Appendix D – Summary of Geotechnical Study: Geophysical Survey Report

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GEOPHYSICAL SURVEY REPORT
F.J. MCLAIN STATE PARK
HOUGHTON COUNTY, MICHIGAN

Prepared For:

MICHIGAN DEPARTMENT OF NATURAL RESOURCES
Baraga, Michigan

Prepared By:

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Materials Testing Consultants, INC.

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REPORT OF GEOPHYSICAL SURVEY
F.J. MCLAIN STATE PARK

1.0 INTRODUCTION

F.J. McLain State Park is a 418-acre State park with approximately two miles of shoreline along Lake Superior situated in T56N, R34W, Sections 21, 22 and 23 in Houghton County, Michigan. The Park is accessed from M-203 near its midpoint with modern and rustic campsites from the midpoint to the east, and road access from the midpoint to the west to a bathhouse and shelter structure. A toilet building is located in the middle of the park in an area referred to as the headland with a sanitary station also located in this area.

The Park is bordered by the Keweenaw Waterway upper entrance (aka Portage Canal) at its southwest corner and was opened in 1938. The Park shoreline along Lake Superior has experienced high rates of soil erosion to the point where portions of campground infrastructure (roadways, campsites, utility lines) have been undermined or are in jeopardy of being eroded in the near future. Master planning at the Park is challenging due to the uncertainty of future shoreline erosion. The Keweenaw Waterway was constructed in or around 1890 interrupting the alongshore transport of sand from south of the waterway to the Park. For many years this natural beach replenishment process was artificially replicated by manual placement of dredged sand particularly stamp sand. Placement of dredged sand was discontinued in the late 1970s believed to have resulted in increased erosion rates along the lakeshore.

1.1 Objectives

The DNR was awarded a 2014 Coastal Zone Management Grant for the purpose of developing a Management Plan for the Park. Completion of a geophysical survey to collect pertinent subsurface data will aid in the management plan development. The geophysical survey will collect data on the depths to bedrock and establish the general subsurface soil profile for the overburden at selected locations across the study area which will include 264-acres of the existing Park generally north and west of M-203 extending to Lake Superior. This data will be useful in future master planning activity for infrastructure relocation.

1.2 Literature Review

Various background data and studies have been reviewed by our office in preparation for our geophysical survey investigation and report. Summaries of this review follow.

1.2.1 *NOAA National Data Buoy Center, Station PCLM4*

This weather buoy is located along the Keweenaw Peninsula along Lake Superior northeast of F.J. McLain State Park near 47.276N, 88.528W. Wind speed is recorded at this buoy but not wave height. Historical data is provided on the NOAA website dating back to 2006. We reviewed the historical monthly data from June 1, 2006 to May 31, 2007 for various sustained wind speeds and wind directions through these monthly time periods. The purpose of this review was to provide maximum wind speeds and directions in a randomly selected year since the prior studies did not provide a very detailed accounting of recorded storm events. This review resulted in the following data sets:

Month	***Date(s)***	***Wind Speed, mph***	***Wind Direction, °***
June 2006	22nd	9.5 to 13.6	45 to 75
July 2006	4th	11.3 to 17.8	340 to 355
	9th	11.6 to 30.5	290 to 5
	9th	13.3 to 27.0	30 to 50
August 2006	7th	11.6 to 22.7	300 to 0
	15th	12.8 to 24.3	305 to 340
September 2006	19th	14.2 to 22.7	350 to 20
	25th	11.6 to 24.7	300 to 330
	28th	14.7 to 24.1	30 to 55
October 2006	9th	13.8 to 25.6	0 to 45
	11th to 15th	14.5 to 37.7	300 to 5
	18th	15.8 to 29.9	290 to 350
	29th	14.0 to 28.5	290 to 10
November 2006	Oct 31st to 3rd	20.5 to 39.2	260 to 330
	29th to 30th	16.5 to 33.0	290 to 330
December 2006	6th to 7th	19.9 to 29.0	310 to 10
	17th	18.9 to 32.3	285 to 330

January 2007	1st	19.2 to 30.1	10 to 40
	8th	18.7 to 29.0	315 to 330
February 2007	11th	18.1 to 24.1	305 to 325
March 2007	2nd to 3rd	12.2 to 29.6	10 to 70
	4th to 5th	15. 1 to 34.5	275 to 20
	19th	18.2 to 34.1	300 to 20
April 2007	4th	26.5 to 38.5	5 to 60
	7th	23.4 to 30.1	350 to 20

Table 1: Wind Event Summary from 2006 to 2007 (NOAA Station PCLM4)

Of the 25 recorded events throughout the year (May did not produce a significant wind event), 13 produced winds between a NW to N (315° to 360° DTN) bearing and 7 events were within a N to NE (0° to 45° DTN) bearing. A wind direction perpendicular to the shoreline southwest of the headland peninsula is approximately 316° and perpendicular to the shoreline east of the headland is approximately 348°. The average wind direction was within 10° of being perpendicular to the shoreline southwest of the headland in 10 of the storm events but was within 10° of perpendicular east of the headland in 3 of the 25 events.

1.2.2 *1982 The Bedrock Topography of the Keweenaw Peninsula, Michigan*

Elmer J. Warren presented this dissertation in partial fulfillment for his Doctor of Philosophy degree to Michigan Technological University in 1981. The F.J. McLain Park is located in an area of Precambrian Freda Sandstone generally dipping 25° or less from the Keweenaw Fault (located south and east of the Park) to the Lake Superior basin. Bedrock is estimated to be near el 600 at the McLain State Park headland.

1.2.3 *1997 McLain State Park Erosion Study*

This study was completed by the U.S. Army Corps of Engineers (USACE), Detroit District in 1997. The study concluded that the Keweenaw upper entrance navigational structures (breakwalls) constructed around 1890 have acted to block the longshore transport of sand from the south and that this material was replaced for many years after the Park was constructed in 1938 by placement of dredged sand consisting of a mining by-product called stamp sand north of the breakwalls along the Park shoreline. The process was discontinued in the late 1970s leaving the Park bluffs more exposed to erosion from wind and wave energy. It was estimated the beach recession rate from 1938 to 1991 (1971?) averaged around 3 feet per year and in a more recent period of 1978 to 1996 averaged around 8 feet per year with a rate of 7.5 ft per year from 1995 to 1997. Periods of record or near record lake levels were also stated as a contributing factor causing erosion of the offshore. It was estimated a beach recession rate of 7.5 feet per year will continue over the next 50 years. The sandstone was reported as being very near the surface near the Keweenaw Waterway sloping up to an outcropping 4000 ft northeast (the Park headland).

