TECHNICAL APPENDIX

EASTERN LAKE ONTARIO SAND TRANSPORT STUDY (ELOSTS)

including

A STUDY OF MAPS, CHARTS AND AERIAL PHOTOGRAPHS UNDERTAKEN TO DETERMINE SHORELINE EVOLUTION IN EASTERN LAKE ONTARIO WITH EMPHASIS ON THE REGION NEAR NORTH POND

by

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in cooperation with
associates and consultants named in the report

with support from

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TABLE OF CONTENTS

Summaries of the research projects

***Grain-size analysis* –** The purpose of this study was to determine trends of change in grain-size parallel to and perpendicular to the shore as a guide to sediment transport directions. We worked with sand sizes (2mm -.0625mm) for ease of operation. Woodrow and Singer (Woodrow, et al, 1999) reported on results of the survey in a poster at a professional meeting.

Well established relationships exist between sand size-characteristics and sediment transport direction. Starting from a single source of sediment, both the mean size of sand grains and their range of grain sizes decrease in the down current direction. The theoretical model posits wave-driven currents, sediment fining and a decrease in the range of grain sizes to the north parallel to the shore and perpendicular to the shore. To test that hypothesis, we analyzed by sieving 150+ offshore samples and 30 beach/dune samples . **Statistics derived from the sieve data, though noisy, confirmed the predicted trends.**

Samples analyzed in this study were surface samples collected by dredge in the lake and by scoop on land. All were collected during summer months under the summer wind/wave regime. **Sand samples and current data are not available from the winter months. Given the different wind/wave regime and the potential for ice cover at that time, it is likely that different trends of textural variation would be in evidence.**

Side-Scan Sonar – In conjunction with the seismic survey described above, a side-scan sonar device provided by Lighthouse Marine was deployed to collect sonic images of the bottom over which the boat moved. Records of lake bottom extending for approximately 175 km were collected disclosing bedrock, gravel, glacial sediment, sand, and sand with mussel patches. Results of the survey were reported by Woodrow, McClennen and Beaulieu (2001).

The type and distribution of sediments on the lake bottom can be summarized as: 1) thin, isolated patches of sand over glacial sediments (and bedrock?) south and west of the Salmon River jetties, 2) an extensive but thin sand sheet north from the Salmon River to near Black Pond with greatest thicknesses of sand off North Pond and near the beach, especially in the inlet-mouth bar at North Pond. 3) small isolated patches of gravel-strewn glacial sediments in the sand sheet off and southwest of Montario Point, 4) clumps of mussel shells more common toward the north and covering bedrock surfaces off Black Pond, 5) elevated bedrock near the lake surface off Black Pond effectively blocking northward transport of sediment, and 6) no sand found north and northwest from the rock masses off Black Pond to Stony Point.

Currents – Ahrnsbrak set out to determine the current regime by setting a single current meter at a location about 2 km off North Pond at a depth of 7 m. Data from this roughly mid-point location along the shore serves as a sample of the currents to be seen along the entire shore. This study also was a test of the northward currents predicted by the Sutton, Lewis and Woodrow (1972) model.

Current meter deployments and retrievals were accomplished during Spring, Summer and Fall of 1998, 1999 and 2001 from the Russell B. Attempts to collect data over winter months were unsuccessful due to the loss of instruments to the instrument-hostile environment of the wintertime lake bottom. Two types of current meters were deployed. One meter provided multi-minute savonius rotor averages for currents while the other was a doppler meter providing 5khz averages.

The current data demonstrated northward current vectors and northward water movement during the summer with increasingly common southerly current vectors in the Fall. Current velocities sufficient to move sand were found to be associated with intervals of strong wave activity and greater turbidity. Internal waves were not detected in the Spring but were inferred from pressure, velocity, and turbidity records in the Summer and Fall.

Ground-Penetrating Radar (GPR), vibracores, C14 dates-The GPS survey was carried out to determine the internal structure, and, if possible, the thickness of dune sands. Virbracores were used to provide essential ground-truth for the GPR records. C14 dates provided a temporal framework in which the evolution of the dune complex could be placed. The equipment used in the survey emits radar waves into the ground and records radar “echoes” from surfaces below ground. Coupled with vibracore dating and C14 dates, the GPR survey provides a strong basis for determining evolution of the dunes.

GPR records were obtained by personnel from Blasland, Bouck and Lee, an environmental consulting firm from Syracuse, NY at six locations in May, 2001. Five of the locations were those at which samples were taken for grain-size analysis and at which vibracores were obtained. The sixth was on the sand mass on the south side of the south jetty at the mouth of the Salmon River. Records were obtained from depths as great as 15 m (48 ft) but most were in the range of 6-12 m (20-30 ft)’.

Records disclosed three units of sediment within the dunes. The upper two of the three units have been confirmed by vibracores. At the top are fine sands ,10 feet thick or less, which are draped across older dunes or built on the eroded surface of older sediment. In the middle is a complex of dune/beach sands and organic-rich wetland or bay sediments, eroded at the top. The middle unit rests on eroded glacial or glaciolacustrine sediments or bedrock. Maximum sediment thickness of sand in any dune is approximated by the relief above lake level of that dune. At Sandy Island Beach, dune crests stand as much as 20 m (65 ft) above the lake. There the total thickness of sand includes the dune elevation above the lake plus approximately 9m (30 ft) of sand filling a channel below the beach and dune. Dune sands are finer extensions of the beach sands. Taking the dune sands as a starting point, the sand sheet is thickest at the dunes, thinner at the beach and in the nearshore, thins further offshore and finally grades into silts in water depths of 15-30 m (50 to 100 ft).

Vibracores not only served as ground-truth for GPR records, they also yielded samples of organic-rich sediment for C14 dating. Although many samples were available, great expense and some duplication would have resulted if all were analyzed. Five samples were selected for radiocarbon dating by the NOSAMS lab at Woods Hole.

Two C14 dates indicate that the youngest organic-rich sediments in the middle unit are as young as 1550 yrs bp. Three C14 dates on organic-rich wetland sediment interbedded span the interval 350-750 yrs BP. The sequence of events seems to have been as follows. During an early low stand of lake level, perhaps 6-8000 years BP, glacial sediment and bedrock were eroded. Lake level rose and the erosion surface was covered by the complex of fine sand and organic-rich sediments now seen in the middle unit. Lake level then declined so that by 1550 yrs bp, a new erosion surface formed. That surface was covered by dune sands and wetland/bay sediments by 750 yrs bp with little change in dune/beach position since then.

Seismic surveys, underwater video, vibracores and C14 dates- Seismic survey records were obtained on more than 100 km of track lines during two cruises, one in 1998 and the other in 1999. In 1998, an Edge-Tech X-Star system was used with a seismic source emitting in frequencies (2-10 kHz) best suited to penetrate silty sand and clay. As part of that survey, a few underwater photographs were taken which provided confirmation of the interpretations made of the seismic records. McClennen worked with Jedd Steinglass on that survey. In 1999, McClennen, and Colgate students Steinglass and Amy R. McKnight carried out a second seismic survey with Neal Driscoll, then of WHOI, and WHOI technician Wayne Spencer. A second X-Star system was used which operated with a broader frequency band (0.5-10.0 kHz) and which was better suited for resolving strata with sand masses. Records from both surveys are on paper and are not digitized. The 1998 records were interpreted by Steinglass. He recognized five units of sediment and bedrock (Steinglass and McClennen, 1999). Woodrow and Beaulieu interpreted the 1998 records and recognized similar subdivisions (Woodrow, et al, 2001).

Seven vibracores were collected from the lake bed at locations along the seismic survey lines to provide “ground-truth” for the seismic records, and samples for grain-size analysis and samples for nine C14 dates. Coring locations were those at which more than one sedimentary, acoustic unit could be penetrated. The cores were obtained in June 2000 by Mark Avakian and Peter Poirer from TG&B, a consulting company from Woods Hole, MA. They worked from the HWS EXPLORER. Cores penetrated three of the five units previously defined.

Bedrock, gravel and cohesive glacial sediments exposed on the lake bottom rejected all attempts at coring and dredging. They were interpreted from seismic, echo-sounder, and side-scan sonar records as well as from the few photos obtained in the first seismic cruise. One such surface was confirmed by a dredge sample taken as a sample for grain-size analysis. It revealed, instead of sand, a tough, burrowed, silty clay at a location about 1 mile west of the Salmon River jetties where seismic and side-scan sonar had indicated a hard gravelly surface with small, scattered sand patches on it. Bedrock was confirmed in side-scan sonar records and anecdotal reports from scuba divers at the north end of the survey area off Black Pond. The clay and bedrock represent the bottommost units seen in the seismic records.

Synthesis of seismic records, video images, vibracore logs and C14 records yields this picture of subbottom units . Ordovician bedrock is overlain by glacial till, glaciofluvial-, and glaciolacustrine- sediment which is covered, in turn, by sand. Bedrock is seen on the lake bottom at Nine Mile Point west and southwest of the Salmon River jetties. Till and other glacial sediment are found off the Salmon River jetties and for some distance to the north with patches of fine sand and gravel are strewn across their surface. Further north, off Sandy Island Beach, sand patches coalesce into a sand sheet broken by small patches of well-rounded (beach?) gravel and/or glacial sediment. The sand sheet thickens to about 3 m (10 ft) about a mile from shore opposite the inlet at North Pond. Below the sand sheet at that point are older sandy(?) sediments which fill a channel eroded into glacial sediment. The channel appears to have drained the area now occupied by North Pond and points to the east of it at a time when the lake level was lower than at present. The sand sheet thins toward the north, its surface marked by patches of mussel shells and it ends at the bedrock exposure on the lake bottom off Black Pond.

Vibracores penetrated the sand sheet, including gravelly sands remarkably like those seen on present-day Lake Ontario beaches, and extended into organic-rich sediments beneath. **C14 dates on the organic sediments above and below the gravelly sands and on shells in the sand indicate that the gravelly sands were deposited between 6540 and 7700 yrs BP. If the gravelly sands are beach sediments and the organics are of wetland/marsh origin, then lake level at those core locations was about 78-82 feet lower than at present. Positioning the assumed beach gravels at these low levels is accounted for, in the main, by isostatic rebound of the crust after Pleistocene glaciation and perhaps by a more arid climate. Relatively stronger rebound to the**

north led to tilting of the shoreline raising it above lake level there while flooding in the south.

Analysis of maps and aerial photographs –McClennen analyzed shoreline change and bathymetry, with emphasis on North Pond and vicinity, working with maps and charts for 1878-1992 and with aerial photographs of the shore and nearby land showing for 1938-1995. Resolution of tens of feet horizontally is the maximum possible given the difficulty of registering the maps, charts and photographs. **At that resolution, essentially no change in shoreline position is apparent. However, it is clear that shifts in the size and location of the inlet to North Pond and in the size and geometry of the inlet-mouth bars associated with it have occurred. The registered maps and charts demonstrate significant shallowing in North Pond but no bathymetric change in Lake Ontario to depths of 200 feet or more.**

INTRODUCTION

> "The beach is so solidly a part of American culture that the connotation overwhelms definition……To some, it is an unending strip of white sand, with waves gently lapping and breezes stirring the moisture-laden air…..To many, it is colorful umbrellas, volleyball games and surfing…..To a very few, it is a front yard."
>
> --From Pilkey and Dixon, 1996, p. xi

When the TNC approached us to undertake this study, we were brought back to research issues which have occupied us and our students over many years. Woodrow and McClennen, their students and their colleagues worked on various aspects of coastal geology along Lake Ontario's south and eastern shore since the 1970's. They have also used those areas as teaching laboratories. Ahrnsbrak and students worked on thermal structure in Lake Ontario. Rukavina became the expert on Ontario nearshore sediments. Halfman and Singer, though new to Lake Ontario, had been working on related problems in New York's Finger Lakes and in Lake Erie, respectively. It was a pleasure to be back.

We were asked to arrive at an understanding of the dune/beach/nearshore, sand-dominated sedimentary system of eastern Lake Ontario in order to provide a basis for rational decision making about shoreline management. Further, we were to offer advice about management to those who would make the decisions.

A model of shoreline evolution published by Sutton, Lewis, and Woodrow (l972) provided an outline of shoreline placements modified by isostatic rebound. In a second paper, Sutton, Lewis and Woodrow (l974) provided detail of modern sediment transport through a study of sand grain size along the US shore of the lake. Fining was noted both offshore and to the east suggesting sediment sorting and transport of finer sands to the east, trends that were continued offshore and to the north along the

eastern shore. That model of sediment dynamics guided our thinking We set out to test the model as shown in Table 1. Our results confirm the model at a ge neral level but not in detail and the model did not account for dune or modern shoreline evolution. Our data supportive of the model include: 1) northward fining and improved sorting of sand both along the shore and on the lake bottom, 2) sand grading offshore into silts and muddy silts, 3) patchy sand distribution in the south and more uniform sand distribution in the north, and 4) transport of water masses and northerly current vectors at least in the summer.

However, some of our data either have no bearing on the model or are inconsistent with it. For example, some eastward-facing bottom structures seen in the side-scan sonar records appear to record E-W movement of sand. Stronger southerly currents are more common in the Fall, and by implication, the winter. Shoreline evolution at the decadal scale was directly observable in the aerial photos and topographic maps . It has been inferred at longer time scale in the sedimentary record seen in the vibracores. The modern shoreline appears to have been at about the present location at least 800 years BP with little position change, except for inlet placement, in the intervening centuries. This pattern of stability of position is seen at the decade level in the aerial photographs and topographic maps.

This report summarizes a multi-component project the objective of which is to provide a rational basis for management decisions about the sandy, eastern shoreline of Lake Ontario. Directly involved in the project were faculty and students from colleges and universities in the US, a team from a Canadian government agency, personnel from The Nature Conservancy and from federal and state agencies, private contractors, and many private citizens. Starting in Fall of 1998, the project was planned for two years; instead it took nearly four years to complete. Funding came from the USA Corps of Engineers, Buffalo District and from the NY State Department of State under the sponsorship of the governments of the NY towns bordering the eastern shore and the stewardship of The Nature Conservancy. Project management was accomplished by Don Woodrow, of Hobart and William Smith Colleges and Sandra Bonanno of The Nature Conservancy.

Table 1.

Equipment/technique	Determination made	Hypothesis to be tested
Seismic reflection and Side-scan sonar	Sediment type, extent, Distribution Character, orientation of features on the sediment surface	Offshore sand body thickens to the north Flow indicators on sediment surface illustrate sediment transport to the North.
Current meter, lake-level recorder	Determine current characteristics and turbidity over time. Determine lake levels at short time-scales for a few days.	Current flows are mainly to the North. Turbidity increases with wave activity. Lake level changes hourly and daily.
Grain-size analysis of sand by sieving and ROXANN survey	Determine mean grain size and a measure of sorting (sieving) and broad grain size and distribution patterns (ROXANN)	Sand is finer and sorting increases toward the north and offshore.
Ground-penetrating radar (GPR), beach and dune	Determine sand body thickness, internal structure	Does not apply
Vibracore, onshore and offshore.	Calibrate interpretations of seismic and GPR records	Northward thickening of sand body
Radiometric (C14) dating of organic sediments	Provide time frame for vibracores, GPR, and seismic records	Does not apply.
Analysis of maps, charts, and aerial photos	Shoreline, inlet, and inlet-mouth bar placement Bathymetry	Does not apply

RESULTS FROM 2001-2002

1. Water Movements in Eastern Lake Ontario – W. F. Ahrnsbrak

Introduction

As part of the Eastern Lake Ontario Sand Transport Study (ELOSTS), water currents, along with water temperature, have been being measured and recorded in the Lake, at a location approximately 1 km. west of the east end of Lake Ontario, off North Pond, during a number of periods between 1998 and 2001. Location of the current meter mooring station is shown in figure 1. Water depth at the station was approximately seven meters. While, in addition to data reported on in this and previous reports, instruments were deployed with the intention of obtaining data for the winter season, those instruments were unable to be located when recovery was attempted in the spring. Therefore, currents discussed in this report are exclusively from the ice-free season. Data have been recorded between mid-May and early November.

