



EVALUATION OF SHORELINE IMPACTS AND LONG-TERM MONITORING OF SHORELINE ARCHEOLOGICAL SITES WITHIN VOYAGEURS NATIONAL PARK



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Report Submitted to the International
Joint Commission
Study No. 12

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EXECUTIVE SUMMARY

Stasis time of water levels is found to be the best metric for predicting erosion effects on the landforms of Voyageurs National Park. Erosion of landforms, in turn, damages both identified and unidentified cultural resources along shorelines, each of which has the potential to reveal information about history and prehistory. Holding all other conditions equal (i.e., weather, substrate, vegetative communities, etc...), the primary difference between the Rule Curves is the amount of time that water levels remain at any one particular elevation. Differences between Rule Curve are useful for predicting the erosion potential of each management strategies. The longer a landform is exposed to wave action, the greater the potential for weathering and erosion, and consequently, the greater the potential loss of archeological resources.

Stasis Time

The 1970 Rule Curve for the Namakan Reservoir has the potential to cause more intense, sustained erosion with a stasis time of 67 days per year within a single 10cm elevation window. This is a difference of nearly three weeks longer than the maximum 2000 Rule Curve stasis period, which is 46 days. These results are similar for Rainy Lake where the 1970 Rule Curve maintains a static elevation for a maximum of 68 days, while the 2000 Rule Curve has a maximum stasis period of 49 days. In each case, the 2000 Rule Curve erodes landforms more slowly than the 1970 Rule Curve due to its shorter periods of static water levels.

Critical Elevations

The 1970 and 2000 Rule Curves induce peak erosion pressures at different elevations. The 1970 Rule Curve for the Namakan Reservoir generates peak erosion at 340.9m for 67 days, while the 2000 Rule Curve erodes soils at 340.6m for 46 days. On Rainy Lake, the 1970 Rule Curve maintains static water levels at 337.7m for 68 days, while the 2000 Rule Curve focuses erosive forces at 337.6m for 49 days. Based on a spatial query of known archeological sites within 10m of shore, the peak erosion elevations of the 2000 Rule Curve (340.6m on Namakan and 337.6m on Rainy) have the potential to affect fewer cultural resources than the 1970 Rule Curve.

Fieldwork

Archeological fieldwork reveals that the 2000 Rule Curve had an adverse effect on archeological resources on both the Namakan and Rainy basins when it was first implemented. The June 2014 flood was illustrative of this effect, as we observed the loss of soil on shoreline terraces due to exceptionally high water levels that exposed new locations to erosion. Although the terraces were exposed to wave action for only a matter of days, erosion was rapid and significant. Increasing water levels from the 1970 Rule Curve to the 2000 Rule Curve had a similar effect, as revealed by archeological researchers over the past twenty years. Current field investigations demonstrate, however, that landforms have now stabilized on both basins under the 2000 Rule Curve.

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We conclude that any systematic changes to water level management (i.e. any new Rule Curve) would re-introduce erosion and restart the destructive process of stabilization, as highlighted by the erosive effects of the 2014 flood.

Conclusion

In sum, the 2000 Rule Curve is recommended by every standard of evaluation for both basins without modification for the continued preservation of cultural resources at Voyageurs National Park.

PROJECT BACKGROUND

The International Joint Commission (IJC) engaged the National Park Service (NPS) to study the effects of water level management on cultural resources at Voyageurs National Park. Two sets of management practices were evaluated on the Namakan and Rainy reservoirs: the IJC's Supplementary Order of 2000 (the 2000 Rule Curve) and the IJC's Supplementary Order of 1970 (the 1970 Rule Curve). The project was undertaken by staff at the NPS Midwest Archeological Center (MWAC) in cooperation with Voyageurs National Park (VNP). In the Plan of Study for the Evaluation of the International Joint Commission 2000 Order for Rainy and Namakan Lakes and Rainy River, authors determined that it is necessary to "determine if the 2000 Rule Curves have had a measurable impact on erosion at a small number of known archeological sites on the reservoirs." To meet the requirements of the Plan of Study, MWAC and VNP jointly developed a scope of work to define the effects of water level management on archeological sites in the park, compare the theoretical effects of both Rule Curves, and to develop quantitative metrics for the evaluation of these and future Rule Curves with respect to archeological resources.

Identifiable patterns related to the formation and preservation of archeological sites (e.g. vegetation differences, beach formation, erosion) under the two management regimes serve as the basis for evaluation. Associating archeological site formation processes with Thompson's (2013) modeled output then supports the identification of critical variables toward the continued preservation of archeological resources. The scope of work also includes several specific questions that are addressed as components of the study:

1. Which archeological sites within VNP exhibit shoreline instability and what are the settings or conditions for these locations?
2. How do water levels, as determined in the Thompson (2013) hydrological model of the 2000 Rule Curve, behave at archeological sites with unstable shorelines?
3. Does the output from the Thompson (2013) hydrological model of the 1970 Rule Curve produce a different set of modeled shoreline impacts or areas of instability when compared to the model of the 2000 Rule Curve?
4. What are the conditions at the selected archeological sites during naturally low and high water conditions independent of the 2000 Rule Curve?
5. What are useful vital signs and monitoring protocols for tracking and documenting future Rule Curves and water level fluctuations?

The impetus for this study is the assumption that cultural resources could be adversely affected by altering the water levels within Voyageurs. The first step in evaluating the impacts of any Rule Curve is therefore to understand the time periods and the geographical contexts in which archeological resources are formed.

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GEOGRAPHIC AND CULTURAL HISTORIES OF VOYAGEURS NATIONAL PARK

Environmental and Geological History

Voyageurs National Park encompasses several large lakes along the border between the United States (Minnesota) and Canada (Ontario). The lakes flow generally from southeast to northwest along the Canadian border and are part of the Rainy River drainage (Figure 1)

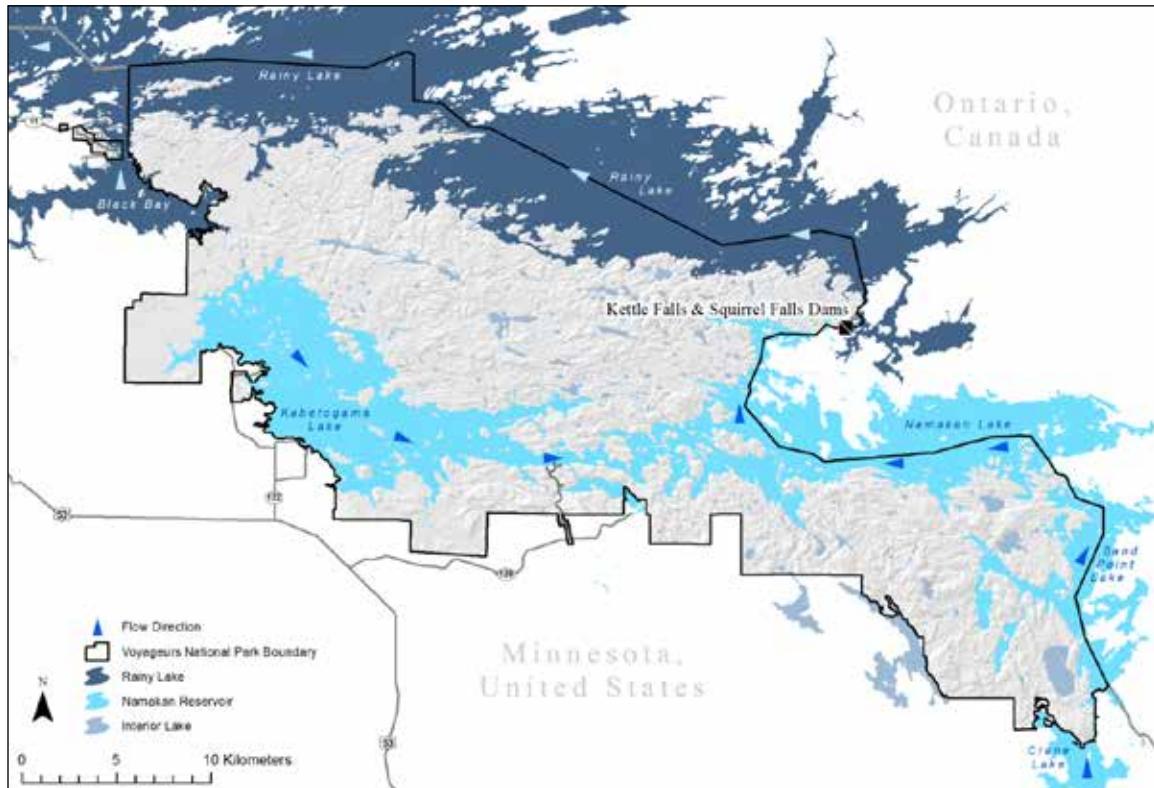


Figure 1. The Namakan Basin and Rainy Lake (after Morin et al. 2014).

Rainy Lake water levels were raised about 1.1m (3.6ft) when a dam was built at the foot of Koochiching Falls in 1909. In 1914, a dam built at Kettle Falls raised the Namakan Reservoir (Kabetogama, Namakan, Sand Point, and Crane Lakes) by 1.3m (4.4ft) (Bullard and Scovil 1931). Besides raising lake levels, the dams also regularized water flow through the basin to provide a predictable and normal source of hydroelectric power for the burgeoning wood products industry.

The surficial geology of the Border Lakes region consists largely of scraped bedrock where soils are absent or bedrock is overlain by thin, patchy glacial till and outwash deposits with limited soil formation (Harries et al. 2004). Shorelines are often rocky. The geomorphic environment around Kabetogama Lake and Black Bay differs

from this general pattern. Sediment accumulation tends to be thicker and soils are somewhat better developed. A portion of the southern shore is fringed with wetlands that were created by the raised water levels in shoreline basins and tributary streams. Differences in soil characteristics and erosional behavior may be attributed to glaciation by different lobes of the continental ice sheet. Coarse grained sediments that contain granite, gabbro, basalt, red sandstone, slate, and greenstone and other ferruginous minerals are found in the Namakan and Rainy Lake basins, while finer, limestone and granite rich sediments are found in Black Bay and Kabetogama Lake (Andrew Breckenridge, personal communication 2014; see also Ojakangas 2009 and Ojakangas and Matsch 1982).

During the last glacial maximum, Voyageurs was covered in ice (Kallemyn et al 2003:vi). The glaciers retreated about 13,000 years ago leaving a tundra-like climate which began to warm, eventually yielding to scattered spruce trees and herbaceous plants which expanded in to the park area from the south (Teller 2013:366). The climate again cooled slightly during the Younger Dryas, ca. 12,850-11,450 before present (BP). Towards the end of the Younger Dryas, several glacial lakes, including Koochiching, merged during the Lockhart Phase of Glacial Lake Agassiz (Hill 2007:37). Lake Agassiz, which covered the entire VNP area during the Lockhart Phase, slowly drained to the south (Teller 2013:367).