The report concludes with a summary of recommended erosion protection alternatives including "structural", "beach nourishment" and "no action." Structural erosion protection (groins, revetment, seawalls, etc.) were not recommended due to overall construction and maintenance costs as well as the inevitable loss of Park recreational area. Short reaches of structural erosion protection were mentioned as a method to protect existing facilities where relocation was not possible, however, no such facilities were noted in the report. Beach nourishment was described as a practical method to reduce future erosion rates to approximately 3 ft per year. Taking "no action" against the shoreline erosions at the Park and allowing the erosion process to proceed without interruption was selected as the preferred option by the USACE. Relocating/reconstructing endangered facilities considering projected erosion rates along with the acquisition of additional property to replace that lost along the Park shoreline due to erosion was recommended.

1.2.4 *2001 Shoreline Stability Study*

Prepared by W.F. Baird & Associates in July 2001, this study used computer modeling, sediment budgeting and GIS Analysis to predict future shoreline recession rates. Recession rates predicted were lower than reported in the U.S. Army Corps of Engineers 1997 study. Shoreline change from 1938 to 1998 along the beach southwest of the headland was reported at 4.1 ft per year and east of the headland over this period, an accretion of 0.2 ft per year. It was stated the shoreline southwest of the headland is converging to a stable orientation and may currently be close to stable. The report reasoned an azimuth perpendicular to the beach of 290° or possibly higher would represent a stable beachfront. The current azimuth for this beach is approximately 316°.

The report concludes that future shoreline recession rates on the order of 0 to 3.3 ft per year are expected with the east fillet beach continuing to converge towards a more stable orientation (and may currently be close to stable). Decreasing recession rates have been measured east of the headland, however, a decreasing sediment supply from the west may affect this rate in the future due to stabilization of the east fillet beach. Additional recommended investigation tasks were outlined at the conclusion of the report which are summarized below:

- A detailed hydrographic survey of the area in the nearshore
- A detailed geologic survey of the area including type and elevation of bedrock
- Additional land surveying to provide greater erosion rate accuracy
- Consolidation and clarification of Keweenaw Waterway dredging records
- Use of aerial photographs taken between 1986 and 1998 to confirm GIS analyses
- A complete two dimensional wave transformation to estimate revised sand transport estimates
- A longer and more current wave hindcast

1.2.5 *2013 MTU Geophysics Class reports*

Three separate groups from Michigan Technological University's Geophysics 3900 Field Geophysics class presented reports dated July 18, 2013 and July 22, 2013 primarily using gravity and seismic geophysical techniques to estimate the bedrock elevation at select locations within the Park. Four seismic locations were selected in these field investigations to determine bedrock elevations with all the points located along the Park drive which parallels the shoreline between the breakwall and headland. Points A and B were located within the headland with points C and D located west of this area. These reports concluded the bedrock depth was at approximately 16 ft (el 600) at Points A and B, 43 ft (el 582) at Point C and at a depth of 72 ft (el 551) at Point D.

1.2.6 *Recorded Bluff Recessions by Park Personnel*

Recession rates from 1995 to 2013 were obtained from DNR Park Administrators consisting of ground measurements from 17 locations extending from the headland approximately 4000 ft east along the Park shoreline. Points 15 and 16 are located in the headland area and Points 3 through 13 are located along the existing modern campground facilities. Cumulative recession rates at Points 15 and 16 were 7 to 54 ft and east of the headland vary from 2 ft to the full amount (>45 ft) at point 11. Point 17 located southwest of the headland recessed 17 ft over this period. This data is presented in more detail in Section 2.2.

1.2.7 *2014 DEQ Bluff Recession Rate Analysis at F.J. McLain State Park – Final Report*

Based on aerial imagery and global positioning system data, shoreline recession rates between 1938 and 2014 were estimated to decrease from 4.3 ft/yr to 0.5 ft/yr along the length of shoreline extending east from the Keweenaw Waterway to the headland (0.5 ft/yr to 1.4 ft/yr at the headland). Shoreline recession east of the headland was measured to range from 0.5 ft/yr to 1.4 ft/yr between the same time period. Bluff recession rates between 1938 and 2014 were estimated to range from 1.3 ft/yr to 2.3 ft/yr east of the Keweenaw Waterway, approximately 0.5 ft/yr to 2.2 ft/yr at the headland and 0.6 ft/yr to 2 ft/yr east of the headland.

Although the estimated recession rates are based upon linear regression and, therefore, provide average recession rates over the 76 year monitoring period, the data appears to indicate that the shoreline immediately southwest of the headland is remaining fairly stable. Bluff recession between the Keweenaw Waterway and the headland appears to continue at an aggressive pace, however, the rate of shoreline recession has decreased significantly since 1938.

Partial summaries of prior reports and provided data sets have been presented in the above Sections 1.2.1 through 1.2.7. For detailed report methodologies and conclusions, copies of the individual reports and any particular report attachments should be reviewed.

2.0 COASTAL ZONE GEOLOGY

2.1 Park Geology

The Keweenaw Peninsula consists predominantly of Upper Precambrian volcanic and clastic sedimentary rocks. In general, Portage Lake Volcanics are overlain by the Copper Harbor Conglomerate, the Nonesuch Shale and the Freda Sandstone. The more recently formed Jacobsville Sandstone is generally present along the south side of the peninsula although faults are common throughout the area, the Keweenaw Fault is the most significant fault, bisecting the Keweenaw Peninsula for approximately 100 miles from the Porcupine Mountains to the Keweenaw Point (Figure 1). The Keweenaw Fault is a reverse fault whereby the Portage Lake Volcanics are thrust southeast over the younger Jacobsville Sandstone (Figure 2).

