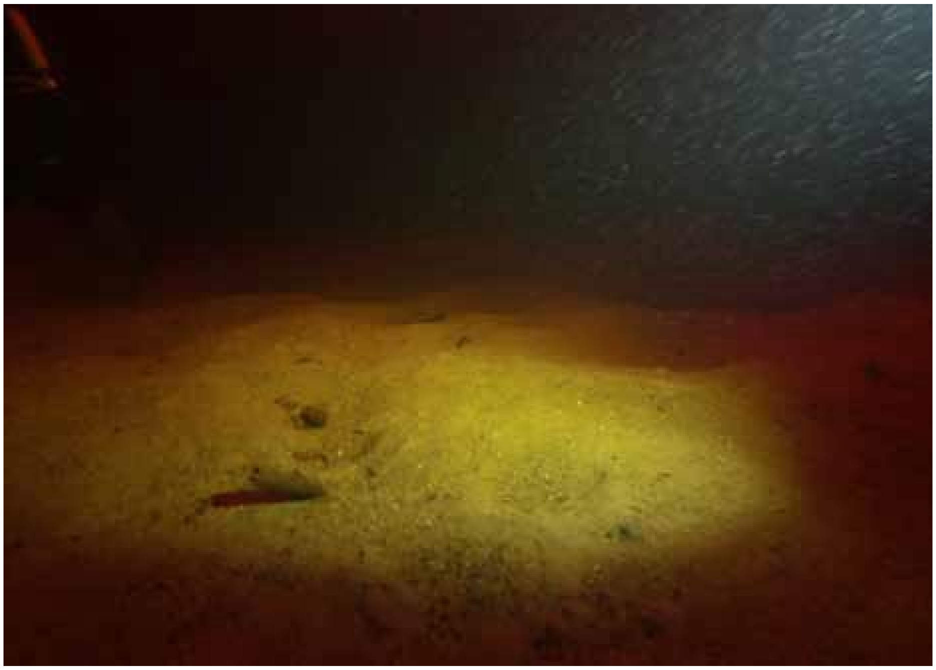


Image 9: Boundary separating the cobble foreshore and silty bottom at the Hawk Bay Site (Location 1101 Fig. A1 and Table A1).

Image 10: Cobble along the foreshore of the Hawk Bay Site, mixed with vegetation and organics (Location 1121 Fig. A1 and Table A1).

Image 11: Boundary separating the cobble foreshore and silty clay at the Hawk Bay Site (Location 1161 Fig. A1 and Table A1.)

Image 12: Boulder sitting amongst silts and clays (Location 1181 Fig. A1 and Table A1)

Image 13: Cobble foreshore of the Hawk Bay Site (Location 1241 Fig. A1 and Table A1).

Image 14: Reedy foreshore of Portage Island (Location 1271 Fig. A2 and Table A2).

Image 15: Marshland of the Portage Island Site (Location 1301 Fig. A2 and Table A2) . Photograph was taken from a boat on the south side of the island, looking west.

Image 16: Reedy foreshore on the south end of Portage Island (Location 1311 Fig. A2 and Table A2).

Image 17: Reedy foreshore of Portage Island. In the foreground is one of the markers used in the underwater survey (Location 1341 Fig. A2 and Table A2).

Image 18: Cobble foreshore of Portage Island (Location 1361 Fig. A2 and Table A2).

Image 19: Cobble and rocky foreshore of Portage Island (Location 1371 Fig. A2 and Table A2).

Image 20: Silts and clays at the Portage Island site are found in away from shore