Around 10,800 BP, an outlet to Lake Superior developed, causing Lake Agassiz's water levels to decline significantly and exposing at least parts of Voyageurs (Teller 2013:367, Fisher 2002:271). Near the end of the Moorhead Phase, water again inundated the park area as the Earth's crust rebounded (Teller 2013:367). The eastern drainage was cut off around 9,900 BP, leading to additional increases in water levels and signaling the beginning of the Emerson Phase, which lasted about 200 years (Yansa and Ashworth 2005:265). While the proglacial lake expanded during this phase, it is unclear whether the entire park was inundated, or if parts were exposed (see Bacj et al 2000:1336, Leverington et al. 2000, Teller and Leverington 2004). Around 9,500 BP, new outlets to Lake Agassiz developed, and the lake began draining (Nicholson 1987:19).

A warming period, known as the Holocene Climatic Optimum (Hypsithermal), began around 9,000 BP and continued through about 4,500 BP (Nicholson 1987:155). During this period, prairie and oak savannah expanded into the VNP area (Nicholson 1987:14). By about 7,500 BP, Lake Agassiz had fully drained from the park area, leaving behind the drainage system that exists today (Kallemyn et al. 2003:6). Temperatures had cooled by approximately 5,000 BP, and the dominant vegetation reflected this shift (Gibbon and Anfinson 2008). Prairie and oak savannah gave way to conifers, supported by higher precipitation, which also resulted in higher lake levels and larger areas of wetlands (Gibbon and Anfinson 2008). This cooler period extended through about 3,000 BP. Since then, modern climate and vegetation patterns have remained relatively stable, with the exception of the Medieval Warm Period (1,000-600 BP) and the Little Ice Age (450-100 BP) when temperatures rose and precipitation dramatically decreased (Gibbon and Anfinson 2008: chapter 6, par 9-10). The subsequent Little Ice Age (AD 1550-1915) was characterized by greater precipitation and cooler temperatures, which resulted in the expansion of Big Woods trees, including basswood (*Tilia Americana*) and sugar maple (*Acer saccharum*) (Davis et al. 1999, Gibbon and Anfinson 2008).

Culture History

A brief overview of Voyageurs National Park's rich culture history demonstrates the occupation of the park from at least as early as ca. 10,700 BP, just as the waters of glacial lakes began to recede. Throughout its occupation, the area that now encompasses Voyageurs has been intensively used and re-used, particularly on shorelines as they existed at the time. In nearly every case, these shorelines (and the cultural materials they contain) are still routinely exposed by modern lake level practices. Although the initial damming of the reservoirs and the subsequent policies of the IJC raised water levels significantly, modern variations in annual water levels still encompass the physical remnants of most, if not all, of history and prehistory.

Paleoindian to Archaic Periods (11,500 to 3,000 years before present)

From the Late Paleoindian period into the historic era, the interconnected waterways of what is now Voyageurs National Park have served as a valuable transportation route for people living on the lakes (Richner 2002:1). Paleoindian occupation and use of the VNP area (ca. 11,500-9,000 BP) is currently not well understood. Though it is possible that Early Paleoindian peoples occupied the VNP area, the evidence is currently inconclusive (Richner 2008:17). Evidence for Late Paleoindian occupation is limited, but numerous artifacts possibly dating to this period have been found in private collections (Richner 2008:11, 15). The proglacial lakes may have drained enough that, during a short window between about 10,700 and 9,900 BP, Native Americans could have settled in or visited the area. Paleoindians were likely mobile hunter-gatherers following big game, though they could have been attracted to the lacustrine resources of the region.

A shift in projectile point styles (from parallel-flaked, leaf-shaped points to stemmed and notched points) marks the transition from the Late Paleoindian Tradition to the early Archaic Tradition and indicates a diversification of subsistence strategies (Richner 2008:17-19). Even though few Archaic sites have been recorded within the park's boundaries, Archaic artifacts are present at several multi- component sites in the region, suggesting that Archaic peoples likely occupied the park from at least 8,000-6,000 BP and certainly from 6,000-3,000 BP. Because of potentially dramatic lake level recessions during the Holocene Climatic Optimum, archeological remains from the Archaic period may currently be submerged (Richner 2008:17). During this time, Native Americans probably began to occupy or utilize the lakes more intensively; however, the lack of information from this early period obscures our understanding of the settlement and subsistence systems. It is unclear if Archaic peoples were living permanently along the lakeshores or seasonally exploiting them.

Woodland Period (3,000 to 300 years before present)

In contrast to the scant material record of the Paleoindian and Archaic periods, Woodland sites and artifacts (ca. 3,000-300 BP) are more abundant (Richner 2008:26). The basins may have been vacant or depopulated during the Early Woodland period (ca. 3,000-2,150 BP), but early pottery sherds have been documented at two locations

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northwest of the park along the Rainy River, and Richner (2008:27) believes that these ware types may be present but misidentified in VNP collections.

Middle Woodland sites (ca. 2,150-1,300 BP) are characterized predominantly by “Laurel” type pottery. These materials appear throughout northern Minnesota and Wisconsin, across Michigan’s Upper Peninsula, in southern Ontario, and across much of Manitoba, but the core is centered upon the VNP area (Richner 2008:27-28). A large number of Middle Woodland Tradition Laurel sites exist within the park, though many are multi-component sites that are not clearly stratified, making precise dating difficult (Richner 2008:30-31).

The Late Woodland period in the VNP area dates to 1,300-300 BP, and numerous materials dating to this period have been identified in the park. After about AD 650, Blackduck wares had replaced Laurel ceramics in the VNP area (Richner 2008:30). Blackduck and Selkirk materials generally exist in the same or similar locations as Laurel sites, the result of reoccupation of the lakeshores (Richner 2008:33).

Historical Period (300 to 50 years before present)

The mid-seventeenth century marked the beginning of the Postcontact period (ca. AD 1650-1940), though it remains unclear exactly when French fur traders entered the VNP area (Richner 2008:39). The first known European to visit what is now the VNP area was Jacques de Noyon, who wintered at Rainy Lake in 1688, though French trade goods were introduced to the area quite a bit earlier (Richner 2008:44). France sent expeditions west “from Montreal to establish a series of posts on the interior west of Lake Superior” by 1717, though it was not “until 1731 when...a post [Ft. St. Pierre] was built at Rainy Lake” at the head of the Rainy River (Richner 2008:45). Then, in 1736, the French established a trading post “on Crane Lake at the mouth of the Vermilion River,” just south of what is now the park (Richner 2008:45).

The English fur trade in the VNP area began officially in 1763. As with French trade goods, British goods almost certainly arrived earlier, possibly as early as the 1670s (Richner 2008:45-46). The North West Company established the first known local post in 1787 not far from where Ft. St. Pierre had been (Richner 2008:46). In 1817, the Hudson’s Bay Company reestablished a post near the headwaters of the Rainy River not far from the North West Company post (Richner 2008:46). In 1821 the two companies merged, and in 1830, the post was renamed Fort Frances (Richner 2008:46).

Numerous Ojibwe sites that postdate ca. AD 1730 have been recorded in the park, most of which appear to be more permanent habitation sites as they frequently contain several structures (Richner 2008:43). It is also possible that other Ojibwe groups inhabited more of the area’s shorelines, though not necessarily in permanent settlements (Richner 2008:44).

Little non-fur trade European settlement occurred in the VNP area prior to the 1860s (Richner 2008:47). During this decade, a gold rush at Vermilion Lake brought “several hundred Euroamericans” into the area, though no permanent settlement

developed (Richner 2008:47). In 1870, the Dawson Trail was constructed through Canada and subsequently resulted in many Euroamericans moving through the area, but not necessarily settling (Richner 2008:47-48).

American settlement was extremely limited until 1893, when a second gold rush occurred (Richner 2008:48). Rainy Lake City developed as a boom town at the west end of Rainy Lake in 1894, though it never attracted large numbers of settlers, peaking with a population of about 200 residents (Richner 2008:48). Gold mines sprang up on a handful of islands, including Little American and Bushy Head (Richner 2008:48).

Homesteading began relatively late in the Voyageurs area, with many individuals not completing the legal homesteading process until around the turn of the twentieth century, or even as late as the 1920s (Richner 2008:49).

Summary of Geological and Cultural Histories

For each of the time periods listed above, archeological evidence indicates that past peoples were intensely focused on lacustrine resources and their settlements were located exclusively along the lakeshores. Through time, however, the elevation and location of the lakeshores have varied widely. At the end of the Ice Age, the lakes were much larger and deeper than today. Later, dryer climate reduced the basins to a fraction of their modern size. Presently, lake levels fluctuate within a narrow band between these two extremes. Consequently, archeological remains occur at, above, and below the present lake levels, and fluctuations as prescribed by the IJC have the potential to dramatically impact archeological resources at any elevation (Figure 2).

Despite basin-wide increases in water levels due to the construction of the dams, the total range of managed lake levels still includes a major portion of the landscape where the historic and prehistoric people of the Voyageurs National Park area lived. Actions by the IJC directly affect these extant remains. Minimizing shoreline erosion takes on added importance because archeological sites are non-portable resources that cannot be restored.

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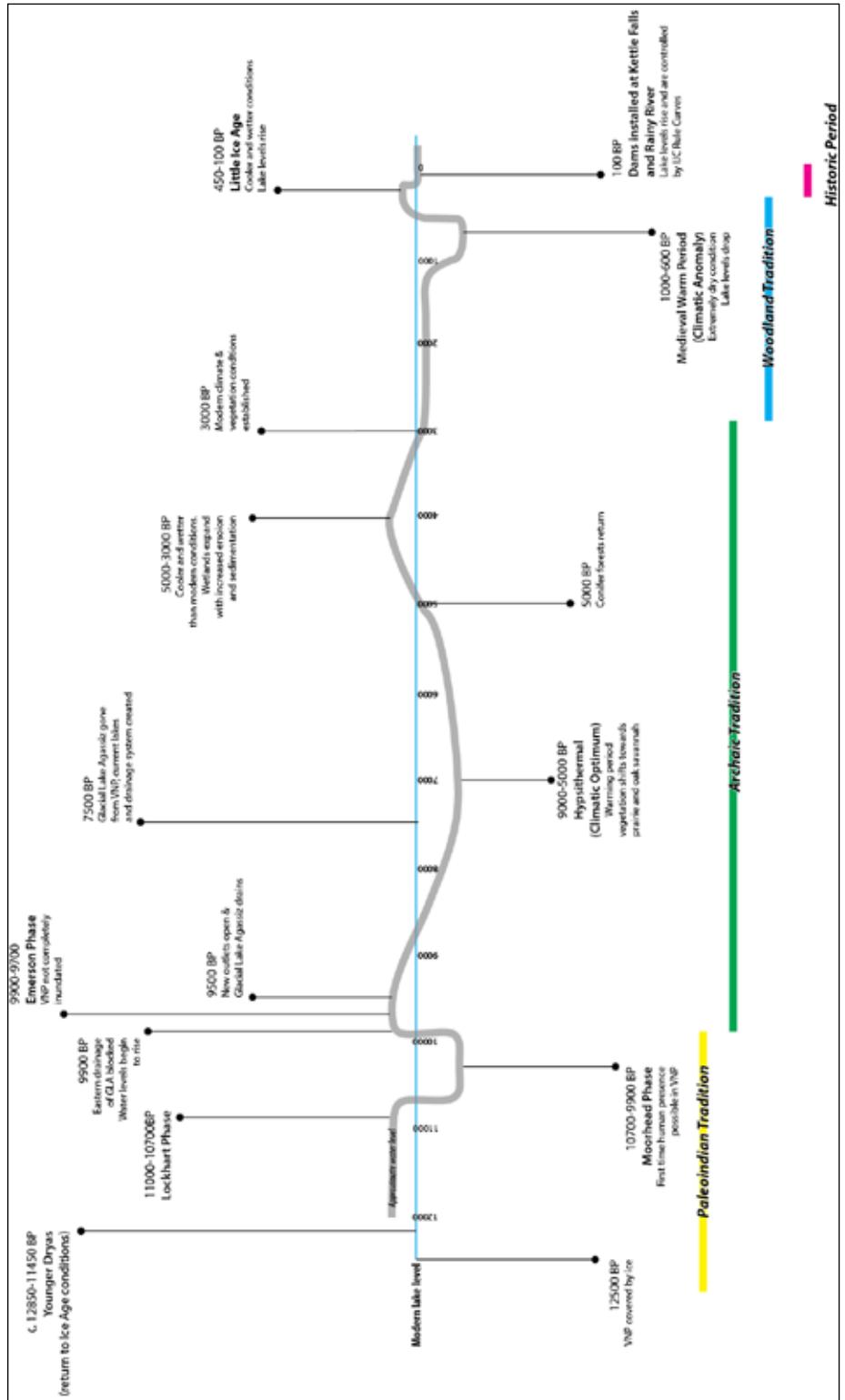