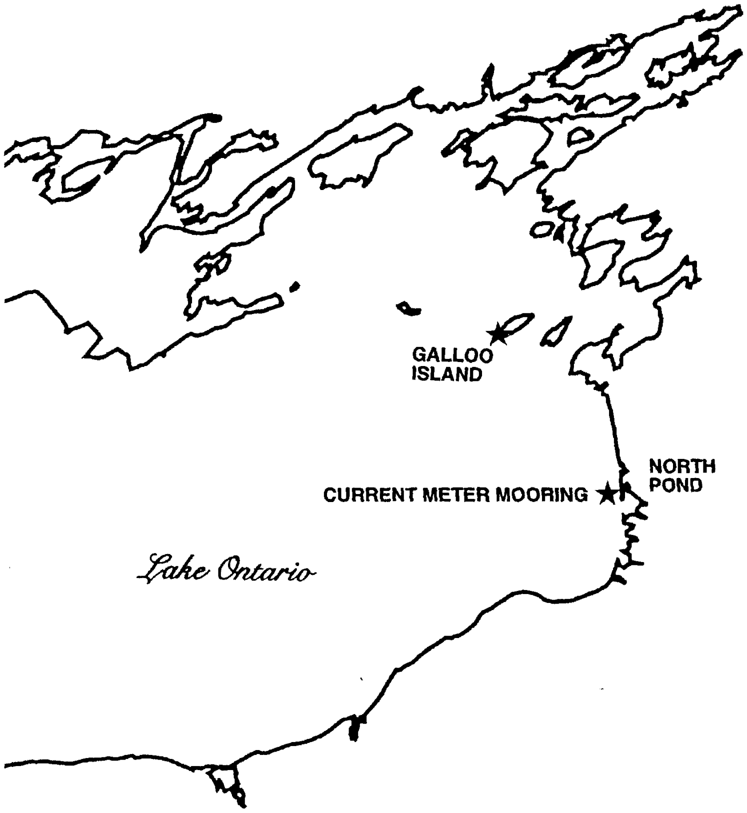


Figure 1. Map showing location of mooring site for current meter measurements in Eastern Lake Ontario.

Throughout the study the current meter being used was an Aanderaa RCM-4 Savonius rotor, vector-averaging current meter in which the recording system has been upgraded to that of the RCM-7 instrument and is shown in Figure 2. The upgraded instrument recorded vector average values for an interval of 5 or 10 minutes, as selected for a given deployment. The instrument was supported by a buoyant sphere and held in place by a concrete block resting on the bottom. Data represent conditions at approximately one meter above the bottom. A sample of the data obtained during a deployment is shown in figure 3. Data shown in that figure are from the deployment during September and October of 2001.

RECORDING CURRENT METER model 4, recording temperature, current speed and direction on magnetic tape. Acoustic transducer permits monitoring of measured data from surface. Sensors for water pressure and conductivity can be installed on request.

Figure 2. Aanderaa RCM-4/5 current meter. The instrument, as used in the present study has been upgraded to RCM-7 recording capability. Photo courtesy of Aanderaa Instruments.

Periods during which data were obtained during 1998 and 1999 are shown in Figure 4.

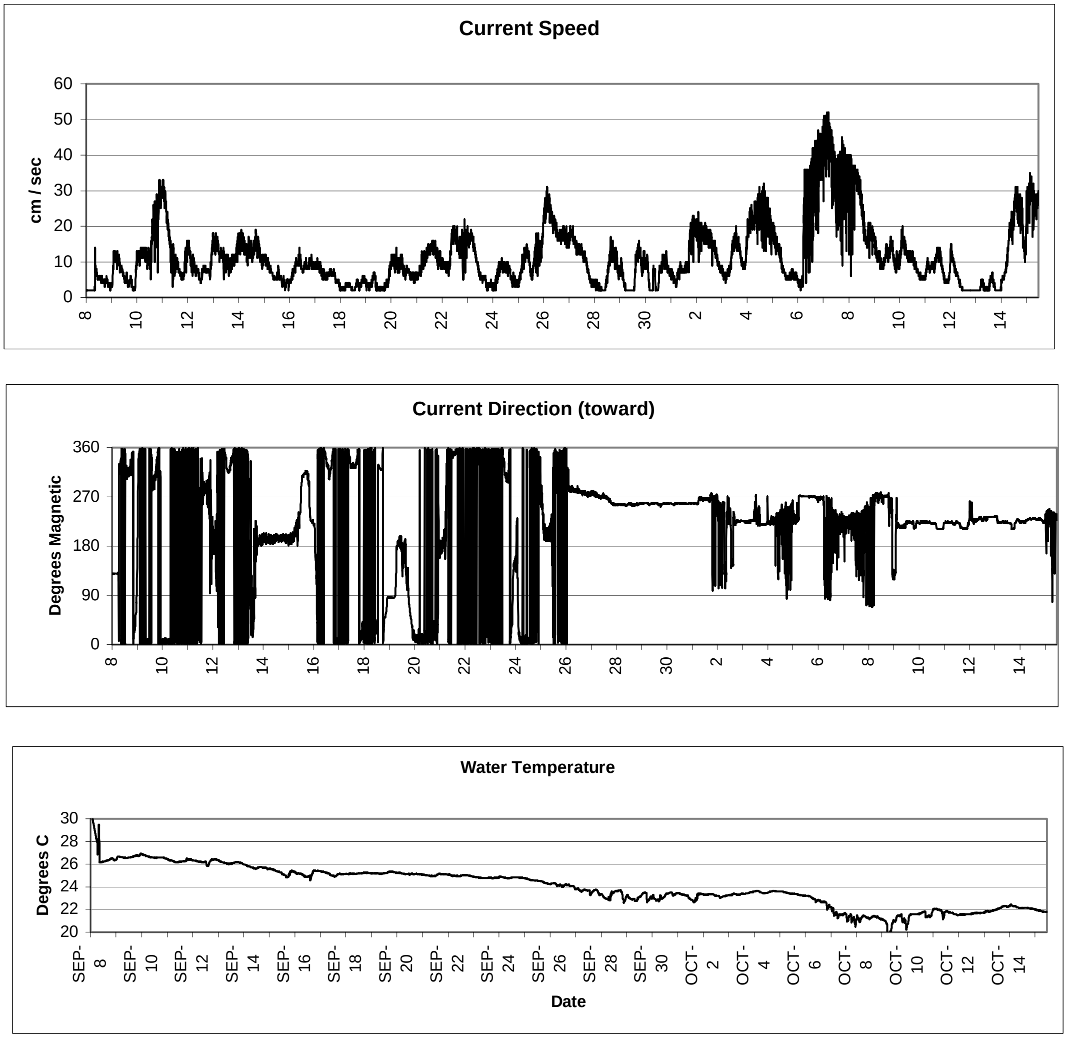


Figure 3. Data from Aanderaa RCM-7 current meter during fall, 2001, deployment, The current meter was moored at a station approximately 1 km off North Pond in eastern Lake Ontario (station location shown in Figure 1).

Results from 1998 and 1999

Currents at the mooring location are generally shore-parallel with the average or net flow toward the north, consistent with both models and observations found in pertinent technical literature (e.g. Beletsky et al., 1999). There is, however, a seasonal change in both the speeds and in the persistence of the direction of the flow.

Frequency distribution of current speeds recorded during the spring and the fall deployments during 2001 are shown in figure 5. Speeds are higher later in the fall than in the spring. During the spring deployment the highest recorded speed was 17 cm• sec^{-1} and the mode speed was in the 2 – 5 cm•sec^{-1} interval. On the other hand, during the fall deployment the highest recorded speed was 52 cm•sec^{-1} and the mode was in the 6 – 10 cm•sec^{-1}. The same tendency, for higher speeds during the fall stratified season was observed in other years' data.

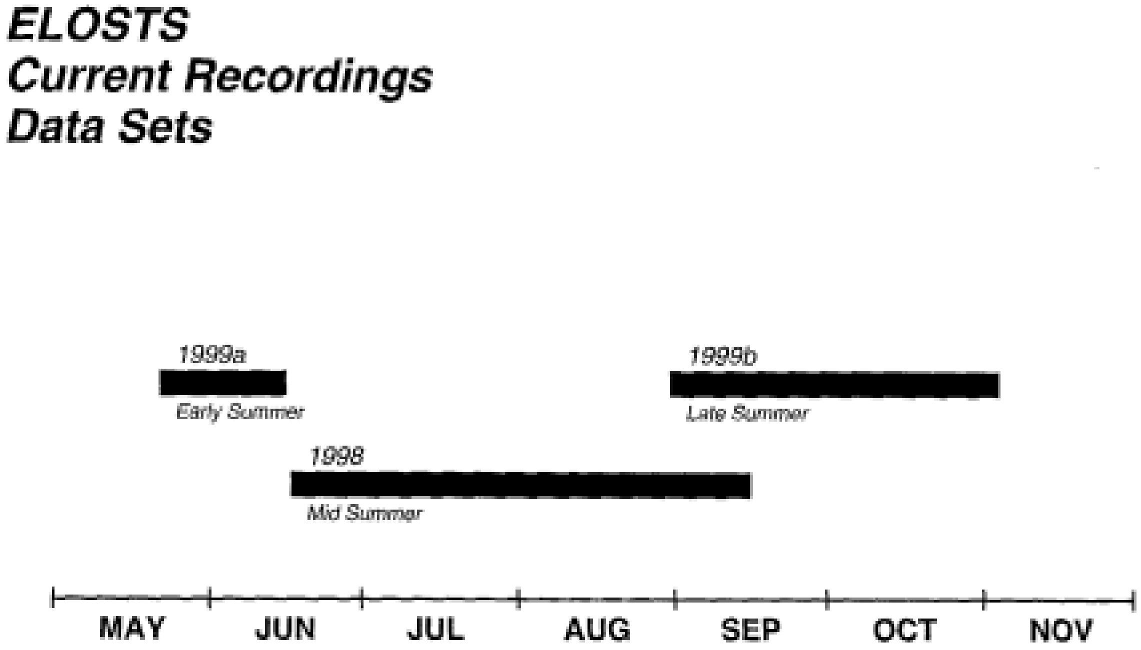


Figure 4. Periods during which current data were recorded in Eastern Lake Ontario during 1998 and 1999.

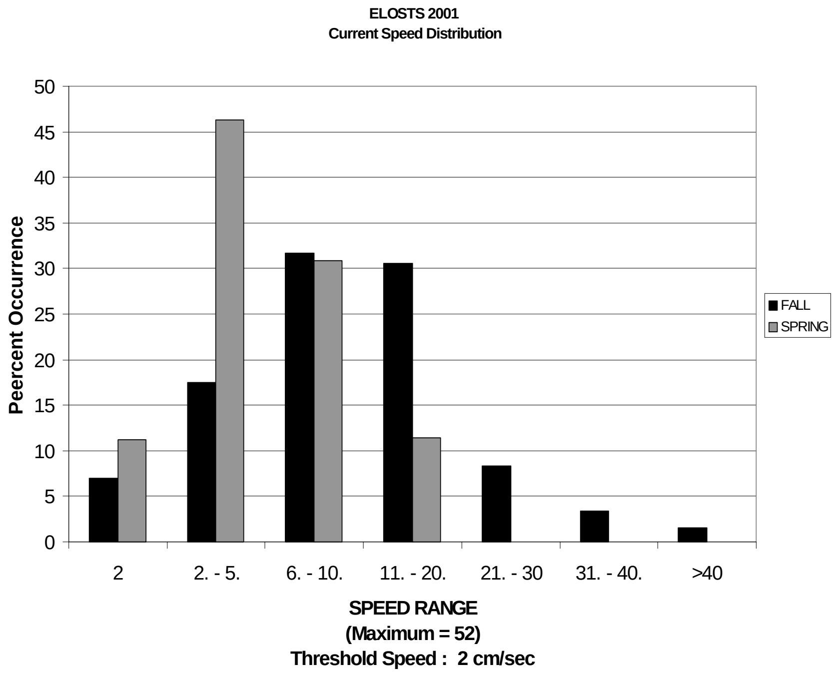


Figure 5. Distribution of observed current speeds recorded during 2001 by Aanderaa RCM-7 current meter. Speed sensor 1 meter above bottom.

Seasonal changes in the degree to which the flow is northward may be seen in figures 6 and 7. Transport roses, shown in figure 6, represent statistical summaries of the directional distribution of direction of flow and show the percentages of the actual transport of water in each ten-degree segment of the compass. Those shown present the data from the three stages of the ice-free seasons during 1999 and 2000. The greatest percent of flow toward the north occurs in the spring data, with the percent of northward flow decreasing as the season progresses. Simultaneously, the percent of flow in a generally southward direction increases as the degree of stratification increases.

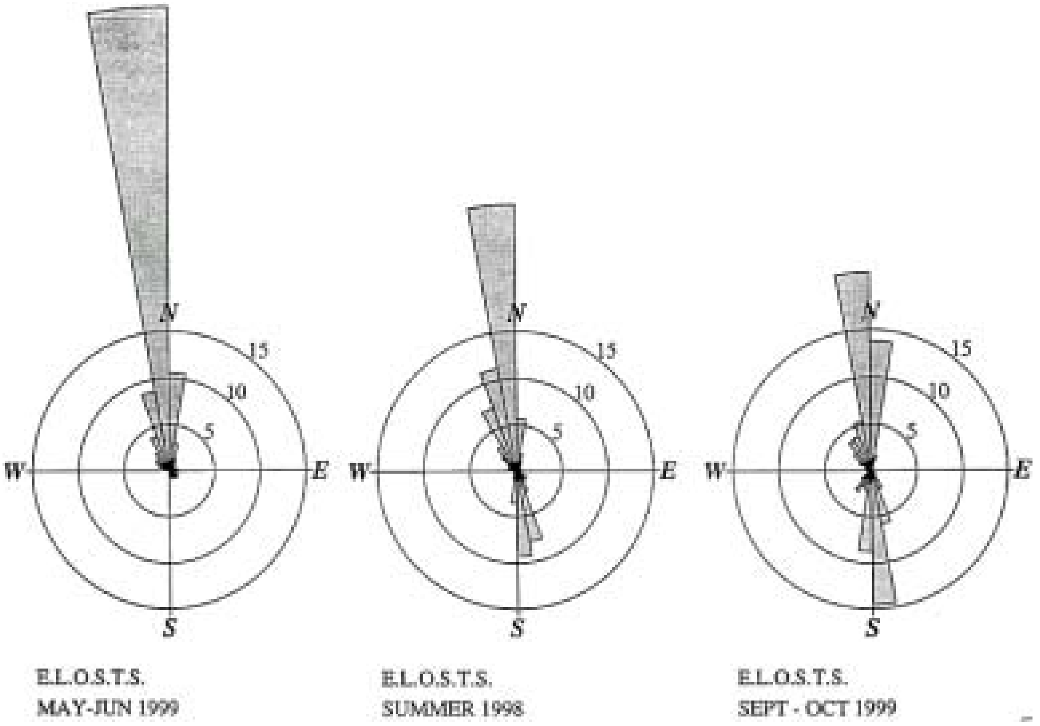


Figure 6. Rose diagrams showing seasonal progression of relative transport of water toward each 10-degree directional sector.

Figure 7 shows diagrams which synthesize the movements of a parcel of water and are constructed by assuming that after a given parcel of water passes the mooring location it, in fact, continues to move with the velocity as recorded at the mooring site. The average or net flow during all three seasons: spring, summer and fall, is toward the north. There is, however, a progression in the degree of persistence of the northward flow. That progression develops as the degree of thermal stratification in the Lake increases. As the stratification of the Lake increases, so do the frequency and intensity of the southward excursions of water, interpreted as being associated with activity of long, internal waves in the Lake. Internal waves are typically thought of as oscillations or undulations of the thermocline of a lake or ocean at times when density stratification exists in the body of water, typically with periods and amplitudes much greater than ordinary surface gravity waves. Fluid dynamics and continuity/conservation of mass considerations dictate that there must be oscillatory horizontal water movement associated with the vertical displacements of the thermocline

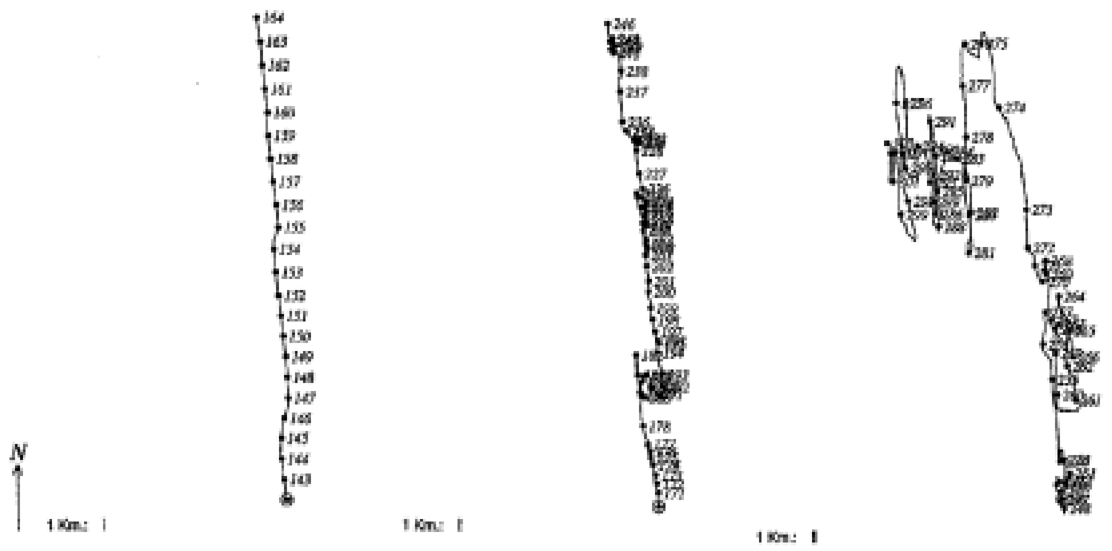


Figure 7. Progressive vector diagrams representing flow in Eastern Lake Ontario. Left to right: spring, summer, fall.