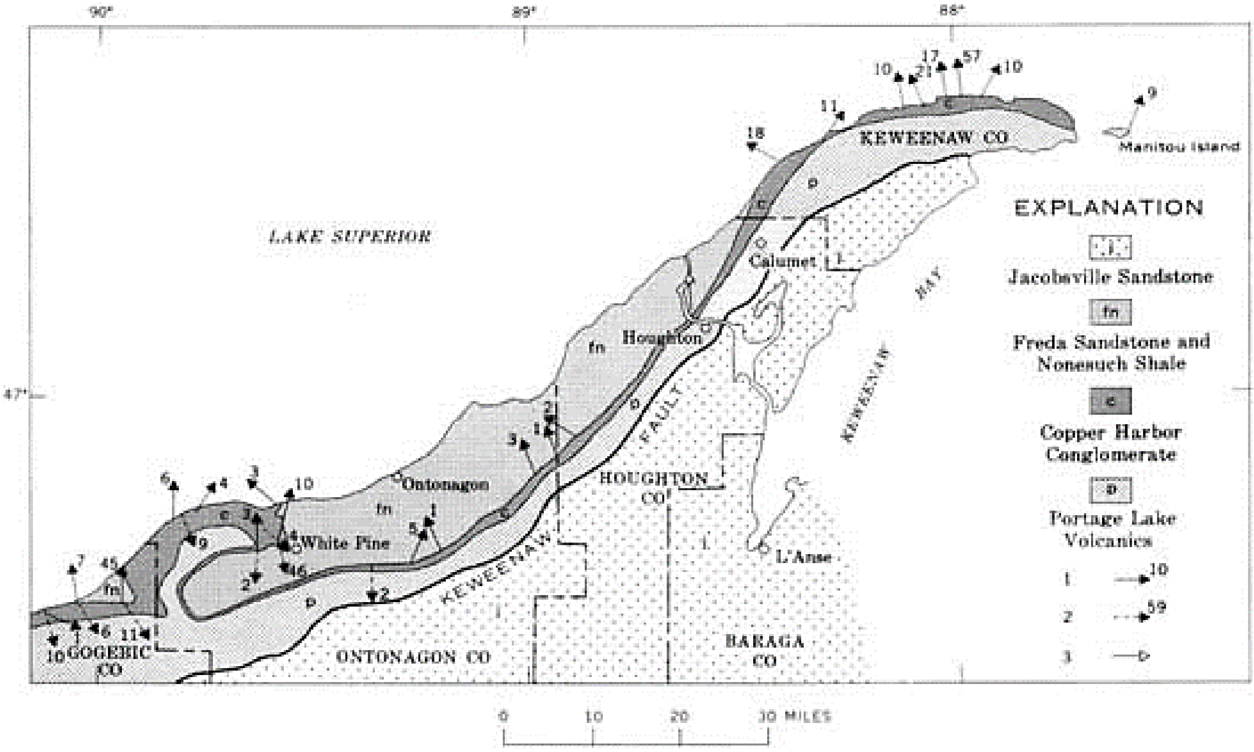

Figure 1: Generalized Geologic Map of the Keweenaw Peninsula (Wolff and Huber, 1973)

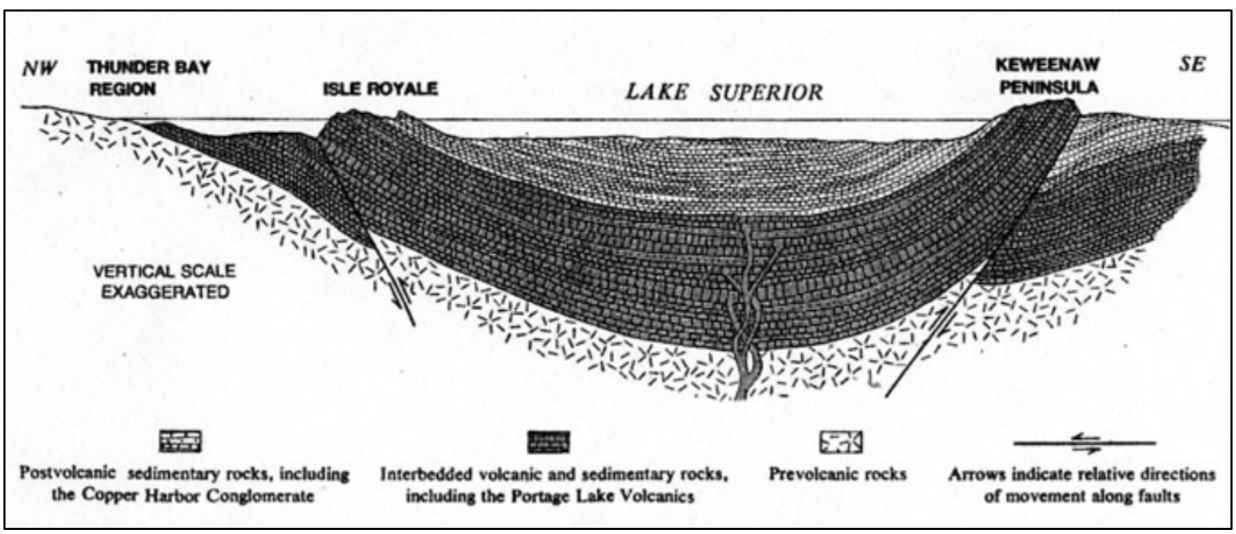

Figure 2: Cross Section of the Lake Superior Basin (USGS Bulletin 1309, Figure 38)

Much of the jointing of the Keweenaw Peninsula bedrock is tectonic in origin rather than glacial, especially along bedrock valleys. Bedrock valleys are common in the Keweenaw Peninsula ranging from 150 to 600 ft deep generally orientated northeast-southwest parallel to the Keweenaw Fault or north-south parallel to the western shore of the Keweenaw Bay. It is likely that bedrock valleys follow zones of structural weakness (fault zones) formed due to a combination of fluvial (river and stream) forces with subsequent glacial modification.

The Keweenaw Peninsula has been subjected to several periods of continental glaciation resulting in erosion of the bedrock surface as well as transport and deposition of geological material due to ice sheet advance and retreat. Abrasion and plucking (quarrying) are the two fundamental glacial erosion processes acting upon bedrock. The most recent major glacial advance occurred during the Wisconsinan Stage glaciation whereby ice sheets over 10,000 ft thick advanced over the Keweenaw Peninsula into central Illinois and Ohio. The final glacial advance was made by the Keweenaw Bay Lobe with southern extents marked by an end moraine which fills the Bear Lake bedrock valley. Glacial lake drainage during the retreat of the Wisconsinan ice sheet resulted in significant flow through the Portage Gap, erosion of the end moraine and the formation of the Keweenaw Waterway.

McLain State Park is located northeast of the Keweenaw Fault in an area underlain by the Freda Sandstone formation. The Freda Sandstone consists of layers of reddish, medium-to-fine grained, weakly cemented sandstone, siltstone and silty shale estimated to be at least 12,000 ft thick (Hite, 1968) commonly underlying lowland and valley areas indicative of their relatively low resistance to erosional forces relative to more resistant volcanic rocks (rhyolite, basalt, felsite, etc.). Glacial drift consisting of till clay typically overlies the sandstone bedrock over which lacustrine deposits of sand and gravel are present deposited as a series of recessional beach ridges. Although the ground surface elevation within the Park is relatively uniform, the variable top of bedrock elevation results in varying thicknesses of overlying unconsolidated material.

The surface of the Freda Sandstone below McLain State Park varies considerably based on geologic data collected by Warren (1981) from geophysical measurements as well as outcrops, water wells and diamond drill holes. The surface of the bedrock west of the Keweenaw Waterway along the shoreline of Lake Superior is estimated to be near el 600, sloping down to els 400 to 540 near the west side of the Keweenaw Waterway. Bedrock is estimated to be near els 500 to 560 along the east side of the Keweenaw Waterway sloping up to approximately el 600 at the McLain State Park headland located approximately 3600 ft east of the east upper entry Keweenaw Waterway breakwall forming a bedrock ridge extend north below Lake Superior and south towards the Bear Lake bedrock valley. Outcropping of the bedrock ridge can be observed immediately north of the headland within Lake Superior. The bedrock surface slopes down from the headland going east along the Lake Superior shoreline to approximately el 400 near the east end of the Park. Bedrock elevations south of the Park slope down to a low near el 100 at the Bear Lake bedrock valley.