Figure 2. A geological and cultural timeline of VNP. The location of ancient activities, and consequently archeological sites, is determined by the elevation of the past lake shores.

WATER LEVELS AND ARCHEOLOGICAL SITES IN RAINY LAKE AND THE NAMAKAN RESERVOIR

Since 1909, the IJC has managed Rainy Lake and the Namakan Reservoir according to policies (Rule Curves and supplemental orders) set forth in a series of international agreements. Water levels are higher relative to their pre-dam heights and, within this elevated state, water levels vary considerably. Variation can be seen in seasonal summer highs (Figure 3) and winter lows (Figure 4), in the overall mean levels between different Rule Curve periods, and in the seasonal rate and timing of water level rise and fall. Furthermore, these patterns vary between lake systems, with Rainy Lake and the Namakan Reservoir managed according to separate Rule Curves (Figure 5). Even though the elevation and timing of lake level fluctuations differ between basins, both follow the same general pattern where the summer levels are elevated, and during the winter they are drawn down to the lowest yearly point.



Figure 3. Summer maximum water under the Rule Curves.

Elevation data for the study were derived from Thompson (2013), who modelled the 2000 and 1970 Rule Curve responses to historical inputs, and validated the model with recorded lake levels from the Koochiching and Kettle Falls dams over the period of record from 1950 to 2012. The measured lake levels reflect the elevation for the water level at the monitoring stations, and may not reflect absolute water level elevations across each basin. However, the general patterns in the data are indicative of relative water level changes basin wide.



Figure 4. Winter minimum levels under the Rule Curves.

The NPS recognizes 446 discreet archeological sites within Voyageurs National Park (Figure 6). Of these, 140 are found within the Rainy Lake, while 299 are found in the Namakan Reservoir (n=439). Remaining sites (n=7) are excluded from this study because they exist in the backcountry, away from potential lakeshore impacts. For this evaluation, each archeological site center is assigned an elevation extracted from the digital elevation model (DEM) prepared by Morin et al. (2014), from which is subtracted a correction value of 0.166m for the park area to convert from NAVD 1988 to USCGS 1912 (Jean Morin, personal communication). This facilitates comparison of site elevations with Thompson's model, and ensures that a consistent vertical datum (USCGS 1912) and horizontal datum (NAD 1983) are used in all comparisons. Because the analysis that follows relies on the relative elevations of archeological sites and water, absolute accuracy to a reference geoid is not required, but consistent and precise elevation values are required.

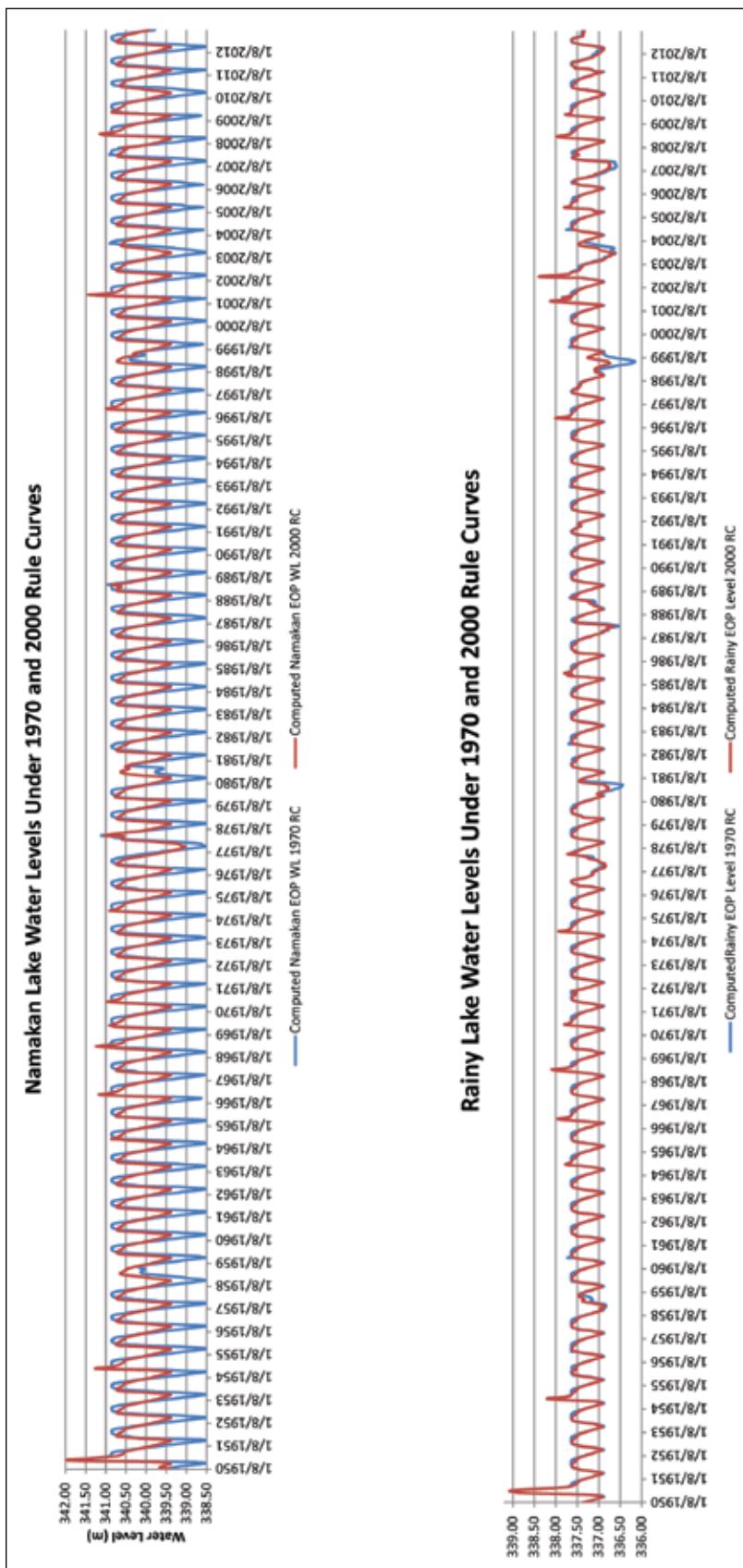


Figure 5. Lake levels as modeled for the period of observation.

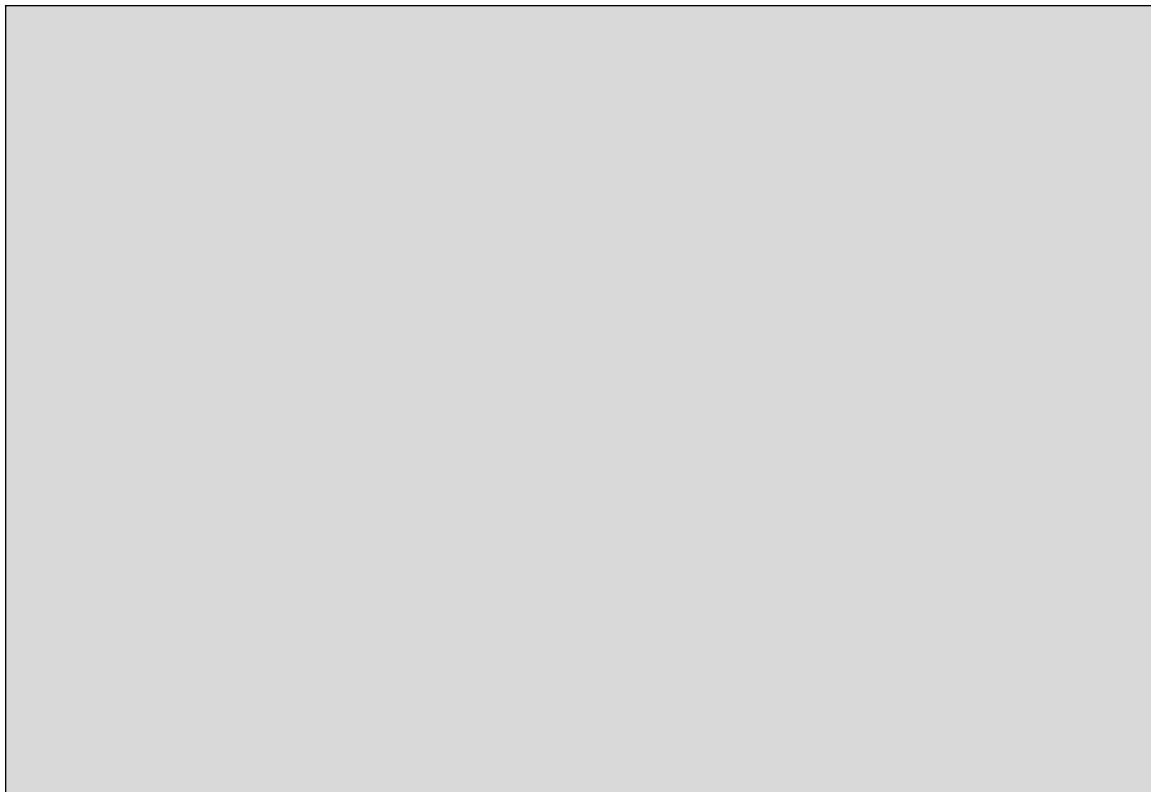


Figure 6. Archeological sites within the study area.