From the 1998 and 1999 seasons, only the data from the Aanderaa RCM-7 current meters are available, and on the basis of those data the following conclusions about water movements at a height of 1 meter above the sediment-water interface were reached:

1. The net or average flow of water at the location of the mooring off North Pond is northward.
2. During the isothermal season of the lake the flow is persistently toward the north. As the stratification of the lake increases, interruptions of the northward flow begin to occur, during which the flow is nearly zero, or even southward. Those excursions last for a few days, and the frequency and intensity of southward excursions of water increases as the degree of thermal stratification within the Lake increases.
3. There is a tendency for “pairing” of an oscillatory nature in the occurrence of high velocity events, with water flowing first in one shore-parallel direction, then the other, suggesting that those currents are associated with internal waves in the Lake.
4. A vector-averaging current meter, recording at a 10- or 20-minute sampling interval with the speed sensor one meter above the floor of the Lake does not indicate what events produce strong enough current speeds just above the bottom to resuspend sand grains or whether

> resuspension events are caused by long internal waves or surface waves generated by atmospheric winds. Orbital velocities of water particle movement associated with surface wave activity may be, for intervals of seconds, considerably higher. On the other hand, for water movements associated with larger-scale phenomena (e.g. long internal waves) the speed just above the bottom will be considerably less than that measured one meter above the bottom.

The 2001 data

In order to identify events during which bottom sediment was resuspended and to help determine what processes are responsible for that resuspension, a new current meter was added to the equipment deployed in the Lake during the 2001 field season. The new current meter enabled the measurement of velocities closer to the bottom and at a considerably higher frequency.

That instrument, an Aanderaa RCM-9 Mark II acoustic doppler current meter, was modified so that it could be deployed in an inverted position, with the sensor head “down”, enabling the measurement of currents 20 cm. above the bottom. The recording system in the instrument was also modified to allow for measurements to be taken at a high frequency (nearly 5 Hz, a frequency higher than anticipated frequencies of surface wave associated orbital velocities). The recording system also allows recording of data for a selected period, followed by a quiescent period during which no data were recorded, in order to conserve memory space within the instrument. This sampling technique is known as burst sampling. In addition to recording x- and y-components of current velocity, the instrument also incorporated a pressure sensor to monitor surface wave activity and a turbidity sensor to monitor water turbidity, indicative of suspended sediment. Figure 8 shows the RCM-9 current meter in its normal operating position. Figure 9 shows that instrument mounted in the tetrahedral frame on the deck of the RUSSELL B prior to deployment in the Lake. Figure 10 shows the instrument deployed on the bottom of Lake Ontario.

The new instrument, along with one of the older, vector-averaging current meters, was successfully deployed at the station off North Pond for two periods: for 23 days during April and May and again for 27 days during September and October. During the fall deployment, however, the older instrument was damaged, presumably by an angler. It is possible, nonetheless, by inspection of the data, to determine when the damage occurred and which of the data are useful. (The damage appears to have occurred during the afternoon of September 27th.)

Figure 8. The Aanderaa RCM-9 acoustic doppler current meter. Photo courtesy of Aanderaa Instruments

In general, the data from the older, RCM-7 vector averaging current meter are consistent with the data acquired during 1998 and 1999 and affirm the conclusions based on that earlier data and stated above. There were, however, a few southward-flowing excursions of water during 2001.

Figure 11 depicts the average turbidity, calculated as an average of all of the turbidity values recorded during the sampling period. During the spring deployment data were recorded for an interval of 150 seconds while during the fall deployment the recording interval was 180 seconds. Turbidity data were recorded at approximately 0.5 Hz. Units are Formazin Turbidity Units (F.T.U.).

The figures depicting turbidity, both from the spring and the fall deployments, clearly show periods of high turbidity, assumed to reflect sediment resuspension. The temporal characteristics of the periods of high turbidity are different between the two deployments. During the springtime the two periods of high turbidity are periods during which the turbidity increases somewhat gradually for several days, four days beginning May 6th, and six days beginning May 13th. This gradual, relatively extended period of increasing turbidity is then followed by a fairly rapid return to clearer water.

Figure 9. The RCM-9 current meter mounted in its tetrahedral frame on the deck of the RUSSELL B prior to deployment in Lake Ontario.

Figure 10. The RCM-9 current meter deployed on the bottom of Lake Ontario.

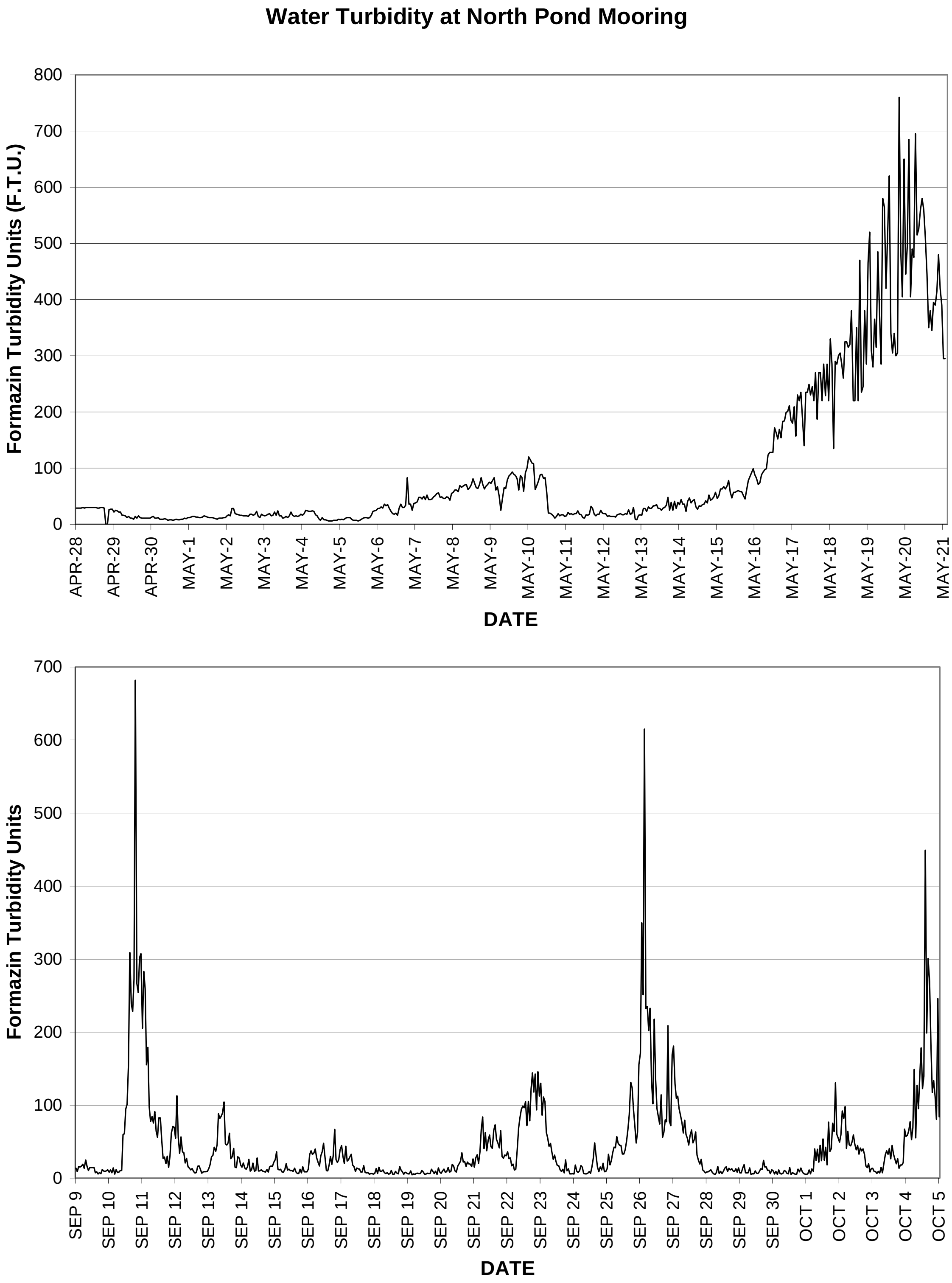


Figure 11. Turbidity values at North Pond Mooring. Above: Spring, Below: Fall

On the other hand, the fall turbidity figure shows three marked periods of very high turbidity/sediment resuspension (occurring on September 10th/11th, September 26th, and October 4th. There are also several periods of lesser level of elevated turbidity. These periods of high turbidity during the fall deployment are shorter in duration than those during the spring and are more symmetric in how they increase and decrease over time.

In order to identify an indicator of surface wave activity, the standard deviations of pressure and of speed were calculated for the duration of the burst samples. Results of those calculations for the fall deployment are shown in Figure 12. On the basis of visual inspection, it appears that standard deviation of pressure defines more clearly those episodes of high surface wave activity and will be used here for that purpose.

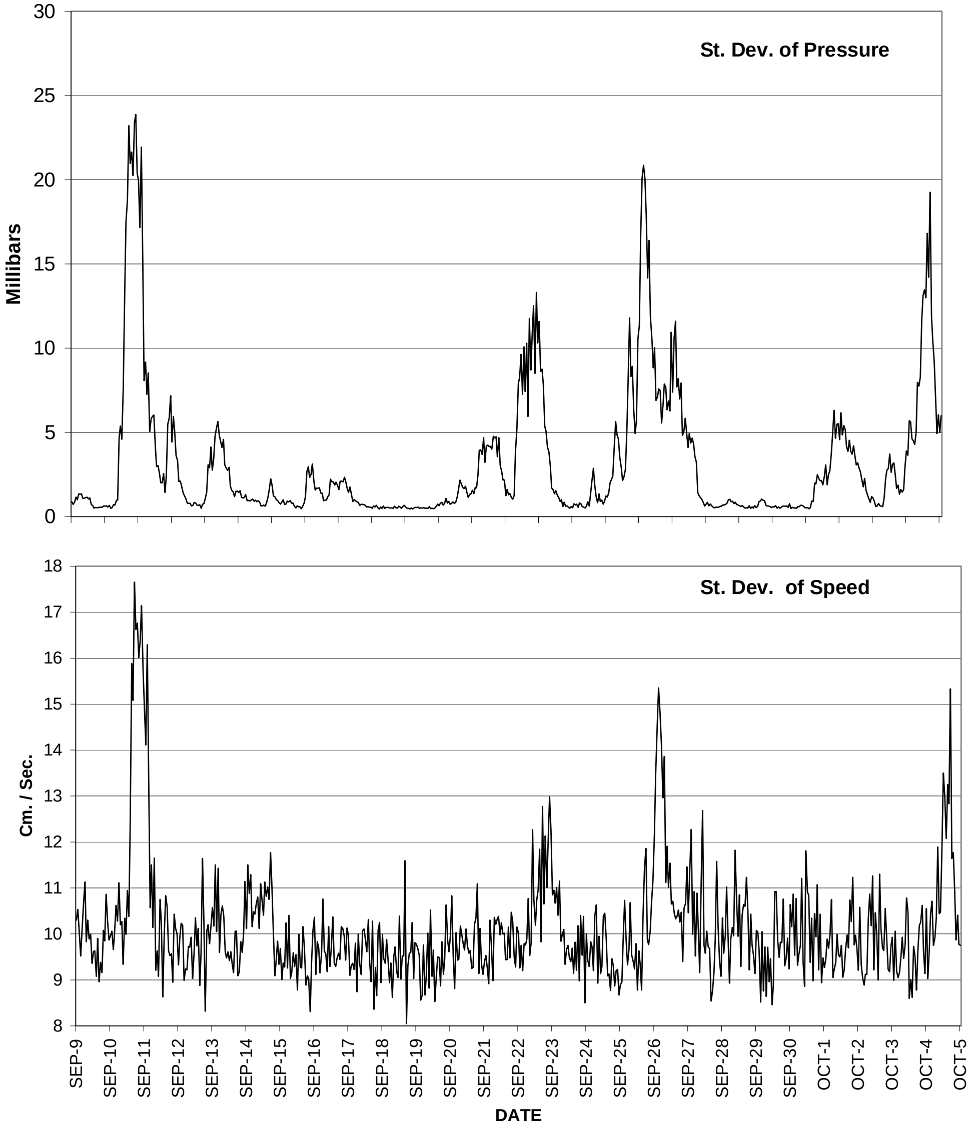


Figure 12. Comparison of Standard Deviations of Pressure (upper figure) and Speed (lower figure) for use as indicators of surface wave activity

Figure 13 shows the standard deviation of pressure with the turbidity variation. That high turbidity accompanies high surface wave activity is apparent. This is wholly consistent with currently held theory, as described, for example by Lesht and Hawley (2002), that surface wave activity is a primary mechanism for the resuspension of sediment in water of the depth in which the current study was conducted. Highest turbidity values, in excess of 400 F.T.U. and as high as nearly 700 F.T.U. occur three

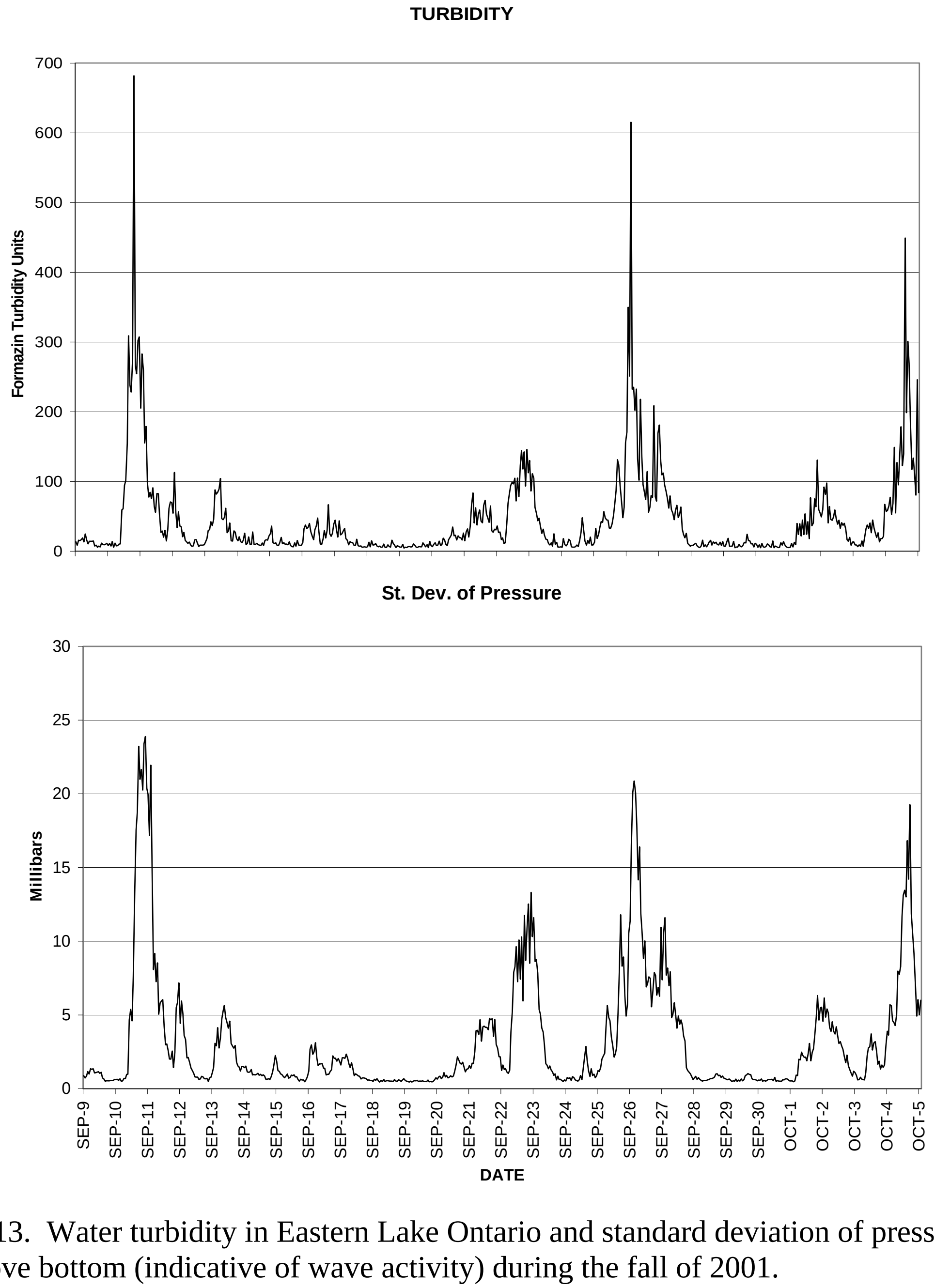


Figure 13. Water turbidity in Eastern Lake Ontario and standard deviation of pressure 20 cm. above bottom (indicative of wave activity) during the fall of 2001.

times during the observation period. Lesser peaks, with values on the order of 100 F.T.U. also occur during the period. In each case the turbidity peaks are concurrent with peaks of comparable magnitude in the standard deviation of pressure, indicative of surface wave activity.