2.2 Coastline Geomorphology

Appendix C contains shoreline photographs. Coastlines are dynamic environments shaped by a number of factors including underlying geology, physical processes (erosion) as well as human interaction and development. A coastline's geology controls the overall coastline geometry as well as sediment type and availability. Erosion from wave or wind energy and human effects acts to further shape the coastline beyond boundary conditions established through geological means.

Geologic factors affecting the erosion potential of a shoreline include, but are not limited to, the presence, type and condition of bedrock with relation to the shoreline as well as the composition of unconsolidated sediment. Sediment with a high silt content tends to be highly erodible while sediment containing a high clay content tends to be less erodible. Granular soil consisting of sand can be very erodible if composed predominantly of fine sand particles.

The primary erosional force for a coastline is derived from wave energy which is a function of wind energy and the length of water over which a given wind has blown (fetch length). Higher winds and larger fetch lengths result in larger waves with more erosion potential. Wave energy dissipating upon the beach and nearshore areas of a coastline result in the transport and deposition of sediment onshore, offshore and longshore.

Wave direction is a function of wind direction which fluctuates considerably across the Park shoreline. Based on University of Michigan's *Numerical Simulation of Nearshore Processes*, included as part of the *McLain State Park Erosion Study* (U.S. Army Corps Of Engineers, 1997) and a 32 year hindcast of wave conditions collected at Station S33, the Park is exposed to waves predominantly from the north and west with significant fetch distances ranging from approximately 50 to 150 miles resulting in average wave heights of 2 to 3 ft and maximum wave heights on the order of 15 to 30 ft. The most frequent wave direction is approximately 270º DTN (degrees true north) acting upon a shoreline orientated approximated normal to 340º DTN (west of waterway), 310º DTN (east of waterway to headland), and 350º DTN (east of headland). The largest wave heights were found to occur from approximately 270º to 292.5º DTN. The cumulative effect is wave energy concentrated offset from normal to the shoreline resulting in a net longshore transport of sediment towards the northeast.

The Park shoreline extends from the east entry breakwall of the Keweenaw Waterway northeast approximately 2 miles. The majority of the shoreline at the Park can be described as an unconsolidated shoreline, comprised of unconsolidated materials consisting of sand and gravel with a relatively high susceptibility to erosion forces. The Park headland, however, contain shallow bedrock very near the Lake Superior water level and is, therefore, less susceptible to erosion.

Lake Superior bathymetry (Figure 3) suggests water depths of 40 to 50 ft approximately one mile north of the Park shoreline between the Keweenaw Waterway and the Park headland. Approximately 2000 to 2500 ft north of shore, water depths gradually decrease from approximately 35 ft to 10 ft at a distance of 500 ft from shore where relatively shallow water resides adjacent to shore. Bathymetry data near the Park headland provides further evidence towards the presence of a shallow submerged bedrock ridge extending northeast below Lake Superior from the headland based on a shallow lake bottom on the order of 10 ft deep extending approximately 3000 ft north from shore. The shallow ridge transitions into a flat plane approximately 20 ft deep extending approximately 5000 ft north-northeast from shore. The west extent of the ridge is marked by a sharp downslope to depths of approximately 40 ft while the east extent of the ridge contains a much more gradual lake floor downslope.

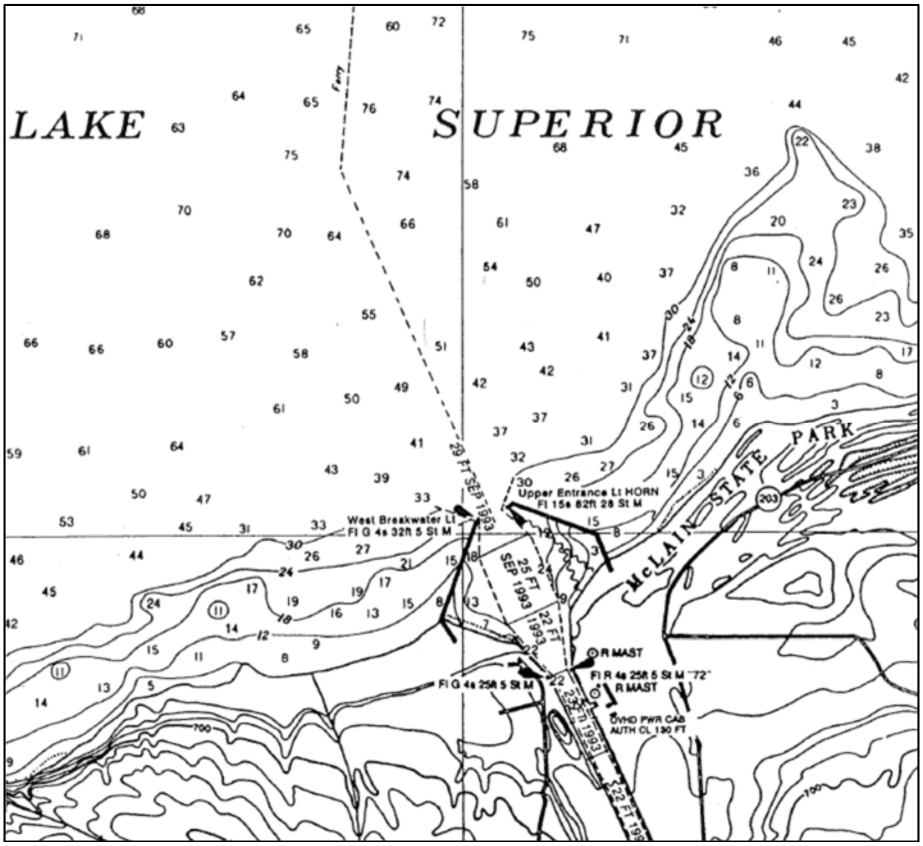

Figure 3: Lake Superior Bathymetry Data (USACE, 1997)

The Keweenaw Waterway upper entry navigational structures were constructed around 1890 and have created a man-made barrier to the natural longshore transport of sediment along the Lake Superior shoreline as is evident from deposition of sediment along the west breakwall. Dark grey sand generated from the processing of copper containing rock in the region known as "stamp sand" was commonly deposited southwest (updrift) of McLain State Park along the Lake Superior shoreline until 1976 when environmental concerns discontinued the continued placement of stamp sand. The combination of longshore sediment transport blockage from the Keweenaw Waterway breakwalls and the lack of shoreline regeneration through material deposition (both man-made and natural) have resulted in accelerated erosion of the McLain State Park shoreline beyond that which would naturally occur (U.S. Army Corps Of Engineers, 1997).

Maximum longshore sediment transport (LST) modeling was performed by W.F. Baird & Associates with predicted transport rates summarized below in Figure 4. The modeling was based upon wave statistics obtained near the Park.