An initial comparison of site elevations to Thompson's modeled water levels reveals that seven sites are permanently submerged under the 2000 Rule Curve that would be exposed annually under the 1970 Rule Curve. Conversely, two sites would be permanently exposed by the 1970 Rule Curve, but are periodically submerged by the 2000 Rule Curve. All other sites ($n=430$) are permanently exposed or permanently submerged by both rule curves, so the rate of erosion on the corresponding landform becomes the critical difference.

The fact that most archeological sites are documented at elevations above the maximum water levels is partly a function of accessibility. Recordation of sites began in earnest in the early seventies, under the effects of the 1970 Rule Curve, and submerged resources are therefore not fully documented at Voyageurs (Richner 2008). Another confounding factor in modeling site elevations is that in many cases, artifact deposits do extend downslope to the lakeshore, but site centers—and hence their recorded elevations—happen to fall atop a terrace. The “undiscovered” status of many sites and the generalized nature of site locations in the geographic information system (GIS) have, therefore, guided our approach to evaluate landforms more broadly, as opposed to focusing on a critical elevation or class of sites. Rather than performing a simple comparison of lake levels with archeological site elevations, it is necessary to evaluate the differences in erosion rates along shorelines, which significantly alters the landforms on which sites occur, in turn affecting the integrity and research potential of archeological resources.

GEOMORPHOLOGY OF RAINY LAKE AND THE NAMAKAN RESERVOIR

Shoreline archeological sites are found in one of three different contexts at Voyageurs: terraces, the littoral zone, and the lake bottom or submerged zone. These environments are adjacent to one another and are interrelated. The boundaries between them can be indistinct but they represent identifiable geomorphic environments that are differentially affected by lake level changes. These categories therefore provide a useful analytical framework for studying the impacts of potential lake level management policies.

Lacustrine Terraces

Lacustrine terrace sites are perched above the normal high water mark. Archeological materials may sometimes be deposited directly on bedrock, but archeological sites are often better preserved in sediments that were deposited by glaciers and held in place by bedrock topography (for example see Lynott et al. 1986 and Richner 2008).

With few exceptions, sediments are no longer deposited on terraces because they are permanently above water. Thin layers of leaf and organic litter may form a so-called 'duff' layer, but these deposits are not considered repositories for archeological resources at Voyageurs. Occasionally, storms can also throw large volumes of sediment atop terraces and bury surficial archeological materials forming deposits called storm beaches. At Voyageurs, storm beaches are rarely encountered and information about their distribution and ages is sparse. At the landscape scale, terraces were formed by the erosion of earlier sedimentary deposits.

Terraces are abrasion coasts that erode when wave action scours the headwall. Wave action undercuts the slope which can catastrophically collapse. The collapsed slope forms a platform or beach which can subsequently erode, albeit more slowly than a headwall. Occasionally, rocky inclusions from the collapsed slope can armor the scarp and form a rocky beach which may also slow erosion at the elevation of the normal high water. The cycle repeats when beaches are fully eroded. Headwalls vary in scale from less than a meter to many meters tall. The rate and degree of erosion are primarily dependent on wave energy and the relative resistance of the substrate (Komar 1998, USACE 1984).

Within the Rainy Lake basin, sediment drapes atop bedrock are very shallow or non-existent. Glacial abrasion scoured the bedrock and subsequent deposition of soils is sparse. Consequently, terraces tend to consist of resistant bedrock, and archeological sites are largely on the surface.

The topography of the Namakan Reservoir is more varied than Rainy Lake. While the landforms east of Daley Creek on Kabetogama Lake tend to be similar to those on Rainy Lake—where archeological sites are found on rocky terraces—the terrain is not as steep or rocky farther west along the shore of Kabetogama Lake and terraces become rare.

The Littoral Zone

The littoral zone is a term used here to describe a point from the normal high water mark to a point beyond the depth of wave disturbance at normal low water. This is the zone where shoreline plants grow. Archeological sites in the littoral zone are directly and regularly affected by wave wash processes.

For the purposes of this study, we defined two geomorphic environments in the littoral zone: the surf zone and the swash zone (Davidson-Arnott 2010). The surf zone is the area of shallow water where waves break. After waves break they continue in a diminished state into the swash zone. Sediment transport, and consequently erosion or deposition, occurs in both the swash and surf zones. In the swash zone, sediments can move landward in the uprush phase or sediments can move outward in the backwash phase. Sediments can also move parallel to the beach with longshore drift. Whether there is a net increase or decrease in sedimentation depends on a multitude of factors including, but not limited to, the overall sediment budget, the type and intensity of waves, saturation of the site, beach morphology, and rock types (Komar 1998).

Overall, the littoral zone is a dynamic depositional environment that is not conducive to the preservation of archeological sites or artifacts. The high energy environment and continual sediment churning by waves negatively impact archeological sites. This pattern is cumulative; the longer archeological sites are exposed to such process the greater potential for the removal or reworking of archeological materials. Sediment transport and wave energy can be reduced by a number of artificial and natural means. In particular, shoreline vegetation can both lessen wave energy and bind shoreline sediments (Komar 1998, USACE 1984). Well vegetated shorelines are indicators of stable geomorphic surfaces.

Lake Bottoms

The lake bottoms are generally believed to be scoured bedrock (see Lynott, Richner, and Thompson 1986); however there is considerable variation both within and between the basins. Kabetogama Lake is the shallowest and has the muddiest bottom while the remaining lakes are deeper and rockier. Organic- rich, fine-grained sediments cover the least energetic, deepest locations. Steeper, shallower, or more highly energetic places may be scoured to bedrock.

Archeological sites found on lake bottoms are normally submerged, and are only exposed during unusually low water events. These sites were created during periods of low water, when persons lived near and used historical shorelines. As a result, the material traces they left were eventually submerged as lake levels rose.

If archeological resources exist on the lake bed, they are thought to be in a depositional environment and, consequently, are actively buried, albeit at a very slow rate (< .1cm/ year) (Myrbo 2008). Organic sedimentation also occurs within the slack water shallows of Kabetogama Lake. Recent coring by the NPS and the University of Minnesota (in progress) demonstrates that about one meter of modern organic rich sediment overlies glacial lake sediments deposited about 10,000+ years ago in multiple

locations across the lake. One meter of organic deposition equates to approximately 1,000 years of sedimentation. The organic sediments are stable while wet or waterlogged, but if they become exposed during extreme low water events, they can be easily eroded.

Summary of Landforms in Voyageurs National Park

During the early Holocene and continuing into the present, erosion has carved the landscape into the terraces and beaches while deposition has formed the lake bottoms. At the local level, the erosion of terraces provides sediments for beaches in the littoral zone. Beaches can subsequently erode or become part of the submerged (lake bottom) zone. As a result, the preceding three geomorphic contexts are historically interrelated.

EVALUATION OF SHORELINE IMPACTS AND LONG-TERM MONITORING

MODELING LAKE LEVELS AND ARCHEOLOGICAL SITE RESPONSE

Thompson's hydrological response model for the Rainy and Namakan Reservoirs applies three variables (in-flow, basin size, and out-flow) to two different management policies on two basins. A comparison of the water levels generated by the two Rule Curve scenarios over the period of record demonstrates that water levels respond differently to these variables, producing patterns that could impact archeological resources over time. Independently, each Rule Curve generates annual water level patterns that are generally consistent, illustrating the targeted response of the water levels. The effects of these targeted water levels on archeological resources are the focus of this analysis, bearing in mind also the differential response of each Rule Curve to unusual weather events.

Lake levels impact archeological sites primarily through wave induced erosion. Erosion changes landforms, and therefore removes context from archeological sites by transporting and disassociating artifacts from their original locations. Wave action can also erode artifacts themselves, in addition to the information-rich soils that surround and hold artifacts in place. It is important to note that erosion occurs only at the lake surface. Although many sources of energy exist (e.g., storms, currents within the lake, wind driven waves), these are functions of the elevation of the water levels. The effects of energy inputs, whatever their source, accumulate over time. Consequently, erosion is a time-dependent process (Rampino 2005:432). The longer the wave zone is focused at a single elevation, the greater the impacts. Lake level management practices create patterns of erosive energy that can be compared across time to understand differential impacts on different landforms. The key indicator for comparing these practices is stasis time, or how long the lake surface is held at any one particular elevation.

Stasis time is a measure derived from Thompson's stage frequency information. It is calculated by grouping water level observations into 10cm elevation 'bins,' then multiplying the number of observations in each bin by seven days (the interval between water level measurements). A 10cm elevation window was chosen as a likely but arbitrary elevation range for impacts within the typical wave zone at Voyageurs; i.e. erosion is most likely to occur within 10cm of any given lake levels due to wind and wave action. Multiplying the number of observations by seven days assumes that lake levels are stable for the entire week between measurements. While these assumptions are a simplification, it is the best approximation and produces an easily comparable metric between Rule Curves. For this study, the total number of days within any particular 10cm window (i.e. observations times 7) was divided by the number of years in the period of record to normalize the stasis time as days per year. Using Thompson's (2013) model, the normalization factor is 63 years (1950-2012). A histogram of these results is presented in Figure 7.

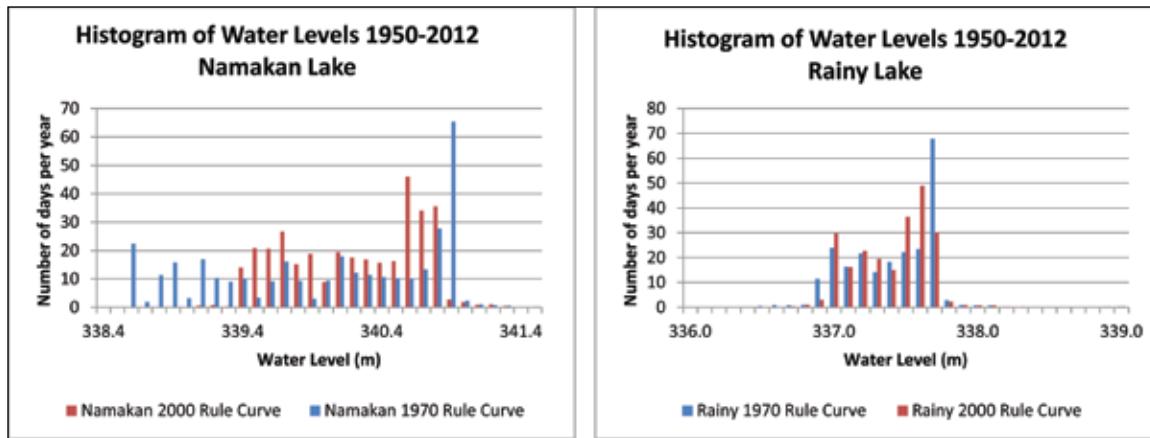


Figure 7. A comparison of the stasis time for each rule curve.