Figure 14 shows the standard deviation of pressure with turbidity variation during the spring deployment. While there is an occasion of turbidity greater than 700 F.T.U. and one of turbidity on the order of 100 F.T.U. during this period of record, it appears that these occasions are not concurrent with periods of high surface wave activity as indicated by peaks on the curve for standard deviation of pressure. Therefore, some other mechanism must be responsible for the sediment resuspension recorded. Internal wave activity is non-existent when the lake is unstratified and must be discounted as a resuspension mechanism. During this season, some process other than surface or internal waves must cause the observed turbidity spikes. These data and analyses were presented at the 2002 Ocean Sciences Meeting, held in Honolulu, Hawaii, in February of 2002. In the discussion following the presentation, one of the members of the audience suggested that perhaps the occasions of high turbidity during the spring were caused by runoff of river water. This is a viable possibility.

That internal wave activity might play a role in water movement affecting sediment resuspension may be seen in Figure 15, in which the water level records from Oswego, N.Y. and the North Pond mooring are compared with the turbidity record. In that figure, water level records at Oswego are from the NOAA web site[*], Values shown are hourly averages of the 6-minute values given on the web site. The pressure record at the North Pond mooring reflects both changes in pressure due to changes in water level at the mooring and changes in atmospheric pressure. However, for present purposes, changes in atmospheric pressure are ignored. For purposes of comparison of water level changes between the mooring and Oswego, it can be safely assumed that most of the time, changes in atmospheric pressure at the two locations is the same. Both records are reduced to fluctuations about a mean value.

While the longer term records at Oswego and the North Pond mooring are nearly the same at periods of days and longer, there are clear extreme fluctuations in water level at the North Pond mooring. The biggest of those fluctuations occur at the same times as the highest values of turbidity (September 10th/11th, September 26th, and October 4th). Lesser magnitude fluctuations in water level at the mooring also are concurrent with lesser spikes in the turbidity (September 13th, 23rd, 27th and October 1st and 2nd).

The present hypothesis is that those lake level fluctuations observed at the North Pond mooring, occurring concurrent with periods of high turbidity, are associated with surface manifestations of internal wave activity in the Lake. Those internal waves are presumably excited by the passage of atmospheric fronts over the Lake concurrent with the occurrence of the depth fluctuations and turbidity spikes. Evidence for this hypothesis is 1) that the fluctuations appear to be oscillatory in nature and 2) that the fluctuations occur during the stratified period and are absent during the time when the Lake is nearly isothermal. While it is not the only mechanism at work in eastern Lake Ontario, internal waves may transport sediment which has been resuspended by other mechanisms such as surface wave action.

[*] *www.co-ops.nos.noaa.gov/data_retrieve.shtml?input_code=100111111vgl.*

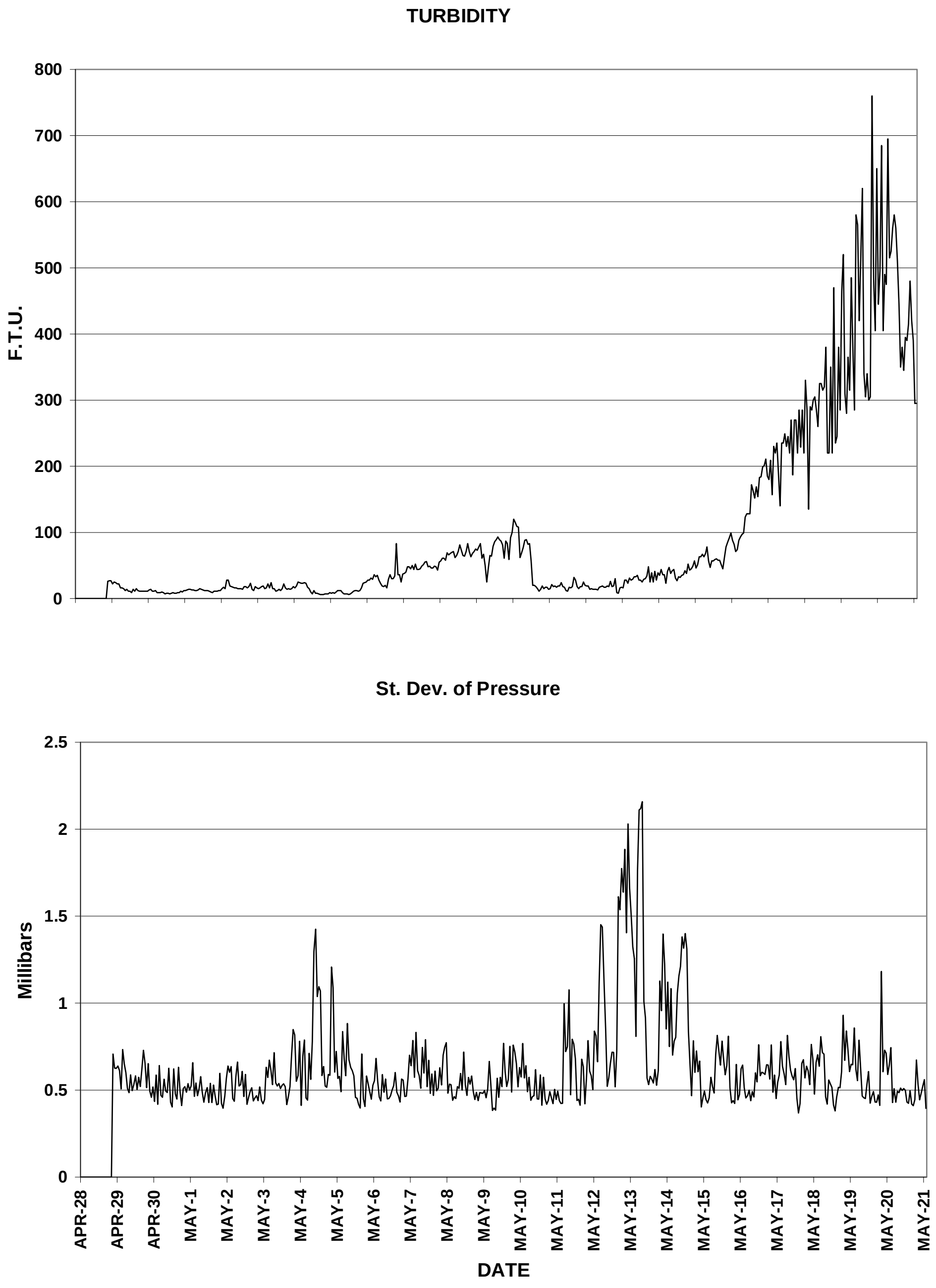
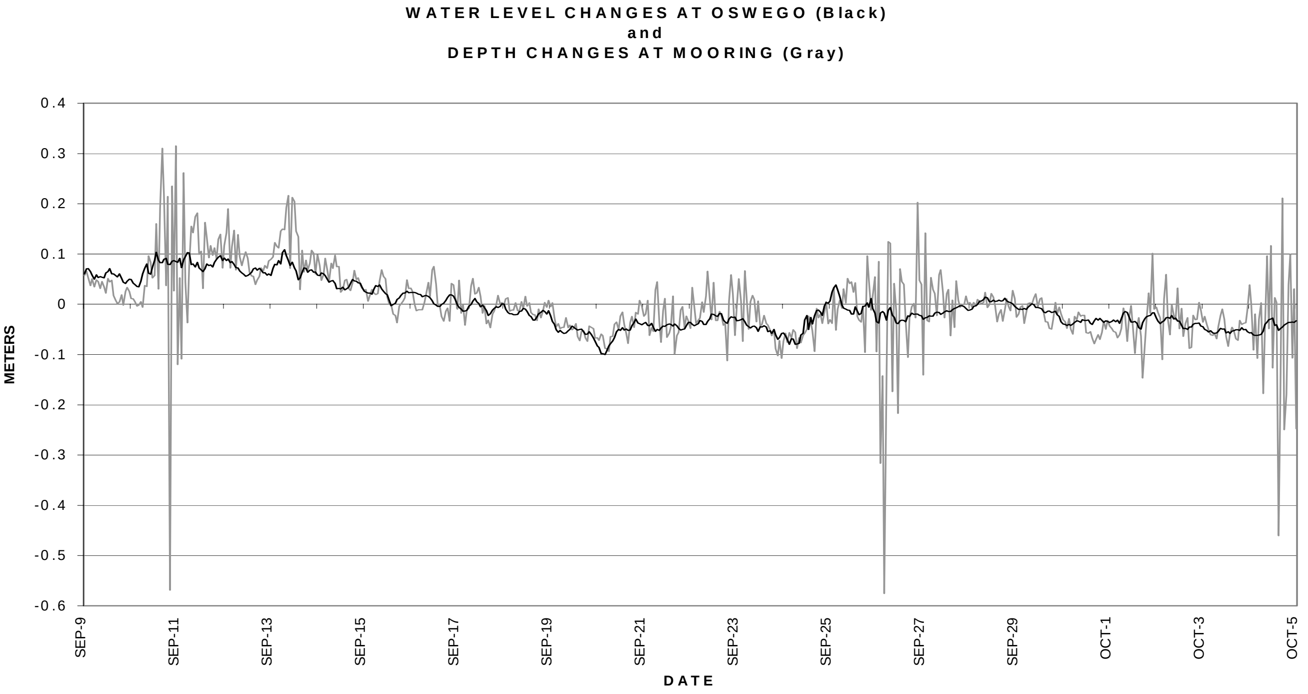


Figure 14. Water turbidity in Eastern Lake Ontario and standard deviation of pressure 20 cm above bottom (indicative of surface wave activity).



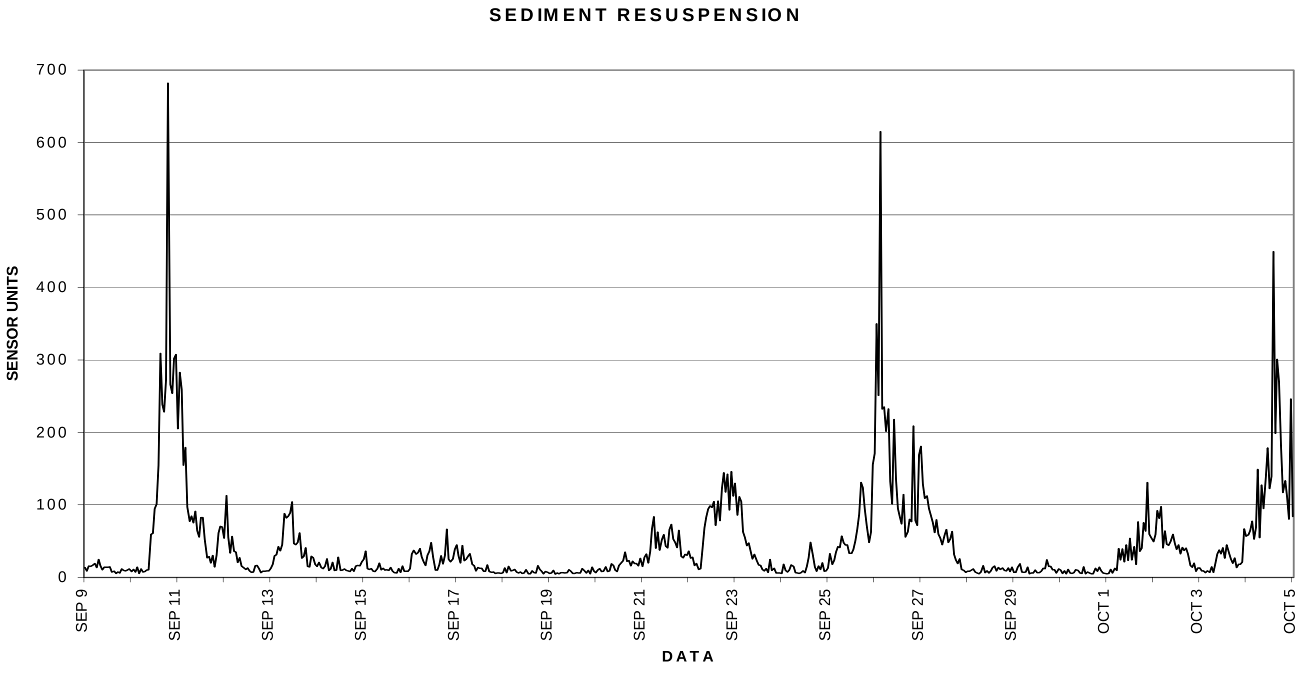
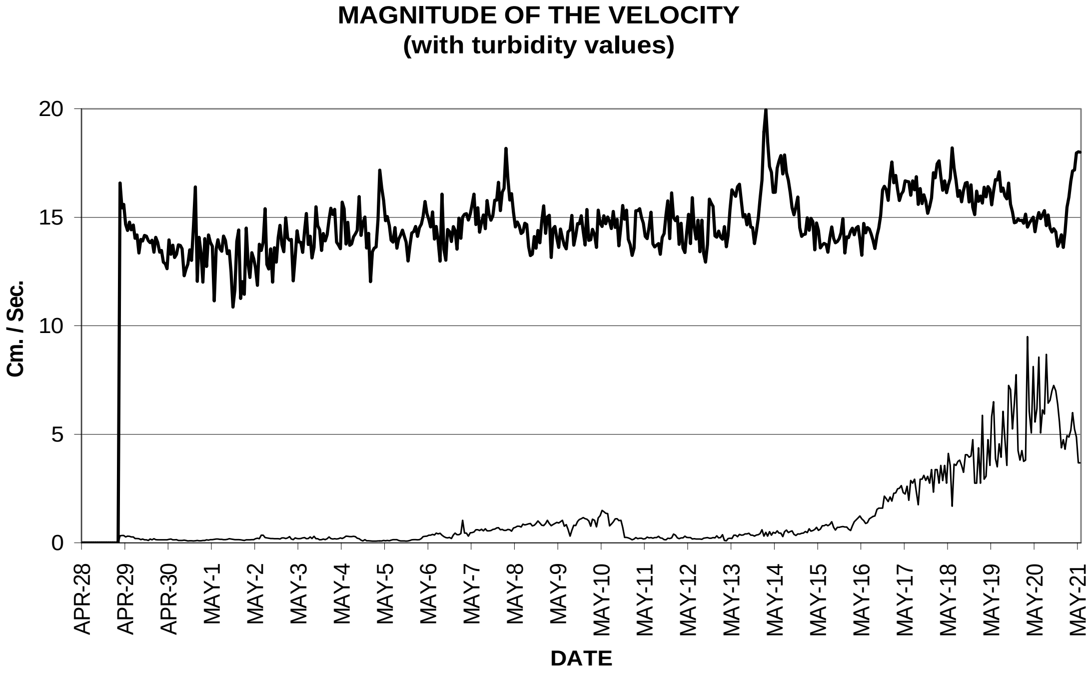


Figure 15. Sediment resuspension (below) and water level changes at Galloo Island and the North Pond mooring (above).