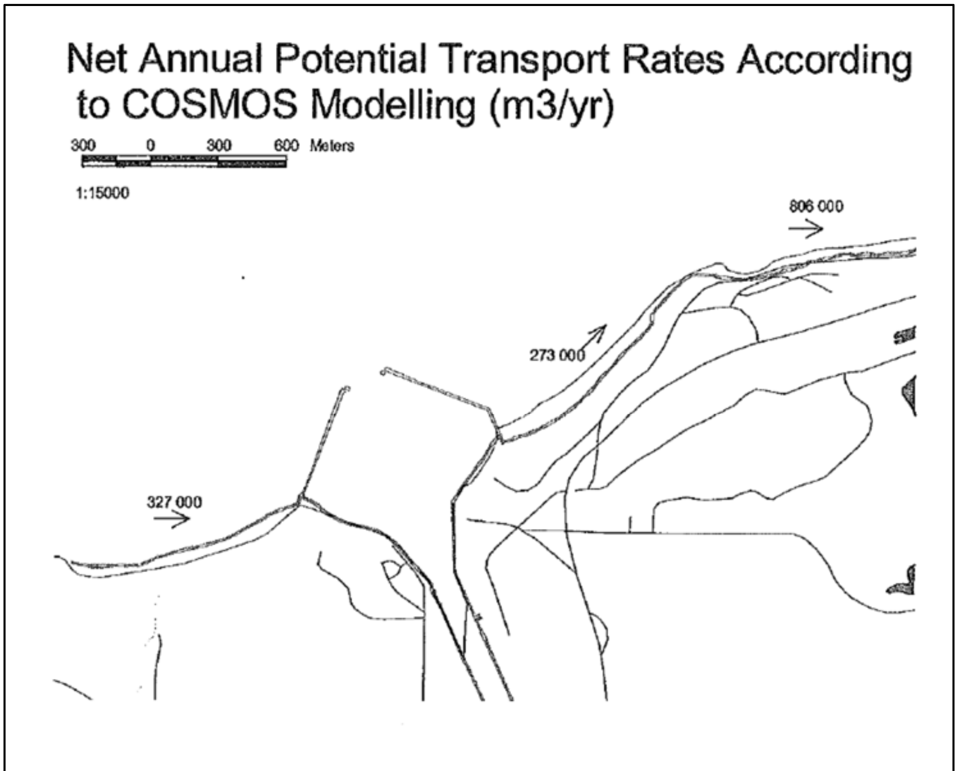

Figure 3 - Maximum Sediment Transport Rates

Figure 4: Maximum Longshore Sediment Transport Rates (W.F. Baird & Associates, 2001)

The results of the modeling concluded a majority of the 327,000 m^3/yr predicted to move across the shoreline west of the Keweenaw Waterway is blocked by the breakwall system resulting in the theoretical accretion of sediment west of the waterway. Sediment availability from longshore transport is, therefore, limited east of the breakwall system where 273,000 m^3/yr of transport is predicted resulting in sediment supply primarily though erosion within this area. Sediment transport modeling immediately east of the headland predicts 806,000 m^3/yr of transport with 987,000 m^3/yr predicted further east still, indicating net erosion rates of 533,000 m^3/yr immediately east of the headland decreasing to 181,000 m^3/yr further east.

Predicted sediment transport rates support the “stable beach orientation” theory hypothesized by W.F. Baird & Associates (2001) which suggests erosion and sediment transport rates will slow as the shoreline comes to an equilibrium orientation near normal to 290º DTN. The shoreline between the waterway and the headland is the section closest to the suggested “stable orientation” which is also the section of shoreline with the lowest predicted sediment transport rates. Historical photographs depict the shoreline orientation between the waterway and the headland has rotated counterclockwise around the headland towards the suspected equilibrium orientation since 1938.

Recession rates provided by Park administrators at 17 locations from the headland extending east approximately 4000 ft from 1995 to 2013 were evaluated as part of this study. Monitoring locations and recession data are summarized in Figures 5 and 6, respectively. Over the approximate 18 year monitoring period, recession rates at the headland average between 0.4 to 1.0 ft/yr. Immediately east of the headland, average recession rates rapidly increase to between 3.0 and 3.7 ft/yr, likely attributed to the presence of unconsolidated materials susceptible to erosion overlying dipping bedrock east of the described submerged bedrock ridge as well as wave diffraction at the headland resulting in a concentration of wave energy immediately east of the headland. Extending east, average recession rates vary 1.1 to 1.9 ft/yr west of the gabion wall, 0.1 to 0.2 ft/yr at the gabion wall and 0.2 to 1.7 ft/yr east of the gabion wall.

The average recession rate between 1995 and 2013 is approximately 1.3 ft/yr when considering each of the 17 locations. Average recession rates between 1995 and 2000 were measured to be considerably higher (2.9 ft/yr) relative to average recession rates measured between 2000 and 2013 (0.6 ft/yr). It is known that Lake Superior water levels were relatively high during the 1990's which may be a precursor for the observed increased recession rates during this time period followed by decreased recession rates measured since 2000 during which Lake Superior water levels have dropped to below average levels.