For the 1970 Rule Curve, Thompson's efforts show that the management parameters (targets and supplemental rules) produce lake levels that rise very quickly in the spring, remain stable throughout the summer, and drop very quickly in the fall. Highest stasis time is during the summer, when near-maximum water levels are maintained for up to approximately 70 days at 340.9m on the Namakan Reservoir, and 337.7m on Rainy Lake. Total stasis time is generally higher than the 2000 Rule Curve, meaning water levels transition more slowly, or are intentionally held at specific elevations. The yearly pattern is a square wave form. The geomorphic effects on landforms of such a pattern are:

A. For littoral sites

1. Well-developed beaches at a particular elevation
2. The surf zone is wide and sandy
3. Vegetation tends to be far from the normal water edge
4. Slopes running away from the water are shallow
5. There is little matrix accumulated between large clasts

B. For terrace sites

1. Intense erosion at a single elevation
2. Possible undercutting
3. Recent bank collapses
4. Complete erosion of the terrace

C. For lake bottom (submerged) sites

1. Sandy (coarse grained sediments) bottoms
2. Shallow slopes

Thompson's model of the 2000 Rule Curve produces a right-tailed curve (positive skewed). Lake levels rise rapidly in the spring and then are drawn down slowly until minimums are reached in the fall. This kind of pattern distributes wave energy across many different elevations through time, evidenced by a reduction in the total stasis time. Highest stasis times occur early in the summer when water levels slowly approach the maximum—but remain within a 10cm window—over approximately 50 days at 340.6m

on the Namakan Reservoir and 337.6m on Rainy Lake. The geomorphic effects of such a pattern are:

A. For littoral sites

1. Narrow poorly developed beaches
2. The surf zone tends to be fine to very fine grained
3. Vegetation is either very close or submerged
4. Slopes running away from the water are steeper
5. Rocks are matrix supported

B. For terrace sites

1. Low levels of erosion at any one elevation
2. Stable headwalls

C. For submerged sites

1. Silty, fine grained bottoms
2. Steep slopes

Stasis time appears to be the best predictor of erosive force, where shorter stasis times are considered less damaging than longer stasis times. The 2000 and 1970 Rule Curves focus wave energies at particular elevations for up to 50 days and 70 days respectively, but these foci also occur at different elevations. To address the effects of peak residence time occurring at different elevations, a spatial query was performed to compare the elevations of peak residence time on the two basins for both Rule Curves.

EVALUATION OF SHORELINE IMPACTS AND LONG-TERM MONITORING

SPATIAL ANALYSIS OF PEAK STASIS TIMES

The dashed line in Figure 8 through Figure 12 circumscribes the elevation of annual peak erosion for the 2000 Rule Curve. This elevation is derived from the highest stasis time for the 2000 Rule Curve (Figure 8), and describes the locations where erosion is expected to be most severe. The pink line similarly represents the elevation of peak erosion for the 1970 Rule Curve. Differences between the two Rule Curves are highlighted in yellow.

Site centers within 10m (horizontally) of a potentially eroding shoreline are assumed to represent the cultural resources most likely to be impacted by erosion.

Archeological sites labeled in black are within 10m of the peak erosive force contour for the 2000 Rule Curve, and more than 10m from the peak erosive force contour for the 1970 Rule Curve. Likewise, archeological sites labeled in pink are within 10m of the peak erosive force contour for the 1970 Rule Curve, and more than 10m from the peak erosive force contour for the 2000 Rule Curve.

Archeological sites that are within 10m of both contours are theoretically affected by both Rule Curves, and are non-factors in this comparison. These sites, as well as those that are not affected by either Rule Curve, are not displayed.

Namakan Reservoir: Results of Peak Stasis Time Analysis

The 2000 Rule Curve focuses erosive forces at approximately 340.6m amsl for an average of 46 days per year. Assuming sites within 10m of the land/water interface are most likely to be impacted by erosion, the 2000 Rule Curve has the potential to significantly erode 16 archeological sites that would not be affected by the 1970 Rule Curve.

The 1970 Rule Curve focuses erosive forces at approximately 340.9m amsl for an average of 67 days per year. Given the same assumptions, the 1970 Rule Curve has the potential to significantly erode 27 archeological sites that would not be affected by the 2000 Rule Curve. Peak impacts would persist for an additional 21 days more than the 2000 Rule Curve (Figure 8, Figure 9, and Figure 10).

Rainy Lake: Results of Peak Stasis Time Analysis

The 2000 Rule Curve focuses erosive forces at approximately 337.6m amsl for an average of 49 days per year. Given the assumptions above, the 2000 Rule Curve has the potential to significantly erode one archeological site that would not be affected by the 1970 Rule Curve.

The 1970 Rule Curve focuses erosive forces at approximately 337.7m amsl for an average of 68 days per year. Given the same assumptions, the 1970 Rule Curve has the potential to significantly erode two archeological sites that would not be affected by the

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2000 Rule Curve. Peak impacts would persist for an additional 19 days more than the 2000 Rule Curve (Figure 11 and Figure 12).

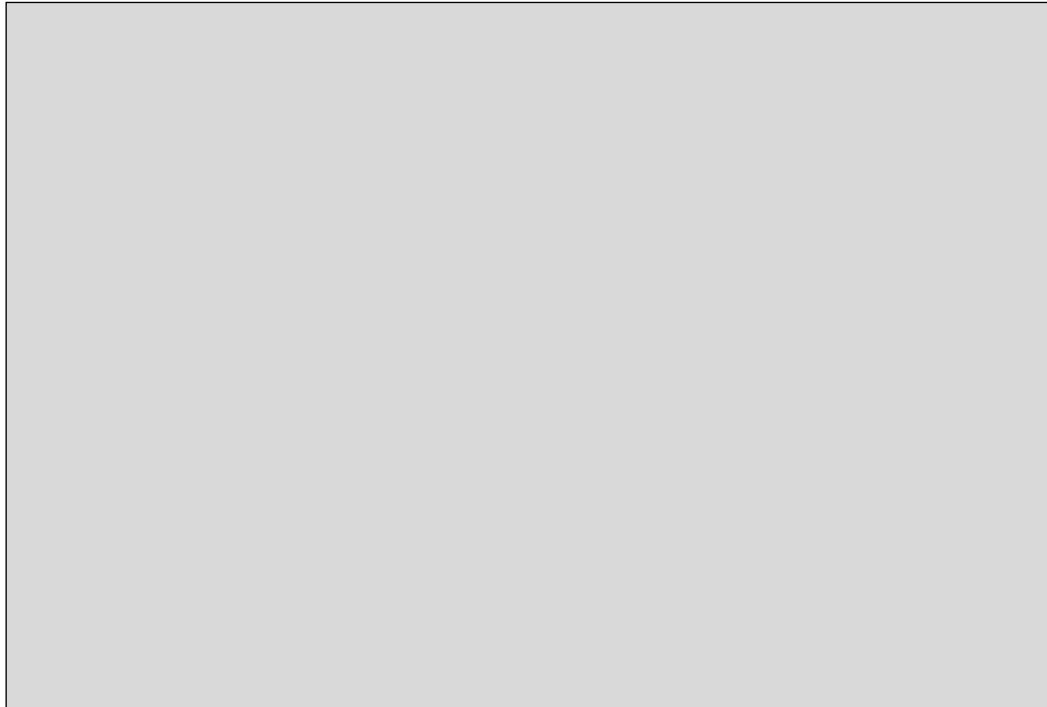


Figure 8. Elevation where stasis is greatest on Kabetogama Lake. Sites with impacts are displayed.

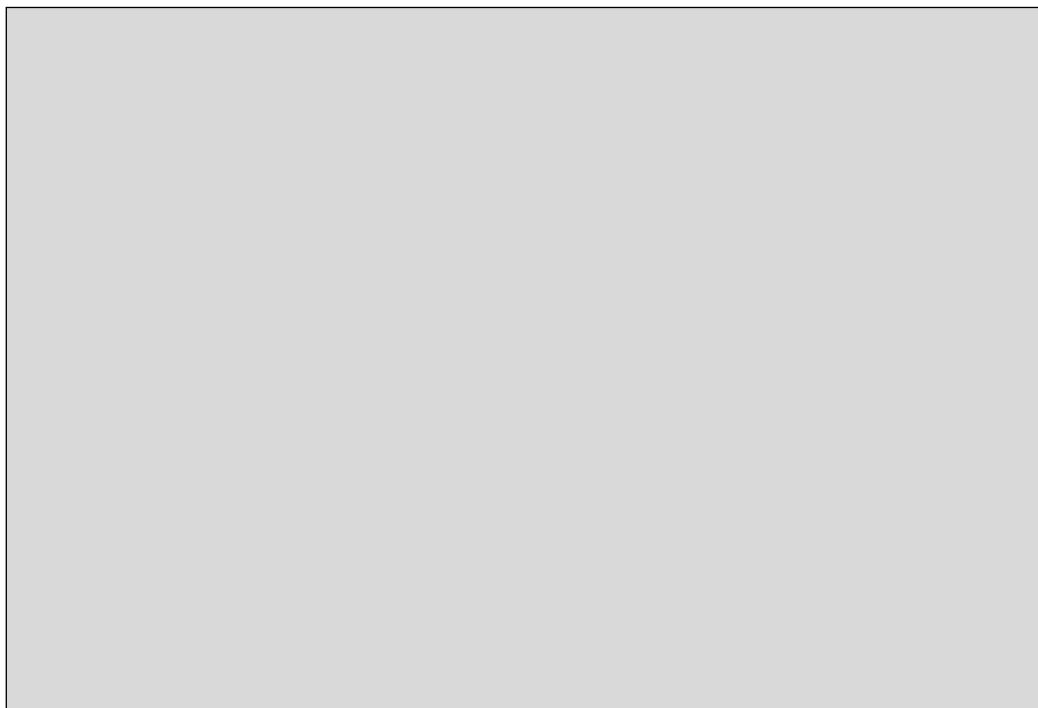


Figure 9. Elevation where stasis is greatest on Namakan Lake. Sites with impacts are displayed.