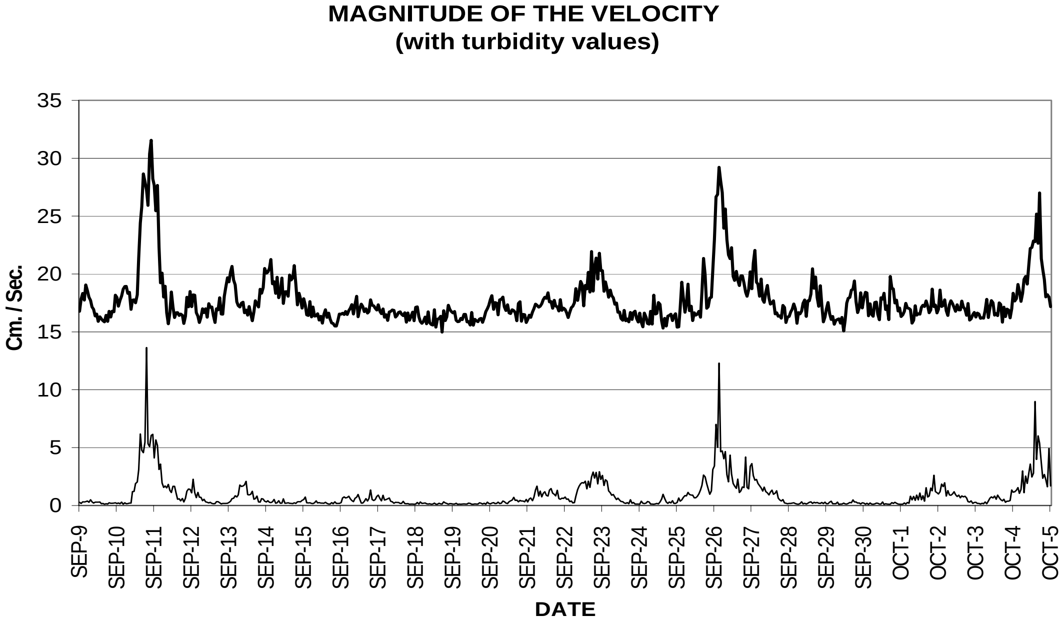
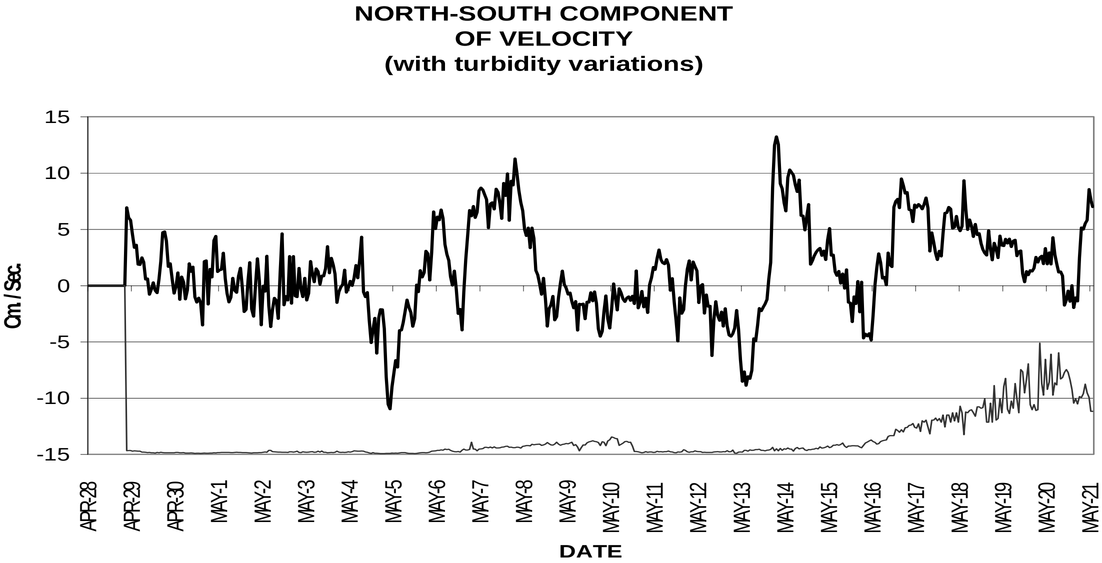


Figure 16. Magnitude of the velocity observed 20 cm. above bottom (bold, upper line) with representation of turbidity (light, lower line). Note that turbidity values are not to scale. For turbidity scale see Figure 11.

Figure 16 shows the average magnitude of the velocities during each of the sample bursts during the two deployments, along with the average turbidity value for those bursts. Note



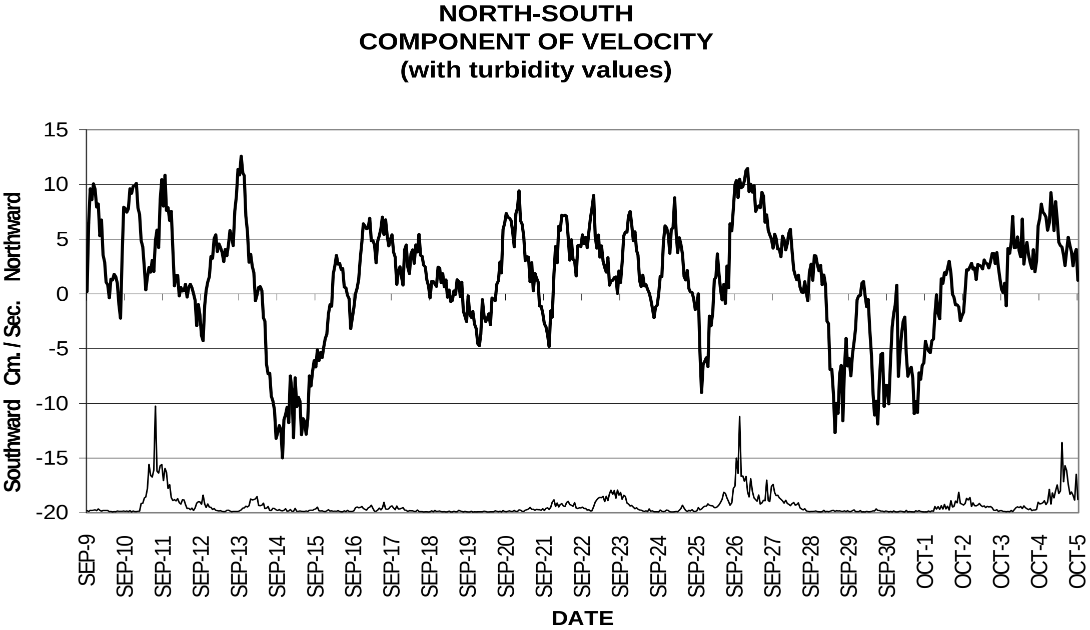


Figure 17. North-South component of velocity (averaged over burst sample interval) 20 cm. above bottom (bold, upper line) and representation of turbidity record (lighter, lower line). Note: Scale for turbidity not shown. For scale of turbidity values see Fig. 11.

the turbidity scale in Figure 11. It can be seen that during the fall deployment the variation in turbidity values matches, nearly exactly, the variation in magnitude of the velocity. It can also be seen that, during the fall deployment, the biggest peaks in the turbidity record occur when the average magnitude of the velocity exceeds 20 cm•sec^{-1}. During the spring, however, agreement between the turbidity curve and the magnitude of the velocity curve is not seen. Clearly, a different mechanism is responsible for sediment resuspension in the spring than is effective during the fall. Unfortunately, no explanation is offered at this time.

Figure 17. shows the north-south component of the velocities (approximately parallel to the shore) during both the spring and fall deployments. The record of turbidity is also shown. It should be noted that in nearly all cases of turbidity values elevated above what might be considered ambient values, the shore-parallel component of the velocity is northward. The two exceptions to this generalization are on May 10th, when there is weak southward flow and again on May 20th, when there is again a brief period of weak southward flow.

Conclusions

1. During the fall, when the Lake is strongly stratified, surface wave action appears to be the primary mechanism for sediment resuspension.

2. During the spring, when the Lake is isothermal or weakly stratified, it appears that some mechanism other than surface wave action produces periods of high turbidity.

3. Both during the spring and the fall, the mean shore-parallel component of the velocity is northward during most periods of elevated turbidity.

4. The same atmospheric processes which produce sediment resuspending wave action also appears to excite internal waves, which may have an effect on the direction in which that resuspended sediment is transported.

5. It is likely that significant sediment resuspension and transport occur during the winter, when strong storms pass through the Great Lakes. Regrettably, during this time no data are presently available.

References

Beletsky, D., J. H. Saylor, and D. J. Schwab, 1999. Mean Circulation in the Great Lakes. *J. Great Lakes Res.* 25(1):78-93

Lesht, B. M., and N. Hawley, 2002. Using Wave Statistics to Drive a Simple Sediment Transport Model. Preprint from WAVES2001, Proceedings of the Fourth International Symposium on Ocean Wave Measurement and Analysis, American Society of Civil Engineers, Reston, VA. In press.

Aerial Photography-Based GIS and Historic Map Analysis of the Eastern Lake Ontario Shoreline – Charles E. McClennen

Abstract

This research report continues the efforts to refine the understanding of the dynamics and history of coastal change along the eastern Lake Ontario shoreline. The coast is dominated by a seventeen-mile long stretch of barrier beaches and dunes with numerous ponds and small river outlets. Coastal land management issues and opportunities have motivated the search for an increased certainty about the active processes and expectations for future change along the shoreline. Analysis of potential errors and their magnitude in this GIS-based study demonstrates that available aerial photography has fundamental registration uncertainty of about 50 feet (15 meters). Of particular significance for the 1974 and 1978 images is the magnitude of the distortion caused by the lens effect in aerial photographic prints. The outer margins of all prints include location distortions of somewhat more than fifty feet at the scales used in this study. In addition, records of lake level fluctuations generated by storm conditions and seasonal climate variability, even when modulated by several decades of lake level management, demonstrate that one to five foot changes are expectable in any given year. This range of lake level fluctuations horizontally shifts the shoreline location anywhere from 50 to over 200 feet, depending on the magnitude of the lake level change and the gradient of the beach face and near-shore zone. Because of the absence of precise knowledge of lake levels at the time of acquisition of aerial survey images it is difficult to distinguish between real geological shoreline changes and the mere appearance of change caused principally by lake level fluctuations. The combined impact of image registration for GIS location and lake level variability may be additive or partially self-canceling. In either case, many of the apparent shifts in shoreline position, beach width, dune location and inlet character fall within the range of these inherent uncertainties. Thus only the most extreme changes, as at the North Pond inlet in the town of Sandy Creek, Oswego County, can be pointed to with certainty, based on the GIS analysis of aerial photographic data collected each decade between 1938 and 1994.

Historic maps and charts allow the extension of the study back to 1862 in a limited way and more substantially from 1878 when detailed bathymetric values were first published for eastern Lake Ontario and the adjacent ponds. Shoaling of North Pond of one to six feet suggests an upper limit of sand removal to the pond from the barrier and near-shore bars in the order of two to five feet. Wind blown transport and inlet currents are presumed to be of major importance for the pond depositional accumulations. Reasons for caution about the validity of these calculations are reviewed and emphasized.

Review of management issues and questions about coastal dynamics lead to the fundamental necessity to appreciate the unpredictable yet inevitable nature of coastal changes to the beaches, bars, dunes, inlets and associated vegetation zones. All coastal development that requires stability of shore and land should be excluded from the zones of likely natural coastal change by carefully designed management planning and regulation. Consideration for the desired human development uses and the value of natural ecosystems should also be included in future coastal zone management analyses.

Introduction

In reviewing the September, 2000 Report to the Nature Conservancy entitled "Aerial Photography-Based GIS Analysis of the Eastern Lake Ontario Shore: Coastal zone change and processes 1938-1994" (McClennen et al., 2000) it was determined that a follow-up GIS study would be of value. The several analysis concerns included; 1) the previous absence of any photographic coverage from the 1970s decade, 2) the lack of a quantitative consideration of the sources of error in the GIS digitization of the photographic coverage, 3) the limited quantitative analysis of lake level change as a factor and 4) the shift of priorities from the coastal zone including the extensive wetlands to the much more restricted areas of beach, dune, inlet and adjacent offshore sand bars. The sand budget focus and coastal change analysis was partially overwhelmed by the aerial extent of the coastal wetlands and their changes over the decades. This review of the beach, dune, inlet and bars with their history of change, as recorded in the aerial photographs and a few 19th century maps and charts, gives primary attention to the features of primary interest.

Aerial Photographic coverage for the entire study area from the 1970s was made possible by combining images taken in 1974 and 1978. However they are less than ideal images for GIS analysis in that the registration points for precisely locating each image had to be taken from the outer limits of each photograph. That is where the optical distortion is known to be greatest. This fundamental aspect of the only available 1970s imagery for the study area makes it impossible to produce highly accurate GIS digitized comparisons between the preceding and subsequent decades. This aspect of the photographs taken in the study area during the 1970s was the reason that they were excluded from the initial study and report to The Nature Conservancy in 2000. Here they have been added as requested because of the numerous changes around inlets that occurred in the 1970s, a decade of particularly variable and high lake levels.

A consideration of lake level variability and impacts on the coastal features revealed in the photographic images is presented. There are three aspects of this review that deserve attention. First, elevated and lowered lake levels directly affect both the apparent beach width and shoreline location at the time photographs are taken. Second, the impact of waves on sediment transport and geomorphic modification of beach, dune, sand bar and inlet features, particularly immediately after storms, is significantly enhanced by above average lake levels. Third, lake level data has not been systematically gathered along the eastern shore of Lake Ontario within the study area. The nearest available hydrographic data comes from two observation stations located at Oswego and Cape Vincent, New York. Linking a particular photographic image series from a known date to these lake level data is complex since the daily, monthly and annual averages include both normal and extreme weather conditions. These kinds of lake level changes have significant impact on shoreline position since the beach faces generally have low slopes or gradients of between one in ten to one in one hundred.

The error analysis of the digitized aerial photographic and GIS data set incorporates several components. The United States Geological Survey (USGS) topographic quadrangle maps of Ellisburg, Pulaski and Henderson, at a scale of 1:24,000, have an accuracy standard that requires 90% of all map points to be within 40 feet of true location. These base maps were used to pick key registration points for locating the aerial photographs in GIS coordinate space. The digitizing tablet reads to within 10 feet at the scale of 1:24,000 used for the published topographic maps. The digitizing accuracy varies somewhat from photographic image to image, depending of the scale of the prints used. They ranged from about two to six feet, with most in the range of three to four feet. Thus the initial required registration of each photographic image is the dominant source of the error, as all registration positions for each aerial photograph were taken from the topographic quadrangle maps. Thus any position shift of coastal features seen in the GIS analysis that is 50 feet or less must be seen as possibly caused by these unavoidable mapping and digitizing errors. Changes of greater magnitude are likely to be real but subject to an uncertainty of about 50 feet (15 meters) in exact location.

Some time was also spent evaluating the quality and information from a series of historic maps and charts. The goal was to identify any coastal changes in location or shoreline shape as well as bathymetry. Differences in the water level datum used for each chart and map were small where it could be determined (< 2 feet between 1960 survey and 1992 chart). The 1878 chart displayed a systematic offset in latitude of approximately 800 feet to the west for all the land features, even those located to the east and fully separated from coastal processes. The significantly deeper pond bathymetry from 1878 enables the calculation of interesting sedimentation rates and depositional volumes. The 1862 property tax map for the Town of Sandy Creek has no latitude and longitude coordinates nor any bathymetry and elevations making it of limited utility for this study. A coastal inlet and channel ways are depicted for North and South Ponds. An earlier (1829) and other historic inlet locations for North Pond are noted by Weir (1977) in his illustrated Masters Thesis.

Finally, an attempt to address a series of questions that have been raised about numerous aspects of the eastern Lake Ontario shore and sediment dynamics is made, utilizing the knowledge gained through the aerial photographic and map analysis. The aerial views and GIS analysis can provide useful information or perspective for only some of these questions. Others, while of considerable interest, must be addressed through different means used in the ELOSTS study. A few questions seem to extend well beyond any of the field research methods applied so far to the eastern shore of Lake Ontario. Ways of addressing those unresolved questions in the future could well require new field research of considerable magnitude.

This report will be posted on the Colgate University web site along with the earlier (McClennen et al., 2000) TNC GIS Study. All the scanned aerial photographic images and digitized shape files for each decade are posted as well: see http://www.colgate.edu/academics/geology/faculty/mcclennen.html. Zip discs of the report, scanned images and back-up GIS files and materials will be provided to TNC with the final submission of this report.

Error Analysis

As indicated in the introduction, there are several sources of position error when conducting GIS-based aerial photographic analysis. Without restating the detailed data handling methodology included in The Nature Conservancy Report (McClennen et al. 2000), it is useful to be reminded that for any image-to-image comparisons to be effective all the aerial photographs have to be accurately positioned in space. Typically some form of latitude and longitude map projection is used, such as the Universal Trans Mercator projection of the USGS topographic quadrangle maps. We took at least four positions of known features from the topographic maps, used them to register each photograph and then proceeded to digitize the photographed boundaries of all the coastal features of interest. The USGS standard of having 90% of all positions within 40 feet of their true location on 1:24,000 quadrangle maps turns out to be the primary limiting factor because all other sources of error are considerably smaller, although important because they are potentially additive. By using at least four registration points, cross checking and internal consistency of each image registration effort can be made in the ArcView version 3.2 (ESRI, 1999) used in the research project.

Registration plots with greater than 0.01 inches of error on the digitizer were rejected as unacceptable and other registration points were selected. The amount of offset depended on the aerial photograph with 0.01 inch on a standard 1:24,000 scale topographic map = 20 feet. Distortions of relative location are inherent in aerial photographs particularly around the outer perimeters of each image. This lens effect is unavoidable in standard aerial photographic prints from negatives. For this reason the central third to half of each image is preferred for precise aerial space and location analysis. Most aerial photographic series are therefore shot with extensive overlap on all sides that may be of interest. Some of the series used in this Lake Ontario study did not have the coast and registration features located in a central part of the images. Thus registration efforts were handicapped, particularly for even the best of the 1974 and 1978 photographic series used in this study. In addition the two 1970s decade photographic series only provided partial coverage of the entire study area. So any changes in shorelines that were as little as fifty feet (15 meters) were viewed as within the margin of error and thus too suspect to accept as geologically significant or real.