Figure 5: McLain State Park Monitoring Nail Location Plan

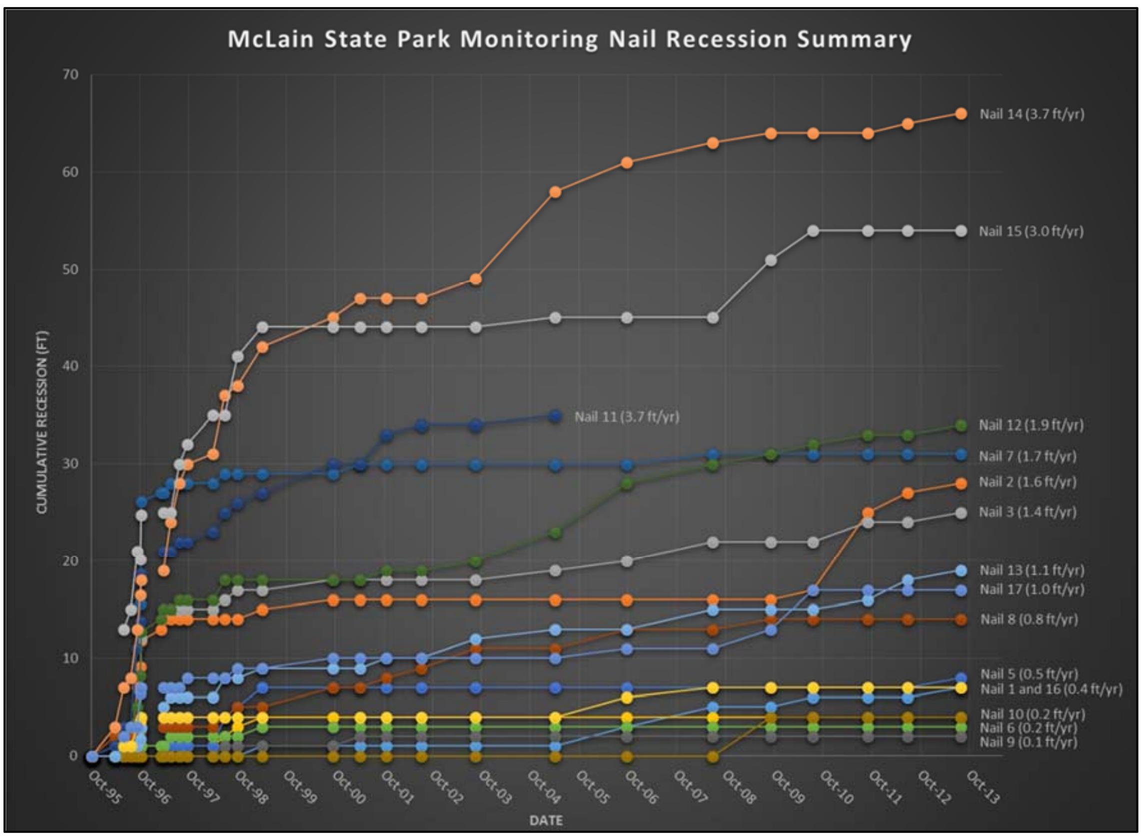

Figure 6: McLain State Park Monitoring Nail Recession Summary

3.0 GEOPHYSICAL METHODOLOGY

Geophysical locating methods are remote-sensing technologies typically requiring verification of results through the direct locating of the object(s) of interest at discrete locations in order to gain a higher level of confidence in the conclusion drawn. Soil borings were selected as our primary method to evaluate the depth to bedrock as well as the secondary objectives (type and depth of soil strata and depth to groundwater) because they are a direct locating technique capable of accomplishing the requested objective with a high level of accuracy and without the need for additional verification testing. Electrical resistivity testing was performed to supplement subsurface information gathered through the performance of soil borings. The methods employed are described herein.

3.1 Electrical Resistivity

Resistivity testing was performed using a SuperSting R1 meter manufactured by Advanced Geosciences, Inc. The testing was performed using a Wenner Array wherein four electrodes are placed in a line at various probe to probe distances (known as the "A" spacing) yielding an aggregate resistivity value to an approximate depth "A". Data was collected at various "A" spacing's with the maximum "A" spacing targeted at approximately twice the anticipated depth to bedrock at the test location. Initially four resistivity tests were performed adjacent to Borings B-1 through B-4 for use in validating the resistivity model against a known soil profile. Five additional tests were performed at locations jointly selected by MTC and the DNR. Test locations and orientations are shown on the investigation location plan (Figure 8) contained in the Appendix A.

Resistivity data was analyzed using one dimensional inversion theory using the AGI EarthImager 1D Software package. Results and conclusions of this analysis are discussed in section 4.1.

3.2 Test Borings

Subsurface conditions were investigated by 43 soil test borings (B-1 through B-40), 3 of which were performed in addition to the originally proposed 40 borings due to auger refusal on suspected cobble or boulder. The soil borings were performed using a CME 55 track mounted drill rig and 3¼ inch hollow-stem augers. Soil sampling (where performed) was accomplished through the Standard Penetration Test (ASTM D 1586). Boring locations are shown on the attached plan, Figure No. 8. Borings were drilled and other sampling was conducted solely to obtain indications of subsurface conditions as part of a geotechnical exploration program. No services were performed to evaluate subsurface environmental conditions.

The Standard Penetration Test (SPT) involves the use of a 140 lb hammer with a 30 inch drop to drive a standard 2.0 inch O.D. split spoon sampler. The number of hammer blows required to drive the sampler 12 inches, after seating 6 inches, is termed the soil N-value and provides an indication of the soil's relative density and strength parameters at the sample location. SPT blow counts in 6 inch increments are recorded on the boring logs. The drill rig was equipped with a CME automatic hammer system which delivers a more consistent driving energy to the sampler compared to the rope and cathead system.

Recovered samples were sealed, labeled and transported to our laboratory. The recovered soil samples were reviewed by an engineer and technically classified according to the methods of ASTM D 2488 "Standard Practice for Description and Identification of Soils (Visual-Manual Procedure)". Estimates of the unconfined compressive strength of the cohesive samples were made using a calibrated penetrometer. A copy of the test boring logs along with a description of the terminology used on the logs and a chart of the ASTM D 2488 group symbol names are provided in Appendix B.

The test borings were performed during two mobilizations with the first mobilization occurring from June 12 through June 18, 2014 and the second mobilization occurring from June 23 through June 30, 2014. During the first mobilization, drilling operations were initially concentrated on collecting soils information, depth to groundwater, and depth to bedrock near the headland in addition to the area of the Park between the headland and Keweenaw Waterway (Borings B-1, B-2, B-3, B-4, B-8 and B-28). Borings B-1, B-2, B-3 and B-4 were located near the previously performed seismic survey locations A, B, C and D as part of the 2013 MTU Geophysics Class study in order to evaluate the reliability of the geophysical data collected and presented in the MTU study. After the completion of the initial borings, additional borings were performed throughout the project limits to gather an understanding of approximate bedrock depths across the project area in addition to a basic understanding of the type and depth of unconsolidated material overlying the bedrock.

During the performance of Borings B-1, B-2, B-3, B-4, B-8 and B-28, our drill rig operator and engineer were in constant communication regarding drilling changes observed (torque, feed pressure, auger advancement rate, chatter, etc.) and the corresponding changes in soil strata observed by the engineer from soil samples retrieved through SPT testing near these drilling changes. The result of this communication was, in essence, a “calibration” of drill rig performance to soil strata type (i.e. surficial granular soil vs. glacial till material), allowing the operator to approximate stratum changes through drill rig feedback. This “calibration” allowed for additional information to be obtained from borings where drilling was performed to only evaluate the whether or not bedrock was presence within the explored depth. Soil sampling was performed infrequently following the performance of Borings B-1, B-2, B-3, B-4, B-8 and B-28, generally only when verification of bedrock was necessary.

Preliminary results were discussed with the DNR after completion of the first mobilization which included a summary of borings completed, encountered bedrock depths, preliminary resistivity results as well as revised locations of soil borings based on access and DNR input regarding desired areas to be developed in the future. It was decided to complete a portion of the proposed borings east of the headland, however, emphasis was to be placed on gathering quality subsurface information from the headland area to the Keweenaw Waterway as this area is most desirable to the DNR for future development. The schedule of borings to be completed during the second mobilization was revised accordingly to meet the DNR objectives.

3.3 GPS Data Collection

Borings and resistivity test locations were determined in the field using GPS observation. GPS Data Collection was performed using a Trimble R6 Instrument coupled with a Trimble TSC 3 data collector. The MDOT CORS network was used as a RTK correction source. The R2K2 Lite RTK mode was used connecting to an aggregate correction source of all nearby reference stations. The Upper Keweenaw station is located at the mouth of the Portage River near the site.

Prior to mobilization several 1 ft georeferenced aerial photo tiles were obtained from the USGS Earth Explorer encompassing the investigation area within the Park. This aerial and the associated georeference information were used for the basis of horizontal control for boring layout and investigation planning. The georeference of the aerial tiles was verified in the field against the GPS location at several points by verifying the coordinates of features in the field that were visible on the aerial photo.