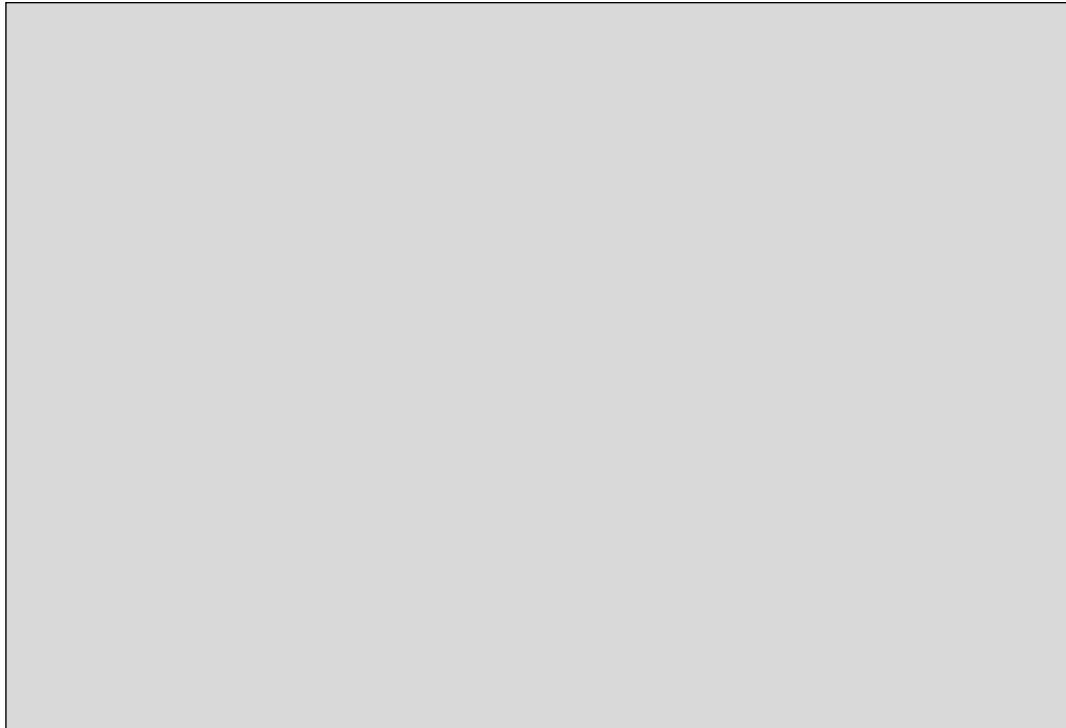


Figure 10. Elevation where stasis is greatest on Sand Point and Crane Lakes. Sites with impacts are displayed.

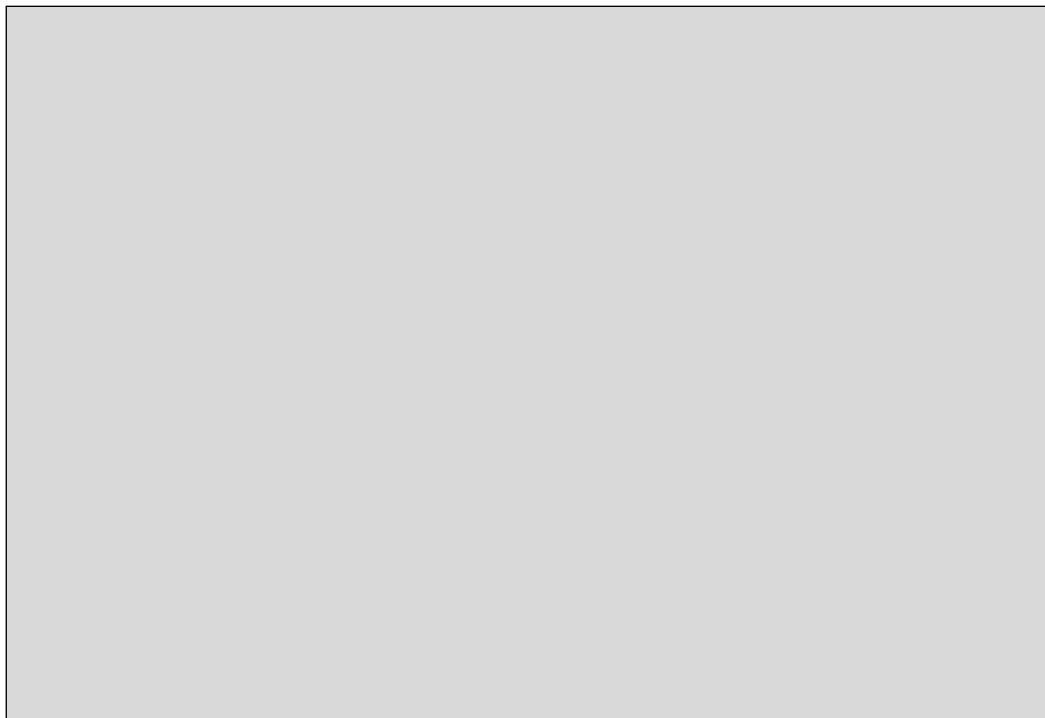


Figure 11. Elevation where stasis is greatest on the west end of Rainy Lake. Sites with impacts are displayed.

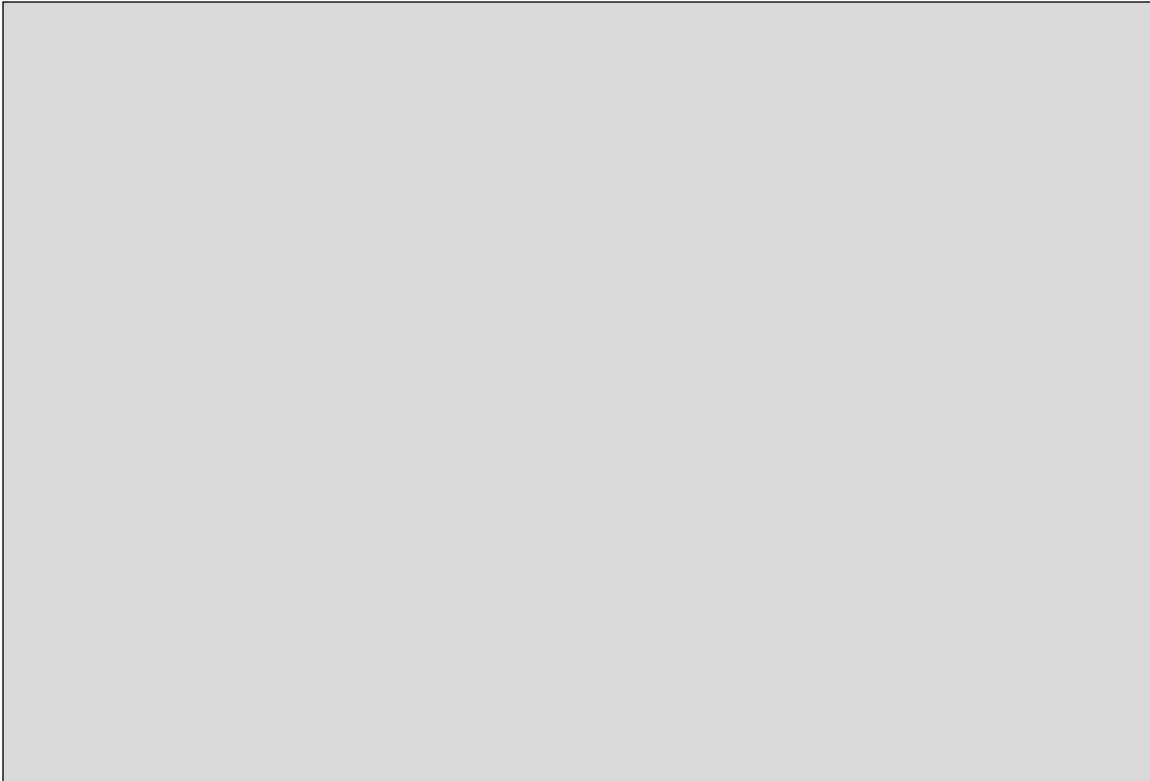


Figure 12. Elevation where stasis is greatest on the east end of Rainy Lake. Sites with impacts are displayed.

Summary of Spatial Analysis

In terms of both the number of sites affected, and the overall period during which erosion is greatest, the 2000 Rule Curve is more conducive to the preservation of archeological resources. Two caveats should be noted, however. First, the 17 sites affected by the 2000 Rule Curve, while fewer, are not interchangeable with the 29 sites affected by the 1970 Rule Curve. Any subset of archeological sites may possess significant information about history or prehistory not present in another subset of sites. Second, many archeological sites are equidistant from the peak erosive force contour of both Rule Curves, and are therefore not displayed in Figure 8 through Figure 12. In such cases, stasis time holds the greatest analytical value by predicting the rate of erosion on these sites. In every such case, the 2000 Rule Curve exhibits shorter stasis time and therefore impacts these sites to a lesser (or slower) degree.

With these caveats in mind, the 2000 Rule Curve has negatively impacted fewer known cultural resources as compared to the 1970 Rule Curve. Stasis time is considered the primary metric in this evaluation, with lower stasis times translating to fewer erosional impacts. Nevertheless, the elevation at which water is held constant has unique consequences for a unique set of archeological resources, many of which remain undiscovered. Prescribing new elevations for water levels would introduce erosion to a third subset of archeological resources, and is not recommended.

FIELD VERIFICATION

Site Selection Process

Fieldwork was undertaken on June 15, 2014 through June 27 to examine and verify the effects of variable water levels through time at relevant sites and landforms. From the total of 446 archeological sites identified at Voyageurs, 32 were chosen as the minimum sample group based on the presence of historical data pertaining to geomorphology. Study sites were selected by the following process:

First, archeological sites with the potential to be affected by fluctuating lake levels were identified. To locate these places, archeological sites listed in the ASMIS database located between the maximum and minimum modeled lake levels for both Rule Curves were selected with an SQL query of elevations derived from the 10m horizontal resolution DEM prepared by Morin et al. (2014). Maximum modeled lake levels vary between Rule Curves and between basins. On Rainy Lake, maximum modeled lake levels are approximately 339.08m (which occurred under the 2000 Rule Curve), while in the Namakan Reservoir, maximum annual lake levels are approximately 342.02m (also under the 2000 Rule Curve). To capture all the sites that are potentially susceptible to erosion due to lake management practices, a conservative elevation buffer of 3m was added to the maximum potential lake level elevation, and archeological sites that fell outside the expanded range were excluded from the field analysis. This strategy identifies the largest population of archeological sites that are potentially susceptible to erosion from changing lake levels. Therefore, archeological sites that are located at elevations less than 345.02m on the Namakan Reservoir, and less than 342.08m on Rainy Lake were compiled into an initial table (n=381).

Next, a subset of this table was generated based on the existence and quality of historical landform information. Sites without reported geomorphic contexts, elevations as reported by previous researchers (which provide more fine-grained topography than the values extracted from the DEM to the site center point), or site map information were excluded from consideration. These exclusions were determined by selecting archeological sites from the initial list that are further augmented by various reports, unpublished manuscripts, and archeological site files at MWAC. The selected sites were considered the minimum sampling group, each having sufficient historical data to reflect the environmental effects of the 1970 Rule Curve on landforms. These sites and the associated data allow for an equal comparison between the Rule Curve scenarios (n=32). This strategy captured most of the sites within the park.

Finally, this list was divided into analytical categories based on the site's environmental contexts: lake bottom (i.e., submerged sites), littoral zone, or terrace. These categories are based on inferred formation processes. In instances where multiple landform determinations existed (for example when a site was listed in the database as submerged and as a beach), the site was placed within the category which was considered most erodible. Within the littoral zone and

terrace categories, a 50% random sample was chosen as a representative number of archeological sites for a time-limited field study. The “lake bottom” category is small enough that all were included for study. The archeological sites remaining on the list are considered the minimum number of sites in three categories necessary to complete the evaluation (n=20). Overall, this sample includes about 5% of all known archeological sites within the park. These sites cover the three major geomorphic contexts that may be affected by lake level changes. Observations made at these sites should be considered generalizable to basin scale processes within the park.