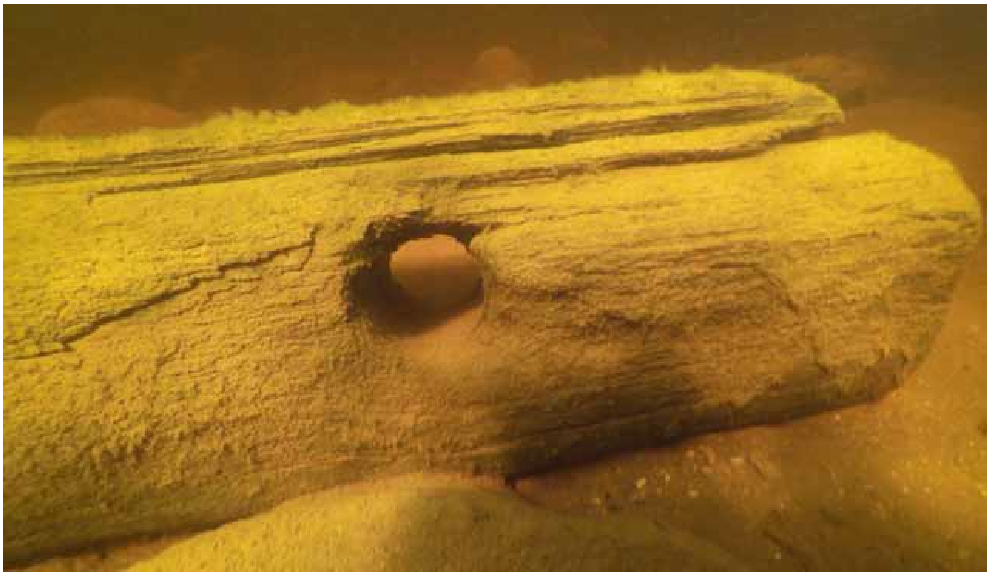


Image 21: Boom Log observed in 2.5m of water, Portage Island (Location 1401 Fig. A2 and Table A2).

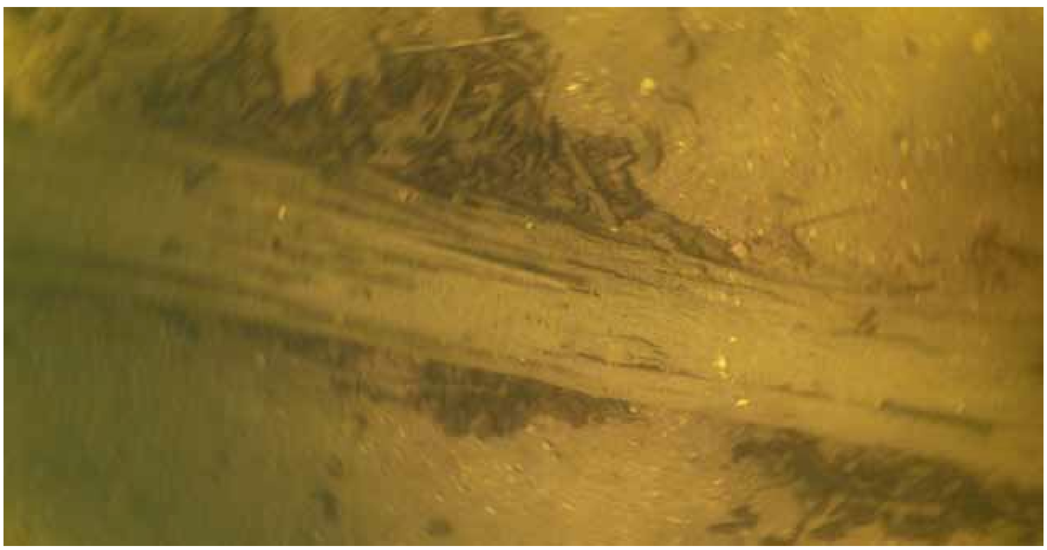


Image 22: Log and sandy bottom, Portage Island (Location 1411 Fig. A2 and Table A2).   .