In addition to the investigation layout the GPS was utilized to collect position and elevation data at each soil boring and resistivity location. At locations where direct GPS observation was not possible due to tree cover a nearby location was surveyed and used as a reference point to determine the approximate elevation of the sampling location through differential leveling.

The elevations used in this report are given in feet and are based on the NGVD 88 datum. If more precise location and elevation data are desired, a registered professional land surveyor should be retained to locate the borings and determine their positions and ground elevations.

4.0 GEOPHYSICAL RESULTS

4.1 Electrical Resistivity

Resistivity data collected during the field investigation was analyzed with one dimensional inversion theory using the AGI EarthImager 1D Software package. The software uses an iterative process to resolve a set of resistivity data at different “A” spacing’s (essentially aggregate resistivity values to an approximate depth “A”) into a unified resistivity profile. In the software results are presented as a profile with layers of a predicted depth and thickness with a unit resistivity value assigned for each layer.

Initial verification of the resistivity method was performed by comparing resistivity data collected at the location of Borings B-1 through B-4 (resistivity tests R-1 through R-4) with the soil profile obtained in the borings at these locations. This process was necessary both to ensure accuracy of the data and to determine appropriate assumptions for the modeling software to yield the desired information. In general, the modeling was unable to identify the top of bedrock as desired for the investigation. Typical predicted resistivity profiles consisted of one or more upper relatively high resistivity layers overlying a comparatively lower resistivity layer to the bottom of the predicted profile at approximately twice the “A” spacing. In tests R-1 through R-4 where soil profile information was known the transition to the underlying lower resistivity layer generally appeared to be consistent with the transition from sand to clay and not clay to bedrock (thus no transitions were predicted by the software below the top of clay).

Although some continuity was noted between the expected soil profile and predicted resistivity transition depths there was significant difference from test to test in the predicted resistivity values for the encountered soil profiles making it difficult to utilize the parity between resistivity and soil layer transitions noted in tests R-1 through R-4 where soil boring data was available to analyze the other test locations. For example, predicted resistivity values for the underlying lower resistivity layer varied roughly between 9 and 1800 ohm-meters. This value is approximately between 0.3 and 30.0 percent of the predicted resistivity of the upper sand on a boring by boring basis.

Although it is possible that there is some variability in the resistivity of the soil from boring to boring it is unlikely that this is the only contributing factor. Given that the predicted soil layers are an aggregate value variability in the amount of components with slightly different resistivity is likely also contributing to this disparity. For example, in the underlying lower resistivity layer the predicted value is a combination of clay and bedrock with varying thicknesses between borings. The resistivity of the upper sand layers may also vary naturally due to different densities, amount of fines and organic materials, moisture content, etc. as is inherent in these types of formations.

Another factor likely contributing to the disparity between predicted resistivity values and the inability of the software to detect the clay-bedrock transition is the inability of 1D resistivity modeling to resolve changes in layer transitions and composition (density, degree of weathering, etc.) over the length of the test. Particularly at longer “A” spacing data points the layer boundary depths may vary enough along the length of the test to effect the analysis. Changes in soil profile along the test are detrimental to 1D modeling as they blur the lines between adjacent layers. Given the relatively high degree of horizontal variability encountered between the soil borings consideration should be given to performing a 2D or 3D survey if resistivity testing is performed on this site in the future to account for this variability. It’s also possible that the resistivity of the clay is close enough to that of the bedrock that the transition may be difficult to detect even after accounting for layer transition variability with 2D or 3D modeling.

Another potential contributing factor during the field investigation was the relatively high degree of variability in the soil at the immediate ground surface which the test probes were driven into. This soil consisted of a mixture of dry beach sand, topsoil and road gravel. Nearby utilities and other subsurface structures may also have affected the testing by providing a less restrictive path for the test current than the surrounding soil. Care was given in selecting the test locations to avoid known utilities however unknown utilities, past structures, areas of past excavation/fill, etc. may exist in the vicinity of the testing. Especially given the high resistivity of the surface material variability’s such as these are of particular concern.

Results of the resistivity testing are included in Appendix B. For each test location both a worksheet presenting the collected resistivity data in tabular form and a predicted resistivity profile are included. Care should be taken in the future use of the profile data with respect to the assumptions inherent in their development.

4.2 Test Borings

The borings in general encountered brown poorly graded sand (SP) overlying glacial till material classified (at borings where sampling was performed) as *silty sand* (SM), *sandy silt* (ML), *silt* (ML), *sandy lean clay* (CL) and *lean clay* (CL) overlying reddish brown weathered sandstone bedrock (Freda Sandstone). Coarse gravel and cobble were frequently noted within the soil borings immediately above and within suspected glacial till material.

The thickness of the soil strata described varied considerably across the project limits. At the headland, the surficial granular soil was typically encountered to depths ranging from 13 to 18 ft below the ground surface underlain either directly by weathered bedrock or several feet of glacial till material overlying weathered bedrock. Coarse gravel and cobble were frequently noted within the soil borings immediately above and within suspected glacial till material.

The granular soil was observed within the soil borings to increase in thickness gradually from the headland to depths over 50 ft below the ground surface near the Keweenaw Waterway underlain consistently by glacial till material consisting typically of silt and clay overlying weathered sandstone bedrock. The top of bedrock was observed to dip more severely from the headland to Borings B-4 where it was encountered at depth of 75 ft. Bedrock was again encountered at Boring B-8 near 70 ft below the ground surface, indicating a flattening bedrock surface immediately east of the waterway.

East of the headland, the granular soil is anticipated to extend to depths of approximately 20 to 30 ft below the ground surface underlain by glacial till and a dipping bedrock surface. The surficial granular soil thickness, however, is expected to be variable east of the headland based on observations of glacial till clay exposed within the face of eroded bluffs immediately above the shoreline. In general, bedrock was not encountered in a majority of the borings performed east of the headland with the exception of Boring B-28 where sampler refusal at a depth of 89.8 ft may be an indication of weathered bedrock material.

Groundwater was generally encountered at or above depths corresponding to the Lake Superior water level, ranging from approximately els 601 to 620. Higher groundwater was typically perched in areas of higher glacial till/bedrock.

At borings where bedrock was encountered within the exploration depth the encountered bedrock surface elevation and boring coordinates were utilized in the development of an approximate bedrock surface topography map. Contouring was accomplished using the Surfer 12 software package. Results of this contouring are presented in Figure 9 contained in Appendix A. The presented contours are based on an approximate bedrock elevation in each boring as determined by review of all available information such as the reported drilling resistance, sampler resistance/refusal, auger refusal, recovered cuttings, etc. Contours are presented on 1 ft intervals in areas of higher boring density where the bedrock surface is close to the ground surface and at 5 ft intervals outside of this area. The points used in the contouring process are shown on the contour map for perspective.