In the field, archeological crews encountered unusually high water during the summer of 2014. As planned, we prioritized the 20 sites previously selected, and were able to expand our visual inspection to a total of 62 archeological sites in diverse contexts (Figure 13). Comparative data are sparse for many of the additional sites, but we chose to particularly examine sites that were 1) potentially affected by high water, and 2) that allowed for photographic documentation of erosion. Ultimately, visiting these sites at practically unprecedented water levels enhanced our ability to understand and evaluate the effects of even short residence times, and the consequences of sudden water level variation. Of the 62 sites visited, 51 were located in the littoral zone and, consequently, were submerged. The remaining 11 were located on terraces.

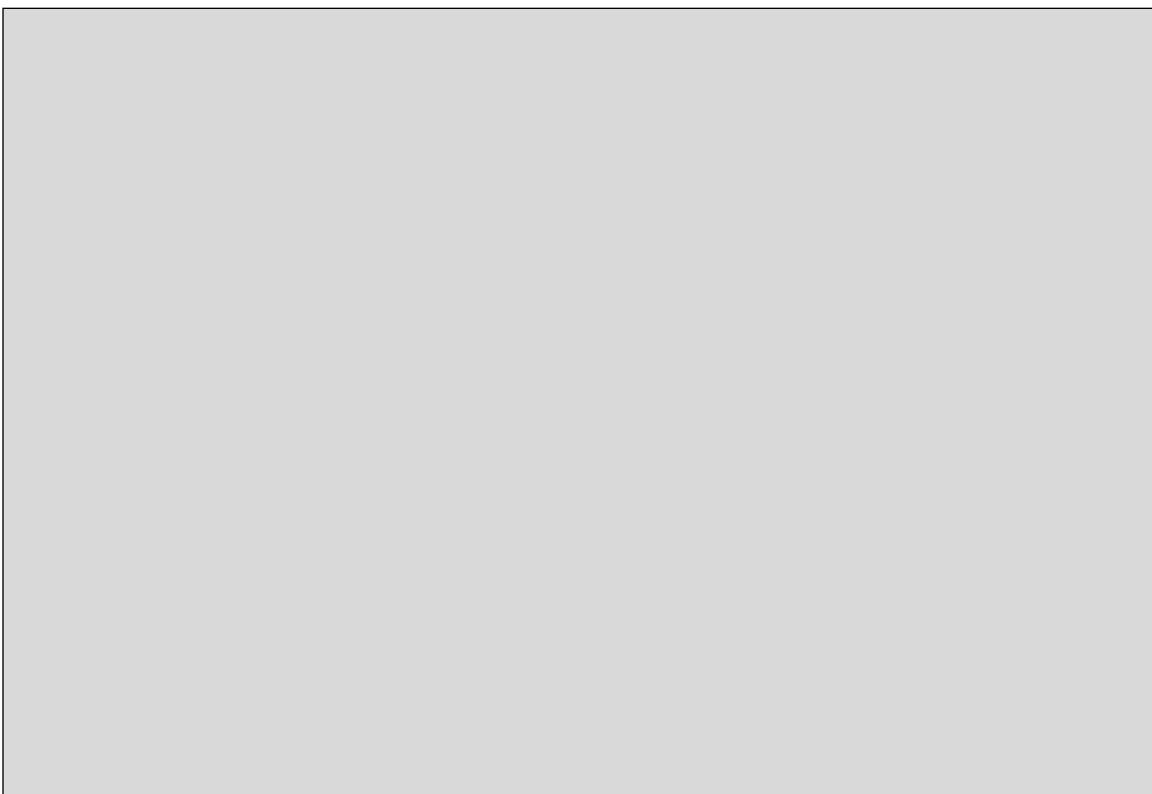


Figure 13. Sites selected for field assessment in June 2014.

Permanent datums were installed at 10 of the 62 sites, and the landforms were mapped to within 50cm using a Trimble differential GPS base station. These permanent,

well-defined markers can be used to recreate similar maps and monitor lake level effects in the future. (Note: we did not install a datum at 21SL204 because the site is located along a heavily trafficked trail and we did not want to draw attention to the sensitive resources.) The landforms were also photographed and all archeological observations were documented (Figure 14). These data are generally reflective of the effects of the 2000 Rule Curve, with the more immediate effects of the flood also plainly visible. Conditions at each site, independent of flooding, verify our expectations of site conditions given the targeted water levels under the 2000 Rule Curve.

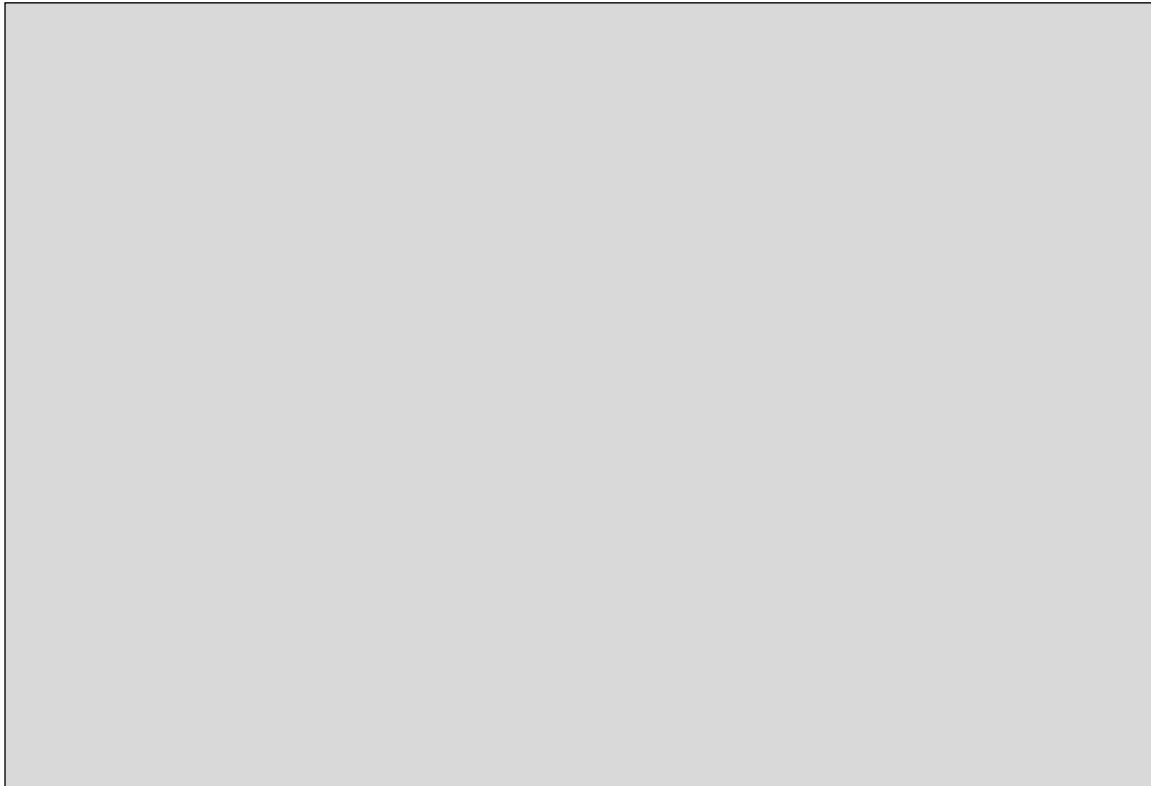


Figure 14. Sites intensively evaluated and mapped in June 2014.

Results

Lacustrine Terrace Sites

We photographed and collected GPS locations at eleven archeological sites that were located on lacustrine terraces. Two sites were located on Rainy Lake while the remaining nine were located throughout the Namakan Reservoir. In comparing the present conditions of these landforms to their documented conditions under the 1970 Rule Curve, dramatic environmental differences were not evident. We were able to identify the same features (natural and cultural) as earlier researchers, and to locate the places where erosion had occurred by the 1970s. We then identified either actively eroding or potentially eroding surfaces at eight locations, all located in the Namakan Reservoir. Three terraces are clearly and observably eroding, while the remaining five terraces are potentially eroding.

EVALUATION OF SHORELINE IMPACTS AND LONG-TERM MONITORING

At site 21SL51 and 21SL53, recent terrace collapses or undercuts were observed due to the flood of 2014 (Figure 15). Erosion was rapid and observable over the course of several days. A similar situation was encountered at 21SL898, but we did not observe terrace collapses (Figure 16). Erosion was identified in the past at these locations, so the overall geomorphic environment created by the two Rule Curves at these sites can be considered similar.



Figure 15. Erosion at sites 21SL51 (top) and 21SL53 (bottom), June 2014.



Figure 16. Headwall erosion at site 21SL898, June 2014.

Five other sites (21SL83, 21SL141, 21SL38, 21SL32, and 21SL1051) displayed either de-vegetated and eroded terrace walls, or places where recent terrace collapses appeared to have happened, suggesting that wave wash is occurring. The potential for further erosion, however, is sparse and situational. In two locations, 21SL83 and 21SL141, the only barren and eroding places are associated with beaver slides. Otherwise, these two sites appear to have stabilized some time ago, based on the presence of trees (>10cm+ diameter) growing out of the terrace face or immediately adjacent to the terrace edge (Figure 17). In these places, the terrace edge may have been stable for roughly 30-40 years based on a growth model (mean of 0.1cm/year) for trees in the Northeast (Teck and Hilt 1991). Erosion at the remaining sites (21SL38, 21SL32, and 21SL1051) is inferred because the terrace headwalls were partially stripped of vegetation, which suggests that wave scouring is occurring. In all cases, preexisting terrace erosion was exacerbated by the high water.

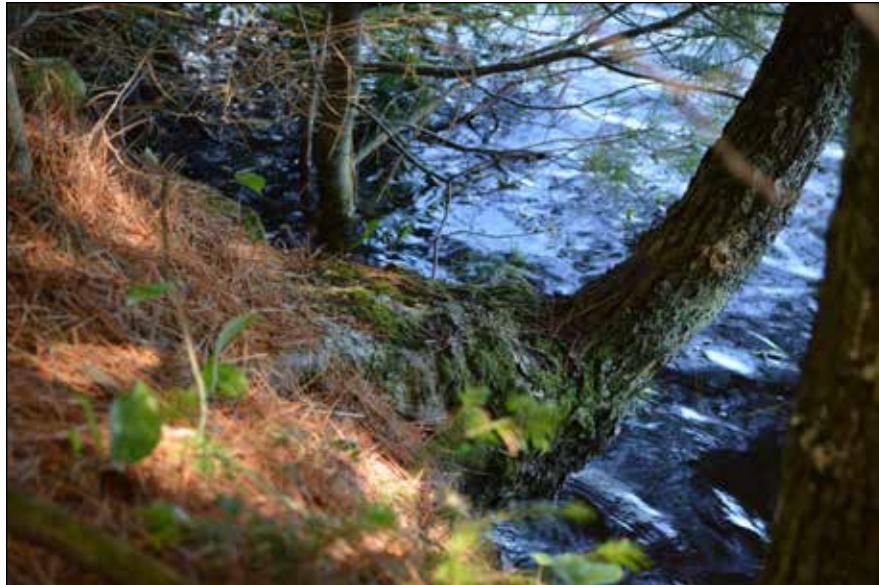


Figure 17. Tree growth after past slumping, site 21SL83, June 2014.