Comments on NYS Map Product Requirements

In view of this described situation with respect to error analysis it is obvious that it has not been possible to generate any map from this aerial photographic GIS study that complies with the National Map Accuracy Standards, USGS and NYSDOT General Map Product Requirements. In fact no level of mapping was attempted beyond the digitization of the aerial photographs and the superposition of such products for the assessment of coastal feature changes. All the GIS files and documentation for the TNC research effort are tabulated and delivered in their entirety on Zip Discs. This paper includes just a couple of figures and a complete updated table of aerial photographic descriptions. See the scanned photographic images for in their entirety for 1974 and 1978 as well as the Mktc folder and sub-folders backing up this report and the associated GIS files. The horizontal datum coordinates were taken from the USGS Topographic Maps with their standard NAD27. No vertical datum was included in the GIS analysis project. Position and Map Accuracy has been discussed above.

Similarly, the Additional Digital Cartographic File Requirements are not realistically applicable to this GIS-Aerial Photographic analysis because of the numerous error factors discussed above and the fact that no maps were required by the research contract agreement. No map products were generated that could be made to conform to the Edge-matching, Common Boundaries, Point Duplication, Connectivity, Line Quality, Graphic Precision and Digitizer Accuracy standard requirements. Polygon Closure was standard for each photo digitization effort. However, as no Digital-Ready Maps were generated, the related requirements provided for review by the TNC for Base Map Media, Map Scale, Map Registration, Map Title and Legend and Cartographic Quality need no further commentary in this report.

Impact of Lake Level Change

As indicated in the introduction, there are several lake level factors of significance in any aerial photographic analysis of coastal areas. The typically low topographic slopes seen along sandy coasts cause major horizontal shifts in shoreline location when water level is vertically displaced. The Great Lakes Information Network provides numerous useful records and tabulations of lake level data on the web. In Lake Ontario storm related lake level changes of a foot or two are documented on the Great Lakes Information Network for both Oswego and Cape Vincent (hhpm@lre02.usace.army.mil/storm/ontstrm). Storm induced rises of one to two feet have been recorded at both stations. The significant probability (20%) of exceeding a one half foot to one foot excess elevation in storms for each month of the year shows that this is a common occurrence. Storm induced higher elevations of lake level are less likely but seen at both the Cape Vincent and Oswego stations in all months. Such elevated lake levels make the beaches look narrower by 50 feet (15 m) to more than 200 feet (61m) particularly in the coastal sections with beach face slopes of less then 1:50, which occurs along the fine sandy shores of the barrier beaches and at the spits by inlets.

In addition to the short term storm events the seasonal and inter annual changes in lake level has been well documented for the Great Lakes and reported on the web at (http://huron.lre.usace.army.mil/levels/maxmin.html). For Lake Ontario the difference between maximum and minimum lake levels for each month roughly span four and a half (4.5) feet to five and a third (5.33) feet. Table II, seen at the end of the paper, indicates the levels of the lake reported by NOAA for Cape Vincent and Oswego, New York on the dates that the digitized aerial photographs were taken. A one foot difference between stations on June 4, 1959 and the total range of 3.05 feet (11/10/38 vs. 05/25/84) indicate the significant magnitude of lake level changes impacting this analysis. Such vertical lake level changes produce striking shifts in the horizontal waterline location, even on steeper sloped beach faces. With the relatively steep beach face slope of 1:10, a five foot shift in lake level moves the shore line a full 50 feet (15 m). At lower beach face gradients, such as 1:50, the shoreline would be shifted horizontally by as much as 250 feet (76 m). This kind of shoreline shift is similar in magnitude to, but can obviously exceed, the uncertainties or errors inherent in this aerial photographic GIS digitizing and analysis. On the more gentle and typical beach slopes such shoreline displacements are known to occur but are not always easily identified in aerial photographic analysis because of the lack of precise knowledge of the local lake levels at the hour of photographic flight times. Published monthly mean lake level data are thus of limited value in photographic image interpretation requiring precise determinations of shoreline positions and their geological origins, if any.

It is logical that changes in lake level cause a relocation of both the shoreline and the locus of wave action on the coast. Most coastal observers note the prevailing pattern of destructive or erosional impact of storm waves particularly during elevated lake levels. Mobile unconsolidated beach and dune sands are subject to rapid geomorphic change when wind driven waters flood the barriers and dunes. Because there are no tidal patterns in Lake Ontario many fail to pay sufficient attention to the impact of changing water level caused by the weather events and climate. Lake level change goes well beyond the inconvenience of narrower or widened beaches, deeper or shallower channels and occasionally flooded front lawns. In some instances storms that occur at times of raised lake level produce lasting geomorphic change, such as the creation of new inlets. This rapid change is well documented by the periodic dredging of inlets demanded by the boating public when inlets are in-filled by mobilized beach sands. The rare, but more vivid, creation of new inlets through the barrier beaches developed during particularly powerful storms that occur each century leave more lasting impacts on the ponds and coastal morphology. Beaches and boating channel ways are both clearly modified and easily recognized on any series of charts, maps and aerial photographs covering such areas. The history of inlet change for North Pond is certainly the best example on the eastern Lake Ontario shore (See; McClennen et al., 2000, Figures 1 &2 of this report, Weir, 1977 and SUNY Oswego web site; http://www.oswego.edu/Acad_Dept/a_and_s/earth.sci/geo_geochem/geol/sandy.html).

Thus lake level changes are a significant part of coastline image and location mapping and they are certainly related to more fundamental coastal reconfigurations. The basic problem of aerial photograph analysis is that it is not always possible to link the exact time of photographing to the exact lake level. Changes observed in individual photographs may thus be either temporary due to short-term lake level rises or of a more permanent nature and reflect a true shift in the location of coastal sedimentary deposits such as bars, beaches and dunes. If the images of coastal changes exceed the scales of uncertainty indicated by error analysis then the change should be viewed as real. If the changes observed are seen to persist, expand in degree or continue shifting with a persistent trend then they can be taken as real. Yet if they are within the range of error and are seen to have an oscillating character they may be due to photo registration and feature location uncertainties rather than true coastal change. In order to evaluate the extent of horizontal shift in shoreline location due to any given amount of lake level change it will be necessary to know the slope of the beach face and near-shore zone along the entire length of the coastal area of interest. So far no such systematic profiling survey has been conducted.

Beach, Dune, Inlet and Bar Changes

As previously reported (McClennen et al, 2000) there are many identifiable apparent changes in the shoreline along eastern Lake Ontario as recorded in the aerial photographs taken over the decades. When digitized with proper registration the horizontal shoreline location shifts mostly fall within the range of 33 to 66 feet (10 to 20 meters). This magnitude of horizontal relocation can easily be explained by three likely and at times interacting factors. First, the beaches actually retreated in response to erosion or advanced due to deposition. Second, the lake water levels differed sufficiently at the times each photographic image was taken thus producing an apparent gain or loss of beach sediment. Third, the part of the photographs used to locate the shoreline were too close to the edge of the image and thus subject to significant lens-effect distortion. Accordingly, based on the error analysis and associated GIS uncertainties, most of these small scale shoreline shifts should be looked upon as probably not being of geological significance. No patterns of multi-decadal trends, in shoreline shifts, were noted. As

McClennen et al. (2000) previously reported, even comparisons of the earliest and latest photographic images displayed shoreline dislocations fully within the recognized range of uncertainty.

The dune vegetation by contrast showed progressive development and thickening over the decades. Seasonal variations of dune vegetation were noted in some of the photographs, particularly in the early spring vs. late summer or late fall. Erosion induced retreat of the lake-ward face of the dunes was indicated locally by a narrowing of the westward extent of the dune vegetation. Re-growth of dune grasses and scrub vegetation in subsequent decades typically followed the storm erosion events. Shift in dune and beach vegetation was most extensive and noticeable around the inlets where the dune deposits can be very thin such as around the North Pond inlet.

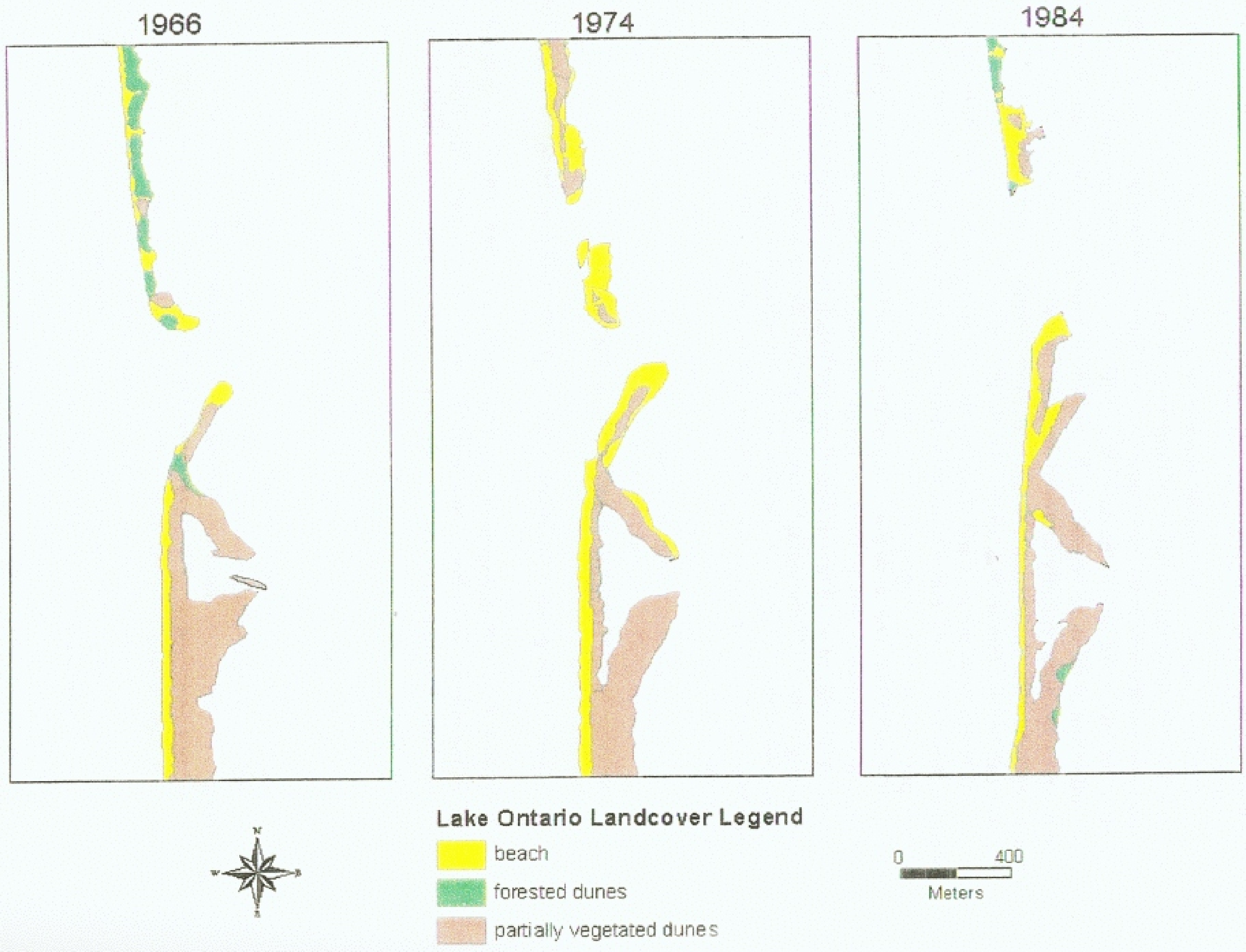
At North Pond the inlet and shoreline, as well as vegetative cover, shifts have been the most vivid in the entire study area, during the decades examined. Figures 1 and 2 show portions of the photographic images and digitized land-cover polygons from 1966, 1974 and 1984. The wave breaching of the barrier beaches during storms has created a new inlet seen only in 1974, which has migrated and been reconfigured by subsequent decades of wave driven near-shore and beach-face sediment transport. The April timing of the 1974 photograph may well account for the absence of any forested dune features in the northern spit. The preceding and subsequent photographs were taken in late May and July when trees are in full leaf and thus more readily identified in the photographs.

(Figures 1. and 2. follow this page.)

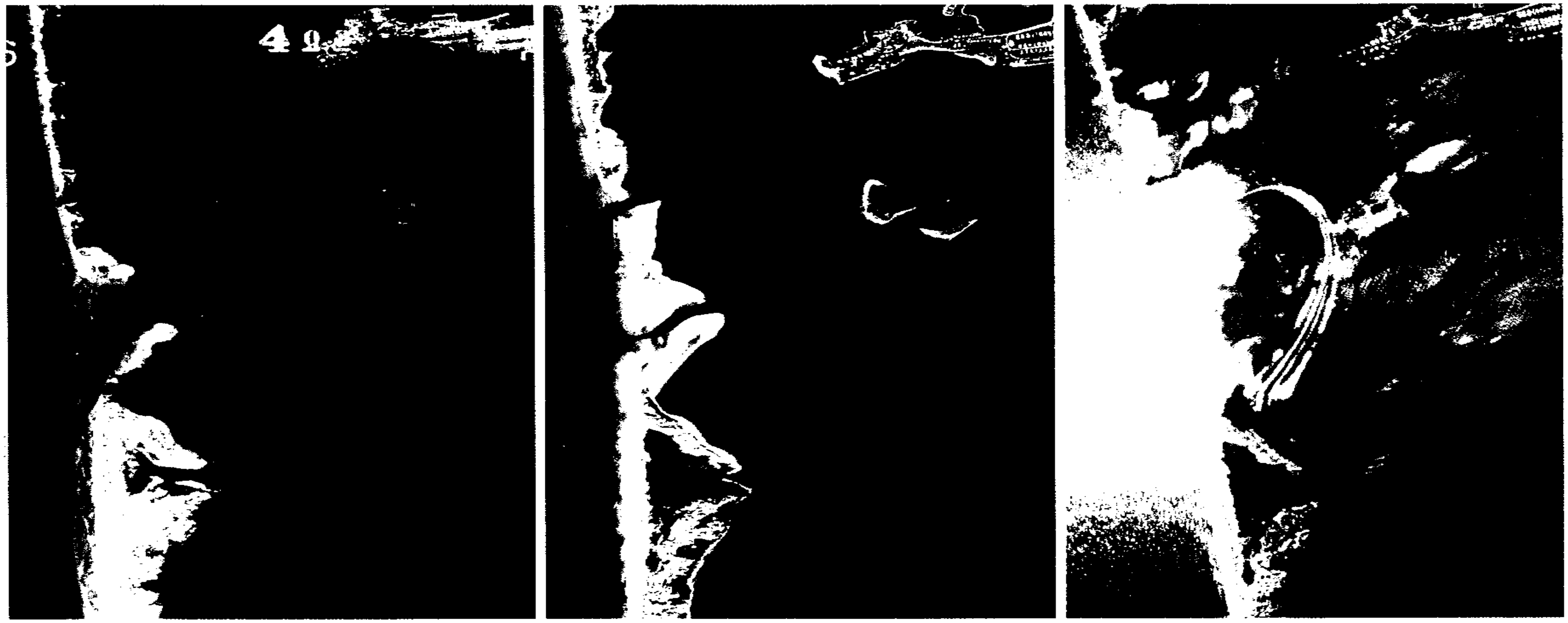
Figure 1. Geographic Information System (GIS) plots from 1966, 1974 and 1988.

Figure 2. Aerial photographs from 1966, 1974, and 1988. Glare obscures much of the inlet to North Pond. Scattered clouds extend over part of the Pond east of the inlet. Prominent curved lines are wakes made by a powerboat.headed toward the inlet.

North Pond Inlet, Lake Ontario 1966-1984



Aerial Photographs of North Pond Inlet, Lake Ontario 1966-1984



1966 1974 1984

Equally striking is the fact that the associated near-shore bars and inlet shoals are always different in form and abundance when comparing the photographic images from the different decades. Fully describing the changes between the decades is prevented because many of the aerial photographs suffer from poor resolution of the lakebed deposits, even in the near-shore shallow waters. Breaking waves and surf foam overwhelm some sand bar imaging. Reflected sun glare off of the waves in lake and pond surface waters is another recurring pattern that prevents a systematic, decade-by-decade, analysis of the near-shore shoals and sand bars located along the length beaches of the study area and at each inlet. However it is no surprise that the indications of greatest mobility of coastal sands occurs at the inlets where in addition to the dominant Lake Ontario wind generated waves there are also inlet associated currents. Spring melt run off and heavy rains generate some of the outflow. Changing lake water levels driven by shifting wind patterns create more frequent inlet currents that are strong enough to mobilize the sandy lakebed sediments.

Consideration of 1862, 1878, 1960 and 1992 edition Charts and Maps

The 1862 Sandy Creek map, by J. B. Butler, shows the surveyed real-estate property bounds. No datum, elevations or bathymetry is recorded making it of limited use in a coastal change study. The meandering channel inlet from Lake Ontario that bifurcates and simultaneously serves North Pond and South Pond is clearly depicted in detail and quite similar to that, seen with less detail, in the 1878 Corps of Engineers Coast Chart No. 2. This was surveyed in 1874 and 1875 and provides very useful bathymetry at the map scale of 1:80,000 for eastern Lake Ontario and the several adjacent ponds. Of particular interest is the comparison of the 1878 bathymetric data with the 1959-1960 Corps of Engineers' bathymetric survey of the eastern end of the lake and the 1992 edition of the National Ocean Survey chart number 14803.