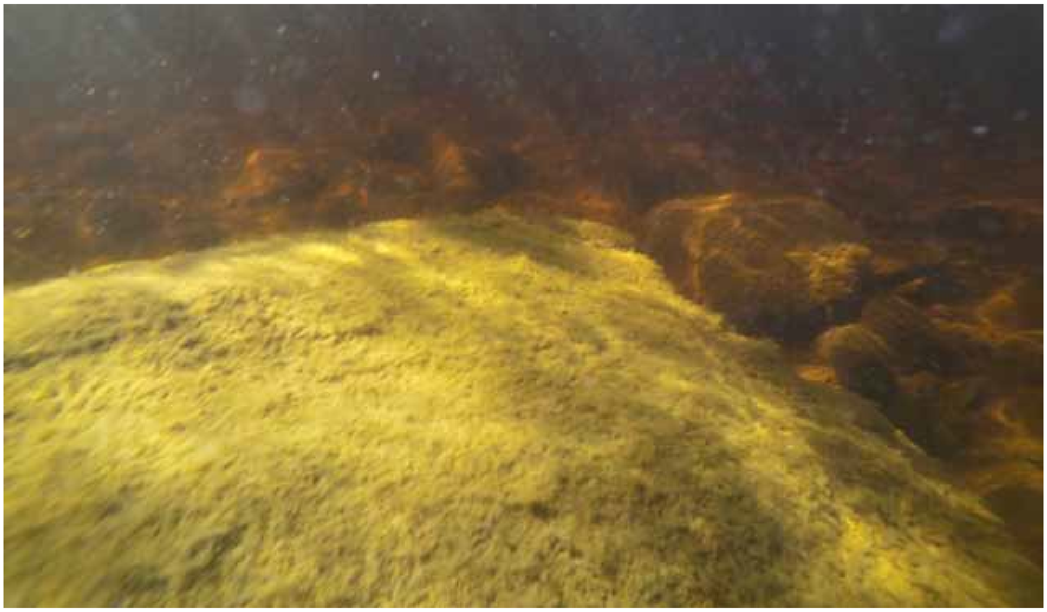


Image 23: Cobble foreshore, Portage Island (Location 1421 Fig. A2 and Table A2).   .

Image 24: Rocky bottom Portage Island (Location 1451 Fig. A2 and Table A2). .

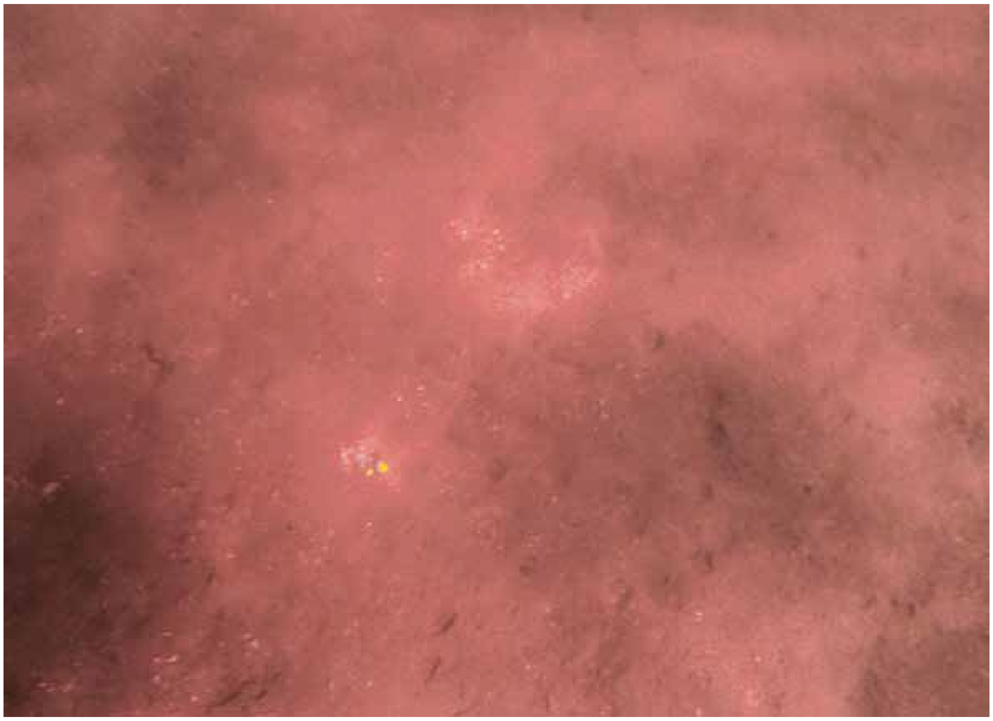


Image 25: Silt and clay bottom, Portage Island (Location 1461 Fig. A2 and Table A2). .

Image 26: Large erratic located on the shore of the Hawk Bay Site. Image captured during the seasonal high water levels.

Image 27: The same large erratic from Image 28 (top left) can be seen sitting amongst a cobble field that would normally be submerged in water. Image captured during the seasonal low (late fall) for water levels.

Image 28: Image donated by Oliver Antilla showing the extreme height of water levels (summer) at Dog Lake, Ontario.