Of the eleven terrace sites we visited, previous researchers identified erosion at eight. Results of the June 2014 survey suggest that erosion is slowing since the sites were documented and, park-wide, landscapes are generally stable.

We did see instances of overtopping, where unusually high water has removed the organic layer on the terrace surface (Figure 18).



Figure 18. Overtopping at site 21SL83, June 2014. Wave washing has removed the organic layer.

We documented a similar situation at 21SL38 (Figure 19). This site consists of two artifact concentrations, one on a beach and one on a terrace (Thompson 1979, notes on file at MWAC). Based on the archeologists' description, the artifacts on the beach were likely deposited as the elevated terrace eroded. Previous maps do not allow for an estimation of the amount of land lost since the 1970s, but the current rate of erosion is probably minimal. Past site condition assessments, from 2006 and 2011, note a barren scarp. However, we observed vegetation and a young tree growing on the edge, suggesting that the terrace edge has not recently eroded.



Figure 19. Terrace headwall at site 21SL38, June 2014.

Overall, our observations suggest that lacustrine terraces and archeological sites located on them are not currently impacted by the 2000 Rule Curve any more significantly than by the 1970 Rule Curve. Erosion was greatest when water levels were altered and then held constant, such as when the dams were installed or when new Rule Curve strategies were adopted. Since then, terrace erosion has either ceased or slowed perceptibly, especially on the Namakan Reservoir, except in cases of extreme (beyond Rule Curve limits) floods.

Direct observations of the 2014 flood demonstrate that erosion effects occur rapidly until landforms reach equilibrium. After the 2014 water levels reached their peak, a residence time of only a few days at that elevation introduced significant erosion at otherwise stable terrace sites. This supports the use of stasis time as a valuable metric for the evaluation of the Rule Curves' effect on shoreline stability.

Littoral Zone Sites

All sites in the littoral zone were flooded during June 2014. Despite their inaccessibility, we visited 51 sites that were described in the archeological record as having sandy, muddy, or rocky beaches. Site 21SL196 was typical of flooded littoral zone sites. Woody plants and grasses cover the site, suggesting that it is typically exposed and out of the wave zone long enough that plants can grow. Archeologist Forrest Frost (1987) describes the site as inundated, as would be expected under the 1970 Rule Curve. During the summer peak, water levels over the site would be very shallow (about 30-60cm) exposing artifacts to wave action throughout this period. A later assessment (Richner 2003) indicates that much of the site was exposed within the beach zone. The site is now inundated during the early summer high stand and exposed during the draw down, as is expected under the 2000 Rule Curve. Although flooded during our 2014 fieldwork, vegetation patterns appear similar to those mapped by Richner in 2003, suggesting that the landform has not been significantly impacted by the 2000 Rule Curve between 2003 and 2014. Similar geomorphic contexts were found throughout the Namakan Reservoir (Figure 20).



Figure 20. Flooded conditions typical throughout the Namakan Reservoir and Rainy Lake (site 21SL200 pictured), June 2014.

As a rule, all archeological sites in the littoral zone are disturbed by waves. During any initial period of inundation, the information loss is greatest as the most fragile artifacts and ecofacts are washed away or degraded. This disturbance certainly occurred over 100 years ago when the dams were first installed, and has reoccurred when water level management policies change.

Lake Bottom Sites

We were unable to observe lake bottom sites in 2014, and archival data on these sites are minimal. These places are typically exposed during periods of very low water that are not regulated by Rule Curve specifications. Because archeological sites in lake bottom environments are continuously buried by organic deposition and silting, the impacts of the two Rule Curves are considered similar and negligible. Lake bottom sites may nevertheless experience detrimental effects of low water during the winter. Although wave action is scant to non-existent, the impact of ice erosion on the landscape of Voyageurs is unknown. Currently, we believe that ice does not exert a major impact on the geomorphology of the park since the typical push-mound (ridge) and scour features found on large lakes (e.g. the Great Lakes) do not occur in the park, but freeze/thaw effects and the weight of the ice itself may directly impact artifacts. We have insufficient knowledge of submerged archeological resources to draw conclusions about these effects.

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PROJECT SUMMARY AND RECOMMENDATIONS

A series of questions posed in the scope of work were designed to guide this study. These questions are addressed below:

1. What archeological sites within Voyageurs exhibit shoreline instability and what are the settings or conditions for these locations?

All 51 archeological sites in the littoral zone and the eight terrace sites listed above (see “Lacustrine Terrace Sites”) exhibit some form of instability. Instability of sites in the littoral zone is generally minimal but erosion is constant as long as the archeological site is within the wave zone. Lacustrine terrace sites are stable but can catastrophically erode in a very short time.

2. How do water levels, as determined in the Thompson (2013) hydrological model of the 2000 Rule Curve, behave at archeological sites with unstable shorelines?

The surface of the water down to the base of the wave zone is the most energetic environment. One direct predictor of erosion is the water’s surface elevation. Erosion is a function of energy integrated over time. The longer the water level remains constant, the greater the erosion at that elevation.

3. Does the output from the Thompson (2013) hydrological model of the 1970 Rule Curve produce a different set of modeled shoreline impacts or areas of instability when compared to the model of the 2000 Rule Curve?

Yes, the two Rule Curves produce different sets of impacts. The impacts of lake level management can be seen by comparing the annual water level fluctuations. The 1970 Rule Curve produces a flat shape with little variability across the summer. This kind of shape indicates that wave energy would be focused at a single elevation for a long period of time, long enough to create wide, well-developed beaches on landforms (and consequently archeological sites) with fine-grained substrates. Initially, keeping lake levels stable for a long period of time may also exacerbate erosion on fine-grained terraces. However on both beaches and terraces, after initial soils loss, erosion rates would slow and landforms would largely become stable again.

In terms of creating new areas of instability, the 1970 and 2000 Rule Curves produce very similar results for the Rainy Lake. For the Namakan Reservoir, the maximum under the 2000 Rule Curve is slightly lower (approximately 20cm) and the minimum is nearly 1m higher, meaning no “new” elevations or areas are affected. The amount of time water levels reside at particular elevations is the critical factor in the rate of ongoing erosion.

4. What are the conditions at the selected archeological sites during naturally low and high water conditions independent of the 2000 Rule Curve?

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Naturally high and low water levels (i.e. water levels that fluctuate beyond Rule Curve specifications) can lead to accelerated erosion. Lacustrine terraces are more vulnerable to erosion since waves can directly abrade terrace scarps during high water. Beaches in front of lacustrine terraces attenuate wave energy during normal water levels, but when water rises above the beach level, vulnerable sediments can be quickly washed away by high energy waves. During exceptionally low water, previously protected archeological sites can become vulnerable to wave erosion as water levels drop, or to wind erosion that can occur when fine-grained organic sediments found on the normal lake bottom are dried.

5. What are useful vital signs and monitoring protocols for tracking and documenting future Rule Curves and water level fluctuations?

Vulnerable archeological sites (“Lacustrine Terrace Sites”) should be visited by an archeologist on a biannual basis, once in the spring and once in the winter. These sites should also be visited during any out-of-specification high water events when possible. A sample of archeological sites should be visited during low water to document any exceptional conditions. A sample of sites in the littoral zone should be visited at least every five years, during low water, to observe any dramatic landscape changes.

CONCLUSIONS

A comparison of field conditions with the modeled lake levels of the 1970 and 2000 Rule Curves reveals several critical variables affecting archeological resources. All things being equal (i.e., soil type, vegetation, aspect, etc.), stasis time is the best indicator of erosion potential. The longer an archeological site is exposed to waves, the greater the chance for erosion. Allowing the water levels to remain static at a single elevation for a significant time period is more detrimental to archeological resources and the landforms on which they occur than a more variable lake elevation. In this respect, the 1970 Rule Curve for the Namakan Reservoir has a greater potential to cause erosion with a mean stasis time of 67 days per year at a single elevation of 340.9m. This represents a difference of nearly three weeks more stasis than the 2000 Rule Curve, which has a maximum of 46 days at 340.6m. These results are similar for Rainy Lake where the 1970 Rule Curve has a maximum static elevation of 337.7m for 68 days, while the 2000 Rule Curve has a maximum stasis of 49 days at 337.6m.

Secondary to differences in stasis time, the elevations of shoreline stasis differ between Rule Curves. This difference changes the expected elevation for erosion, and affects a different subset of archeological sites. Based on a spatial query of archeological sites within 10m of the two peak- erosion elevations, the 2000 Rule Curve potentially erodes a total of 17 recorded archeological sites, as opposed to 29 sites affected by the 1970 Rule Curve.

Changes to maximum water levels tend to affect landforms significantly for a period of time, as sediments are quickly eroded. They eventually stabilize as erosion slows to a point that it becomes negligible, except during exceptionally high- or low-water events when erosion can accelerate. During the flood in June 2014, we observed the loss of soil on previously unaffected shoreline terraces within a matter of days. Currently however, landforms have stabilized under the 2000 Rule Curve. Changing the prescribed maximum water levels would introduce further erosion, before eventual re- stabilization. Even though the landforms are stable, they are eroding over the long term, regardless of these or future management practices. Holding lake levels steady for centuries to millennia will eventually remove archeological sites on vulnerable sediments, though these time scales are typically beyond the scope of management.

Prescribed minimum water levels indicate which archeological sites are submerged, and how often. Under the 2000 Rule Curve, seven sites are nominally submerged that were exposed under the 1970 Rule Curve. Because lake bottom sites exist in a depositional environment, completely submerging archeological sites buries and preserves sites in place. The 2000 Rule Curve maintains those seven sites (and others that remain undiscovered) in a more stable, less energetic physical environment than the 1970 Rule Curve. It should be noted, however, that while submerging sites would appear to preserve them in place, other potential effects such as chemical alteration of materials, transport of fine materials, and the mechanical effects of ice are not well understood.

In conclusion, the 2000 Rule Curve likely had an adverse effect on archeological resources when it was introduced, but landforms have since stabilized under the current

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timing and duration of summer water levels. Moreover, the 2000 Rule Curve exhibits lower total stasis time, reducing the rate of erosion at specific elevations as compared to the 1970 Rule Curve, and potentially affecting fewer sites overall. The 2000 Rule Curve also inundates (i.e. protects) archeological sites that the 1970 Rule Curve does not. The 2000 Rule Curve is therefore recommended without modification on both basins for the continued preservation of cultural resources at Voyageurs National Park.

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