The 114 year period, between 1878 and 1992, provides our best long-term basis for evaluating bathymetric change and deposition or erosion. The Lake Ontario depths show no apparent or substantial changes. This assessment is limited in precision by the margin of uncertainty resulting from the depth notation units of fathoms, in 1878, and then the more precise unit of feet, in 1992. However, the obvious differences in water depths for North Pond in the Town of Sandy Creek cannot be explained away by such uncertainties because both charts have depth expressed in feet. Any possible map-datum differences cannot explain the bathymetric shoaling because it varies considerably within the area of North Pond. North of Greene Point sedimentary infilling of one to three feet is indicated by the charted water depths. West of Carl Island it is intermediate at three feet. In the main body of North Pond, south of Greene Point and Carl Island the shoaling over the same time interval is more substantial at three to six feet.

The greater rate of infilling of the central and southern part of North Pond is consistent with several coastal features observed on the aerial photographs dating back to the 1930s. The barrier spit north of Carl Island has had wooded dunes for most of its length during the 20th century. The barrier spit south of Carl Island has been the locus of several inlets that have developed and subsequently re-closed, except for the present one just west of and adjacent to Carl Island. The trees and other vegetation of the wooded dunes to the north would greatly inhibit wind blown transport of sand and silt from the beach eastwards into the pond. Just to the south the prevailing westerly winds would have had a different impact. The series of documented pond inlets and the subsequent infill sediments have provided extensive areas of exposed beach sands and low dunes. Considerable sediment seems to have been blown eastward into North Pond or carried in through the series of inlets cut through the southern portion of the barrier. These, in combination with organic deposition and land-derived sediments, have probably been the dominant causes of the recorded shoaling. While the depths of several other coastal ponds are given on the 1878 chart they are not recorded on any of the later charts used, so sedimentation rates elsewhere along the coast could not be determined by this method of chart analysis.

In order to get a volumetric estimate of the amount of sediment lost from the beach and barrier dunes into North Pond some simple reasoning and calculations were utilized. First, it was assumed that perhaps only half of the thickness of recorded shoaling was attributable to beach and dune sources. Second, for convenience of analysis it was determined that the mean shoaling was approximately two feet north of Carl Island and four feet to the south. The area of the two sections is taken to be 26 million and 76 million square feet respectively. Using these two assumptions and the square area estimates the total volume of beach and dune sand transported eastward from the barrier into North pond is approximately 178 million cubic feet or just about 6.5 million cubic yards.

A reasonable question then is, what impact would this volume of sediment have had if it had been in fact removed from the beach, barrier dunes and near-shore bar deposits. Spreading it evenly over the three and a half mile length of the North Pond barrier with an approximated average width of 2,000 feet would produce nearly a five foot thick deposit over the barrier and near-shore bars. However, a more reasonable model would be to assume that the loss of barrier deposits fed into North Pond also came in part from the beaches to the north and south. Long shore and beach transport, driven by northwest and southwest winds, is certainly important along the seventeen mile stretch of the eastern shore of Lake Ontario. One could thus reasonably consider the impact of spreading the calculated volume over the full seventeen mile length, but on a narrower width band of only 1000 feet to account for the lack of barrier dunes in several sections. This calculation indicates that one would have had to remove a thickness of just under two feet of sand from the beach and near-shore bars for the entire seventeen mile length of the study area in order to obtain half the calculated volume of sediment needed to fill North Pond since the 1878 bathymetric survey. Before we take these calculations too seriously the rough nature of the assumptions must be recalled and there are other considerations.

First, the depth measurements of the nineteenth century were most likely determined by the leadline technique or possibly by using a pole, since all depths were less than twenty feet. When the lead weight or pole rests on the bottom it has penetrated most of the soft organic rich sediments resting on the bottom of this type of pond. Secondly, the twentieth century surveys are done with sonar, which gives a different depth values. The reason is that at the 10 to 24 kHz frequency range used in echo sounding equipment the sound waves reflect off of the top of the soft organic rich sediments as well and the more solid underlying sandy deposits that would stop a leadline weight or be felt by someone using a pole to determine the water depth. These survey factors would tend to cause an over estimate of the sediment volumes used in this analysis. Other factors should be mentioned. It probably is safe to assume that the other back barrier ponds have received some wind blown and wash-over sediments from the beach and dune areas. The aerial photographs and field observations indicate that these processes are and have been active but not the full extent of this sediment redistribution within the coastal system. The above calculations are thus viewed with considerable caution. They are never the less valuable as providing an order-of-magnitude estimate and possibly an upper limit guide to the volumes of beach, dune and bar sediment transported by selective processes to the adjacent ponds in this area over the last century or more.

The 1878 chart has another set of notations that is of interest when considering the Lake Ontario bottom sediments in the offshore zone. The bottom is characterized mostly as sand or more rarely as hard and this pattern extends five to ten or more miles offshore. So for more than a century sandy sediments seem to have prevailed from the shoreline out several miles into the lake where water depths reach 150 to 300 feet. This is not a surprise given the knowledge that the lake water surface and thus the beaches have been as much as eighty feet lower in the last eight thousand years. The presence of sand indicated periodic mobilization, possibly from some combination of storm waves, internal waves and currents. The lack of indications of the presence of finer silt and clay accumulations precludes any thoughts about this being a stagnant lakebed setting, even out in these depths. The magnitude of any exchange of sand through transport between the beach and near-shore bars and these greater depths has not been possible to analyze based on the available data and field sampling.

Thoughts on Coastal Process Questions and Sediment Budgets

During the winter of 2000-01 two sets of questions were provided to The Nature Conservancy with respect to the ELOSTS project. The aerial photographic analysis described above seemingly has relevance to some of them as addressed below. Other of the questions are apparently well beyond the scope of this GIS study. First, are the points raised by Barry Pendergrass, of the NY DOS, then those of Geoffrey Steadman, originally formulated back in April of 1997 in a report prepared for The Nature Conservancy.

Pendergrass: 1) This second GIS report for TNC does focus strictly on the barrier beach changes including the offshore bars (when detectable), dune features and inlets, with careful consideration of lake water levels during the surrounding period in which the images were taken. As discussed above, it is impossible to know the precise lake level at the time of taking each photograph along the eastern edge of Lake Ontario. Table II located at the end of this report provides the daily heights of the lake on the dates of the digitized aerial photographs for the two nearest water level gauge locations; Cape Vincent and Oswego, New York. Note at these two stations there is as much as a one foot of difference in elevation, as recorded on 06/04/59. On the dates of the photographs a range of 3.05 feet has been recorded. Typical lake level changes of several feet do significantly impact the digitized location of the shoreline in the photographs because the beach face slopes are generally quite gentle (< 1:10 gradient). It is also important to recognize that storm events associated with higher than usual lake levels frequently coincide with beach and dune erosion. Inlet reconfiguration and relocation or even breaching of the barriers to form new inlets are all seen in the photographic record following some of these periods of major lake level fluctuation. This knowledge does not however provide predictive foresight. Only the management concept that during periods of high lake level storms can have greater coastal erosion impact than when the levels are lower than average. Wind direction, intensity and duration of each storm are also known to be significant. Seasonal variations of both lake level and the weather events should thus play a significant role in future management analyses.

2) The decade of the 1970s is a period that includes episodes of particularly high lake levels and not surprisingly particularly vivid changes in the barrier and inlets west of North Pond in the township of Sandy Creek, Oswego County. As described above the GIS analysis of the 1970s photos is somewhat problematic in terms of precise east-west shoreline location because the areas of interest in the available images are confined to the outer limits and thus most distorted portions of aerial photographs. There is certainly no question about major northward relocation and even creation of a new primary inlet location during this decade.

3) The issue of error analysis including sources and magnitude of each type is discussed above. All the GIS conclusions of this paper have been evaluated with the known uncertainties clearly in mind. It would have been better to know the precise lake level at the site of each photograph at the time it was taken and to also be able to identify the location of photo registration control points with greater than a 40 foot (12 meter) uncertainty. However, that is not possible with the historic photographic and lake level records and base maps available for the data collected over the last seven decades. Steadman’s (1997) sand transport and management implication issues are worth discussion, as seen in light of this GIS aerial photograph analysis report.

1) The natural forces affecting littoral processes and shoreline modification indicated in the aerial photograph analysis are clearly wind and water transport, particularly associated with storm waves, rip currents, inlet currents and barrier wash-over events. Meteorologically controlled lake levels are another natural influence on the just mentioned forces. Vegetation, or lack of it, on the beach and dune deposits has significant influences as well.

2) The principal human activities and man made features affecting beach and dune portion of the eastern Lake Ontario shoreline are associated with the increased development, resident and visiting population, and associated land uses. Dwellings, access roads, parking lots and recreation roads as well as boat launch facilities, docks, navigation channel creation with improvements and periodic maintenance are all quite visible on the series of aerial photographs covering the decades. Erosion control structures are only sometimes extensive enough to be recognized on the photographic images. All of these human activities and features are designed in fact to modify the natural coastal features and/or processes.

3) The photographic analysis does not, by design, extend to comparative ocean coasts. However, the lack of tides and saline waters each have obvious impacts on the sediment dynamics and biological population factors. The fetch limited wave spectrum reduces the prevalence of swell waves and the associated beach berm development that is so typical of sandy ocean front shorelines. Once sands are moved off shore by storm waves in Lake Ontario it is thus less likely that subsequent onshore sediment transport during swell wave conditions will occur. Seasonality of lake level fluctuations is not typically a dominant factor in coastal ocean settings.

4) The sediment sources along the eastern shore of Lake Ontario are not indicated in the aerial photographs. However, the local post-glacial reworking of late-Wisconsinan deposits by wind and lake waters seems the most likely primary source of the barrier beach and dune deposits. During this multi-thousand year period of shoreline evolution and beach development lake levels are believed to have fluctuated by many tens of feet above and below present levels, not just the few feet recognized in the historic record.

5) The photographs provide no clear indication of littoral transport direction along most of the shoreline. At the inlets there are indications of reversals in transport direction, possibly with a northward bias at the North Pond inlet during the time interval between the nineteen sixties and seventies images.

6) No quantification of sediment movement is possible in this limited GIS study.

7) Relative importance of onshore-offshore vs. longshore transport is also not determinable in this type of GIS aerial photographic study.

8) If by the term “offshore boundary” the outer limit of beach sand transport is intended, then the photographic data is not sufficient to make a valid determination. Even detailed field studies with this goal have typically failed to establish such boundaries, if they even do exist. Fine sediment fractions are extensively dispersed when part of a suspended transport load.

9) Following from 8) above it is not possible to use photographs to answer this question about transport of sand in or out of the littoral zone. The uncertain definition of the “littoral zone” and unspecified time period of consideration make this a very complex question to address.

10) The extent of offshore sand deposits is best determined from a combination of the lakebed sampling, coring and sub-bottom profiling. This is addressed in the larger ELOSTS report. How extensively coastal sand deposits are affected by littoral processes has not been sufficiently studied along the eastern Lake Ontario shoreline.

11) The cobbled sections of the shoreline along the barriers are not detectable in the aerial photographs because of their small size and limits of scale. Objects of less than ten feet in diameter are hard to identify. The shades of gray in black and white photos are sufficiently variable along pure sand beach segments that the darker tones expected with some cobble areas are not distinctly recognizable.

12) Not enough is known from the photographic images, or any other source, to identify or theorize about trends in erosion and accretion along the eastern shore of Lake Ontario. Too many of the recorded changes fall within the range of known GIS analysis and other inherent photographic error sources. Accordingly, there is no justification to further quantify these changes over time.

13) No prominent examples of efforts to modify the sand transport in this sector of Lake Ontario are known or indicated in the aerial photographs. Periodic maintenance dredging has been reported for a number of the inlets with no systematic monitoring or measurement of the sedimentary dynamics, volumes or consequent patterns of modifications to even local erosion, transport and deposition. Thus it is hard to judge in terms of success and failure or even compare any management efforts on the ocean shores or those of the other Great Lakes. Most dredged inlets are reported to fill in rapidly even in the next major storm or two.

14) This GIS study was not designed or funded with sufficient scope to include comparisons with the other Great Lakes sand dune areas.

15) This GIS study was not designed or funded with sufficient scope to include any physical or mathematical modeling for the study site or the Great Lakes shorelines more inclusively.

16) Littoral transport of the beach sediments will continue to modify the eastern Lake Ontario shoreline and inlet locations as well as the extent and location of dune deposits along the barrier beach segments. Lake level fluctuations and management, particularly elevated periods with coincident storm events will most likely continue to be of greatest significance for any changes to the coast.

17) While there are always theoretical opportunities to modify littoral sediment processes, the economic climate and limited anticipatable benefits under any current and reasonably predictable uses appear to preclude any substantial large-scale private or public investment. Accepting the natural changes recorded and observed in the photographic series over the decades appears to make a much better management strategy.

18) The Nature Conservancy can use the understanding of littoral processes and resulting dynamics, revealed in the aerial photographic, and other ELOSTS studies, to educate the users and managers of Conservancy properties. Rather than expecting and working toward managed stability of coastal beach, inlet and dune features the policy of accepting natural change should be embraced. If inlets are to be periodically dredged in the future, care should be given to the selection of dredge spoil disposal sites. Lake level management should be encouraged with the fullest possible understanding that elevated water levels coincident with severe storms are the conditions most likely to engender rapid beach, dune and inlet changes along the barrier and cliff shorelines of eastern Lake Ontario. The best practices management includes keeping permanent man-made structures well back from the zone of natural migration of any dynamic shoreline, whether it is eroding or accreting.

Management Implications

With these several considerations of the aerial photographs, lake level and the historic charts and maps described above we now have a better handle on the processes and rates of change that can be determined. We also know that many interesting questions cannot be answered with the desired quantitative precision because of the fundamental and recognized limits to the available databases and methodologies. Never the less, there are obvious management implications worthy of consideration. They can be clustered into several related categories for convenience of presentation. However the interconnections and sometimes-contradictory aspects should not be ignored.

Overall, one must appreciate the fundamentally dynamic nature of coasts when thinking realistically about the many different aspects of coastal management. The bars, beaches, dunes, inlets, ponds, and wetlands are subject to intermittent relocations and other modifications. The timing of any such changes is as unpredictable as the stormy weather that causes much of the change. On the other hand, it is certain that eventually, and perhaps only rarely, there will be major changes along any stretch of barrier shoreline. Because of the simultaneous certainty of change with uncertain timing, it is best to prevent any development that depends on coastal stability. Homes and other structures, such as access roads and parking lots, should be kept well back or inland from the zone of dynamic coastal modifications. Forcing stability for human convenience will eventually require excessive expense and confrontations with tragic losses. The mobile sands of bars, beaches, dunes and inlets are central to this dynamic aspect of unconsolidated coasts. Wise management planning excludes the installation of stable or fixed development structures in the dynamic portions of the coastal zone.

Calculations of coastal retreat and erosion as well as deposition rates are hard to establish because of several variables and lack of sufficient databases. Beach erosion often alternates with deposition as sand is exchanged between the beach-face and near-shore bars. Similarly, inlet migration and relocation rates as well as the timing and intensity of storms are essentially unpredictable. Any management plan that depends on such rates and predictions is subject to probable failure. Without quantitative knowledge of sediment transport by waves, wind and currents it is virtually impossible to anticipate the consequences and successes of inlet maintenance dredging, dredge spoil deposition or other beach nourishment programs. Similarly, dune building and stabilization programs must be viewed as essentially uncontrolled experiments with little or no predictive certainty.

Implications of lake level management are complex but some trends can be anticipated with confidence. High lake levels enable greater navigation access into shoal waters. While attractive to many, particularly in the ice-free boating season, it has the obvious associated risk of increased flooding and the likelihood of beach or dune erosion during windstorms. The impact of elevated water levels on coastal vegetation in wetlands and usually dry land is indeed complex. With elevated water levels the seasonality, duration and depth are worthy of consideration when trying to anticipate the impact on plant survivability and longevity as well as vigor of growth and competitive advantage for individual species. Lowered lake levels relocate the focus of wave and current action while expanding the coastal portions exposed to direct wind erosion and transport. As the off-shore lake bed slopes are typically less than those in the breaker zone, any lowering of the lake surface will stimulate a reconfiguration of the near-shore sands so as to conform more nearly to the equilibrium profile. Current flow, through the pond inlets, is more restricted when lake levels are low. So one can anticipate reduced pond level fluctuations and perhaps greater rates of inlet scour. Also dune growth and reworking should theoretically be enhanced by the wider and more exposed dry beaches during low lake levels, unless the wind blown surface is ice or snow covered. Lowered lake levels should reduce the probability of storm wash-over events across barriers and the related formation of new inlets into the ponds. However, the wider beach faces exposed during periods of reduced lake level are an attraction to those who like to drive off-road vehicles along the shore. Such traffic moves sand down the beach face toward the lake and can also lead to crushing and killing of dune grasses and other vegetation. This in turn provides greater access by the wind to any un-protected or un-stabilized barrier sediments.