As opposed to contouring the ground surface, the bedrock topography cannot be observed directly complicating the contouring process somewhat. A judgment call needs to be made with respect to decisions such as if high points are located along a ridge or represent isolated outcroppings. In this case, the contours have been developed to provide relatively smooth transitions based on the collected data without distinct ridges or valleys. For this reason, the contours should be considered approximate with respect to how they depict the transitions between the data points used in contouring. Particularly at the edges of the contoured area where bedrock is deeper, there may be significant variability between the presented contours and actual conditions due to the limited sample size in these areas.

5.0 CONCLUSIONS

The bedrock topography is shown in Figure No. 9 in Appendix A based on data collected in our field geophysical investigation. The highest bedrock is located just south of the existing Park entrance and headquarters building rising to el 608 along M-203 dipping gently down toward the headland point to el 593, and dipping approximately 5% from the high point to the southwest and northeast. Borings B-9, B-11 and B-40, completed near the Keweenaw Waterway, did not encounter bedrock and did not find evidence of bedrock being close to the surface as stated in the U.S. Army Corps of Engineers report.

Borings with soil sampling were completed in the headland (Borings B-1 and B-2), in a line from the headland to the southwest (Borings B-3, B-4 and B-8), and along the bluff east of the headland (Boring B-28).

Headland

Brown to light brown poorly graded sand (mostly medium to fine-grained sand) with a loose grading to medium dense relative density was encountered in the upper 14 to 15 ft. Till material consisting of very dense sandy silt with gravel, cobble and sandstone fragments was encountered in Boring B-1 from 14 ft to 21 ft and hard sandy lean clay in Boring B-2 with gravel and cobble from 15 ft to 17.5 ft. Standard Penetration Test refusal was encountered at depths of 21.5 ft and 17.5 ft in Borings B-1 and B-2, respectively, on sandstone bedrock corresponding to els 594 and 598.3. Groundwater was encountered at els 608.2 and 610.8 at the time of drilling.

Southwest of Headland to the Keweenaw Waterway

Granular soil strata were encountered in the upper 21 ft to 52 ft with the granular soil depth increasing with distance from the headland. The relative density of the sand was loose to medium dense within approximately 20 ft of the ground surface grading to dense to very dense. Gravel and cobble were noted during the drilling in the granular soil within primarily 10 ft to 25 ft of the ground surface. The sand was typically underlain by very stiff to hard brown lean clay extending to sandstone bedrock at a depth of 40.5 ft in Boring B-3, 75 ft in Boring B-4 and 71.5 ft in Boring B-8. In Boring B-4, a medium dense to dense silt stratum was encountered from 26.5 ft to 45 ft. Groundwater was encountered at the time of drilling at els 612.6, 612.8 and 610.9 in Borings B-3, B-4 and B-8, respectively.

East of Headland

Light brown poorly graded sand with a medium dense relative density was encountered in the upper 15 ft of Boring B-28 overlying a hard sandy lean clay stratum from 15 ft (el 602.4) to 25 ft. Loose to dense sand strata were encountered form 25 ft to the 90 ft exploration depth. Groundwater was encountered at the time of drilling at a depth of 11 ft (el 606.4).

The poorly graded sand encountered within our field investigation below the ground surface was comprised predominantly of fine to medium grain sand particles indicating a grain size generally ranging from 0.074 to 2 mm (0.0029 to 0.0787 inches). Generally, for a constant flow velocity, the erosion and transport potential of sediment will increase with decreasing grain size (neglecting intergranular forces such as cohesion). The relatively small grain size for the encountered sand indicates the poorly graded sand is susceptible to erosion.

Bedrock elevations encountered in our investigation correspond closely to the elevations predicted in the MTU seismic surveys conducted at Points A, B, C and D as well as the gravity survey data presented. Our limited electrical resistivity testing confirmed the MTU conclusion that resistivity testing is not effective in defining the bedrock elevation.

The McLain State Park shoreline is a product of geological constraints, human development and erosion. Considering the data gathered to-date in conjunction with a review of previously performed studies and data sets provided, evidence points towards the slowing erosion of the shoreline between the headland and the Keweenaw Waterway. The headland area of the Park is the most stable area with the lowest erosion rates due presumably to the presence of relatively high bedrock preventing the erosion of susceptible material both on-shore as well as off-shore. Recession data collected east of the headland predicts an average recession rate of 1.3 ft/yr from 1995 to 2013 with elevated erosion rates occurring from 1995 to 2000 during a period of high water levels in Lake Superior. Fluctuating water levels within Lake Superior are expected to result in fluctuating erosion rates across the Park.

The theory that high bedrock relative to the ground surface is responsible for lower shoreline recession rates is supported by historical aerial evidence as well as recession data recorded over the last 18 years, particularly at the headland where bedrock is known to be high relative to other areas of the Park and where estimated recession rates are the lowest across the Park shoreline.

6.0 RECOMMENDATIONS

In consideration of the construction and/or relocation of existing structures/infrastructure within the Park, future development areas may be divided into four categories defined below:

1. Imminent Hazard Area – Area susceptible to erosion with the next 10 years
2. Intermediate Hazard Area – Area susceptible to erosion within the next 10 to 30 years
3. Longer Term Hazard Area – Area susceptible to erosion within the next 30 to 60 years
4. Low Hazard Risk Area – Area not susceptible to erosion within the next 60 years

Habitable structures and utilities, should not be considered within areas categorized as “imminent hazard” areas. Moveable structures may be considered within “intermediate hazard” areas as well as pavement areas if some risk associated with pavement loss due to erosion can be accepted. Semi-moveable structures may be considered within “longer term hazard” areas while permanent structures may be considered within “low hazard risk.”

It is our opinion that future development should concentrate the construction of permanent structures and infrastructure within the area south of the headland area due to the low rate of erosion expected along the shoreline of this area when compared to the shorelines to the west and east of the headland. A second option for development, and one with more risk associated with future erosion, is development of the Park between the headland and the Keweenaw Waterway. Although a higher risk option, evidence based upon prior studies suggests decreasing erosion rates within this stretch of shoreline as a somewhat stable shoreline orientation is developed with respect to preferential wind and wave direction. In lieu of installing an erosion prevention system (i.e. structural erosion protection), permanent structures may be considered in this area set back a distance from shore corresponding to an agreed upon average erosion rate and the desired design life of the proposed structure or infrastructure. Erosion rates are expected to be significantly less (if not negligible) immediately south and west of the east Keweenaw Waterway breakwall.

Future investigation/research which may be helpful in more accurately predicting future shoreline erosion rates are summarized below:

- The available data and prior reports should be studied to conclude whether the shoreline between the breakwall and headland is stable or approaching stable over the next decade as suggested in the 2001 Baird *Shoreline Stability Study*.

- Further research should be conducted to evaluate the correlation between periods of higher recession rates and lake water elevations.

As discussed previously, coastal systems such as that at McLain State Park are dynamic and as such no guarantee is made here on behalf of Materials Testing Consultants that future bluff recession will occur at historic rates.

REFERENCES

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