Finally, the variability in weather and climate patterns makes coastal zone prediction and management problematic. Since the weather (storm wind) provides the primary source of energy for many forms and processes of coastal change, this is of fundamental importance for coastal managers. Day to day changes, month-to-month variability and inter-annual fluctuations all play their part. As one decade is different from the preceding and following, so centuries are somewhat contrasting. These realities have important consequences for precipitation, runoff, evaporation, lake levels, waves, wind and presumably currents. Thus the ambition for reliable predictive models and associated specific management strategies remain an unresolved challenge. We can be certain of the expected change direction in some circumstances but not in others. Furthermore, we are not sure of how to predict when particular circumstances will combine to bring about the kind of significant changes that have occasionally occurred in the past. Both the sedimentary and biotic changes can have impacts on human activities and thus are appropriate subjects of management consideration. Ecological factors have their own innate value for many people. The relative importance of human desires and impact vs. natural coastal variability is thus important to evaluate in any worthy management analysis. Such analysis is going to be most informed if there is intentional inclusion and consideration of the full range of factors and variability that has been experienced and recorded over the last few centuries. Using shorter periods of time reduces the likelihood that a valid understanding can be developed. Short-term fluctuations must be clearly distinguished from long-term trends as discussed earlier in this report.

Conclusions

The analyses in this report provide a valuable follow-up to the McClennen et al. (2000) Report to The Nature Conservancy and address the several requested issues raised for consideration. The 1974 and 1978 aerial photographic coverage was registered and digitized for inclusion in the GIS database. Due to the fact that the 1970s coastal sections of interest were primarily from the perimeter sections of the photographic images the lens-effect distortion was significant; perhaps over 50 feet (15 meters). Changes in the location of the shoreline caused by erosion and deposition were often masked or overwhelmed by the simultaneous uncertainties grounded in the changes of lake level and restricted GIS registration precision. However, the changes in North Pond inlet location and associated spits and shoal location were recognizable and greater than the sum of all the other uncertainties. The attempts at quantitative assessment of shoreline migration observed through the six decades of the aerial photographic coverage in the prior study was put in perspective by the error analysis. Shoreline location changes of up to 60 feet observed in the aerial photographic images can be due to differences in lake level, photo registration limitations, or true changes of the coast. Subtle discrimination between the relative importance of these simultaneously active factors is usually not possible. Larger changes are limited to inlet locations, along the eastern shore of Lake Ontario.

Calculations of the sediment volume based on charted shoaling of North Pond (178 million cubic feet = 6.6 million cubic yards) and coming in part from the barrier beach and dunes to the west enabled an estimate as to the amount of sand possibly removed from the barrier since 1878. The two to five foot sediment thickness is seen as a likely upper limit when the total length and width of the barrier and the bathymetric measurement techniques of the 19th and 20th centuries are carefully considered. Terrestrial and organic sediment sources entering from the east are also presumed to be significant in the coastal ponds. Quantitative estimates of sediment transport and volumes of greater precision are not seen as possible given the present available field observation data and limits of photographic resolution.

Management planning implications are numerous and clearly interrelated based on the set of considerations and observations of coastal processes addressed in this study. The fundamentally dynamic nature of coasts, when driven by weather energized forces of waves, wind and currents, as well as changing lake levels, leads to complex possibilities and low accuracy for predicted rates and timing of critical events. The desire to develop permanent and rigid or stable structures on unstable and mobile coastal deposits should be minimized or prevented by informed coastal zone management programs. Flooding, erosion rates and deposition are all influenced by lake levels in combination with the continuously changing variables of weather and climate. The weighted values of human preferences for development and usage over natural processes should be carefully balanced by the inclusion of as many biological and sedimentary processes and factors as possible. Because of the interrelationships between so many variables and coastal factors it is virtually impossible to anticipate the development of any quantitatively precise predictive models for coastal evolution. However, long-term trends and the expectation of change as a certainty is valid and of significance for any coastal management planning.

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generously provided the loan of the 1970s and other aerial photographs reviewed in this study.

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	Table I.						
1966	EFE-1GG-89	7/1/66	South Central Pulaski	24" x 24"	Agriculture Stabilization and Conservation Service 801-975-3532	1:20,000	1:7,920
	EFE-1GG-87	7/1/66	North Pulaski	24" x 24"			
	EFE-4GG-63	7/1/66	South Central Ellisburg	24" x 24"			

	EFE-4GG-65	7/1/66	North Central Ellisburg	24" x 24"	801-975-3532		
	EFE-4GG-67	7/1/66	North Ellisburg	24" x 24"			
	EFE-4GG-69	7/1/66	South Henderson	24" x 24"			
1974	S48 36075 174-197	4/00/74	North Pulaski	24"x20"	Oswego County	?	1:15840
	S48 36075 174-201	4/00/74	Ellisburg	24"x20"			
1978	USDA 38 36045 178-246	9/23/78	South Henderson Northern Ellisburg	24" x 24"	Agriculture Stabilization and Conservation Service 801-975-3532	1:38000	1:17600
	USDA 38 36045 178-248	9/23/78	South Henderson	24" x 24"			
1984	NOS-4460	5/24/84	Pulaski	27" x 27"	Natural Ocean and Atmospheric Administration (NGS)	1:30,000	1:10,000
	NOS-4462	5/24/84	Central Pulaski	27" x 27"			
	NOS-4464	5/24/84	South Ellisburg	27" x 27"			
	NOS-4466	5/24/84	Central Pulaski	27" x 27"			
	NOS-4468	5/24/84	North Pulaski	27" x 27"			
	NOS-4374	5/24/84	South Central Henderson	27" x 27"			
1994-95	N.A.	4/22/94	Central Pulaski	40" x 40"	USGS - Eros Data Center	1:40,000	1:10,000
	Wild 15/4 UAG Nr 13095-153 NAPP-0864	5/3/94	South Central Ellisburg	40" x 40"			
	Wild 15/4 UAG Nr 13095-153 NAPP-0866	5/3/94	North Central Ellisburg	40" x 40"			
	Wild 15/4 UAGA-F Nr 13086-152,93	4/17/95	South Central Henderson	40" x 40"			

Table 2. NOAA Lake levels for the dates of aerial photographs listed in Table 1*.

Date	Oswego	Cape Vincent
06/29/38	245.04	245.13
11/10/38	244.00	244.08

05/09/42	245.01	245.08
09.06/55	246.26	246.37
08/11/58	244.47	244.50
06/04/59	244.61	245.62
07/01/66	245.85	245.89
04/01/74	246.46	246.30
09/28/78	244.98	244.85
05/25/84	247.05	247.05
04/22/94	246.16	246.16 (these are 4/94 third quarter-month means)
04/17/95	244.95	244.95 (these are 4/94 third quarter-month means)

*Daily mean water levels from the Oswego and Cape Vincent gauges – 1910-2001. Readings in feet, corrected to IGLD 1985, supplied by Sandra Bonanno, The Nature Conservancy, from NOAA records)

Ground Penetrating Radar (GPR) Survey ---- Donald Woodrow

Abstract

Three sedimentary units are disclosed in Ground-Penetrating Radar (GPR) records collected at six locations along the eastern shore of Lake Ontario by Gabel and Willis and Singer and colleagues. The three units are as follows. At the top are modern beach and dune sands less than 10 feet thick. In southerly beaches sand is mixed with gravel. Below the top unit is a middle unit which is not developed at all locations. It is made up of older dune- and channel-fills sands and interbeds of sand and muddy, plant-rich sediments interpreted as wetland deposits. The middle unit is as much as 30 feet thick. At the bottom and separated from either the top or middle unit by a strong reflector are glaciolacustrine sediments, till, or bedrock. The base of the bottom unit was beyond the range of GPR at two locations.

Five radiometric dates (C14) on organic-rich sediments from the top and middle units indicate that beach and dune sands arrived at their present locations as long ago as 1290 years BP. Sands of the top unit rest on an erosion surface. Sediments in the middle unit on or immediately below the erosion surface yield dates of 1250 and 1290 years BP. Middle unit sediments rest on what appears to be the eroded surface of bedrock or glacial sediment. The age of the oldest sediments in the middle unit is unknown.

Interpretation of the GPR and vibracore records leads to a scenario of shoreline evolution. At some time prior to 1250-90 yrs BP, lake level was sufficiently lower than at present exposing bedrock or glacial sediment at four of the GPR locations: Black Pond,

Montario, Sandy Island Beach (beach side), and Salmon River Jetty. By 1290 yrs BP, lake level had rise and the eroded bedrock/till surface had been buried under a developing barrier system. Bays and estuaries developed behind the barrier system as lake level stabilized near present lake levels. With shoreline stabilization, Marshes have encroached on the bays and estuaries in the Salmon River estuary, in North or Sandy Pond, Colwell Pond and the mouth of Sandy Creek. Otherwise, the geomorphology of barrier system and the wetlands behind them have changed little over the past several hundred years.

Introduction - GPR records were obtained at 6 locations along the eastern shore (Figure 1) in order to decipher the evolution of the beach/dune system. GPR surveys are an investigative technique now widely used (Allen and Plumb, 2000, Bristow, Chroston, and Bailey, 2000, Neal and Roberts, 2001, van Heteren and others, 1998, Sato and VerSteeg, 1996). The present survey was carried out by Ray Wagner and Todd Merrell of Blasland, Bouck and Lee, an environmental consulting firm. The survey dates were May 7-10, 2001 (Blasland, Bouck and Lee, 2001). GPR data obtained earlier at the same locations by Jill Singer and her associates from SUC Buffalo were of value in refining locations to be sampled by BBL personnel.

The GPR records selected for reproduction in the survey report are in two formats. In one, the land surface is treated as horizontal obscuring the true land shape as it emphasizes changes at depth. These records are normal practice in most GPR surveys which are most often carried out over short distances on horizontal surfaces in the search for buried pipes, tanks, etc. In contrast to normal practice, the GPR original records obtained for this project extend over hundreds of feet across a rolling landscape with elevation changes of many feet. Without taking into account changing ground elevation, reflectors seen in the records are not shown in their true orientation. To avoid that problem, a second set of GPR records, with elevation superimposed, was prepared to display inclined reflectors in close approximation to their true orientation. Determination of elevation was possible by referring GPR lines to points surveyed for a study of beach profiles (Sehnert, 2000) taken at locations very close to the GPR lines.

Interpretation of the GPR records reported on here incorporate Wagner’s interpretations (Blasland, Bouck and Lee, 2001) supplemented by data from an earlier vibracore survey (Singer, personal communication)) and by C14 dates. An early draft of the BBL report was discussed at a meeting and in phone calls between Woodrow, McClennen, and Wagner. Copies of the final draft were provided to The Nature Conservancy but given its physical size, the final draft is not duplicated here.

Various aspects of this study have been presented to geologists and other environmental scientists at professional meetings. Poster presentations were offered by Woodrow at the annual meeting of the International Association of Great Lakes Research, May, 2001; at a conference on restoring natural flows hosted by the Great Lakes Protection Fund, October, 2001; and at the annual meeting of the Geological Association of America, November, 2001. Wagner submitted an abstract, which was accepted for presentation, to the Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP), February, 2002. Circumstances made it impossible for Wagner to attend the meeting and the paper was not presented.

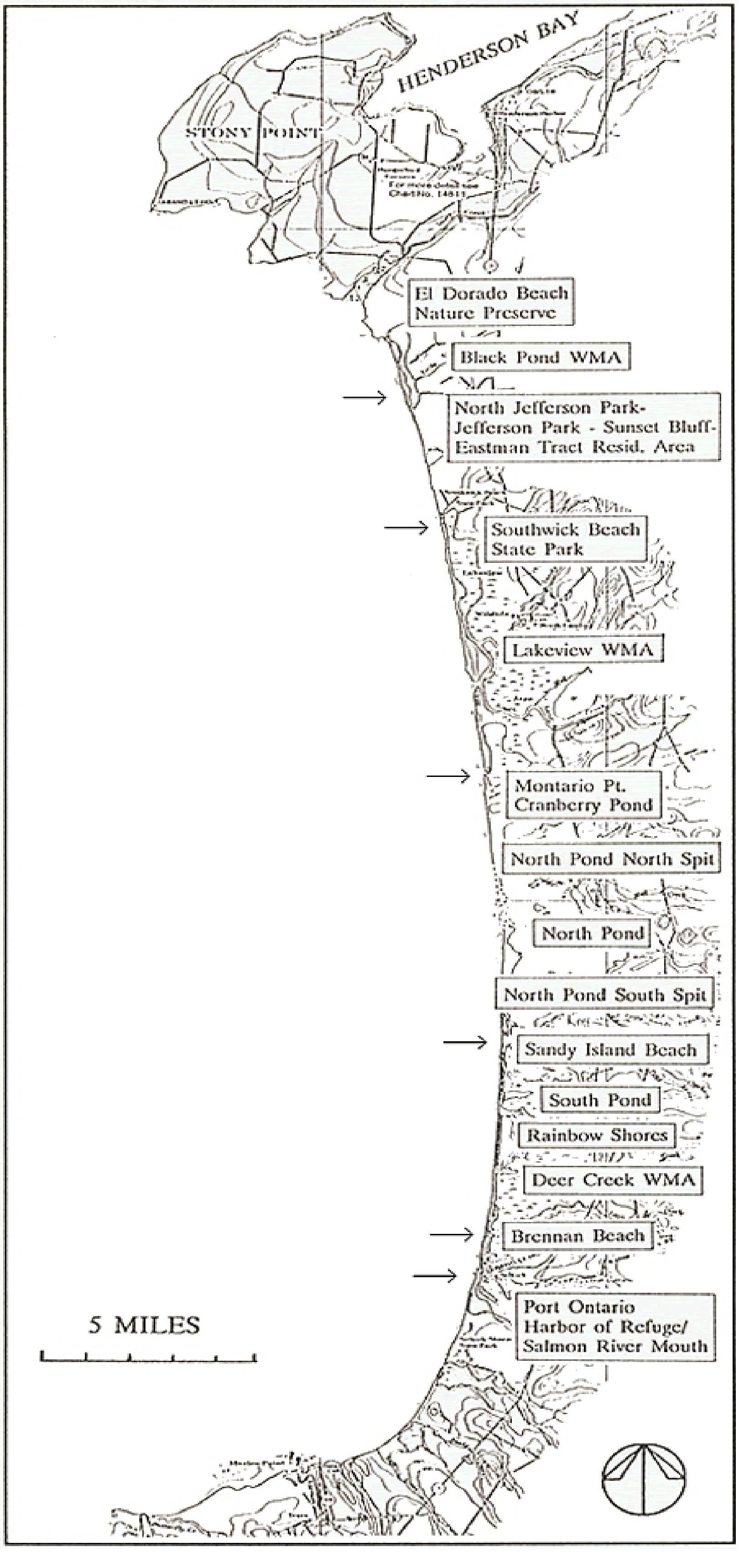
HENDERSON BAY
STONY POINT
For more detail see Chart No. 14811
El Dorado Beach Nature Preserve
Black Pond WMA
North Jefferson Park-Jefferson Park - Sunset Bluff-Eastman Tract Resid. Area
Southwick Beach State Park
Lakeview WMA
Montario Pt. Cranberry Pond
North Pond North Spit
North Pond
North Pond South Spit
Sandy Island Beach
South Pond
Rainbow Shores
Deer Creek WMA
Brennan Beach
Port Ontario Harbor of Refuge/ Salmon River Mouth
5 MILES

Figure 1. Location map. Positions of GPR lines noted by arrows. Shoreline vibracores were collected along the GPR lines.

Combining GPR data with radiometric (C14) dates of organic-rich horizons within the sand bodies and with data from vibracores taken at or very near the location of the GPR lines, makes it possible to interpret, at least qualitatively, the evolution of sand bodies. Among the six GPR locations are five at which beach sand samples and reconnaissance GPR records were obtained in 1998 (Woodrow , et al, 1999; Singer, personal communication). The sixth GPR location is on the south side of the Salmon River jetty where sand is known to be accumulating. Vibracores are not available for that sand mass. All of the locations are accessible and they display environments from shoreface to wetlands (including low dunes). As such, they provide access to the sedimentologic conditions and geomorphology seen along the shore.

Used in the survey was a Geophysical Survey System Inc SIR System 2000 with a 200 megahertz (MHz) antenna mounted on a sled-like device and towed by a small, wheeled, all-terrain vehicle. Details of system characteristics and instrument settings are given in the BBL report. .Latitude and longitude for points along each survey line were determined using a hand-held Magellan 330 GPS receiver.

To explain the system, its use and limiting factors, the following quote from the report is helpful:

“Ground-penetrating (GPR) is an effective survey method that transmits high frequency electromagnetic waves into the ground and detects the energy reflected back to the surface. GPR operates on a principle similar to seismic reflection except, instead of acoustic waves, electromagnetic waves of radio and microwave frequencies (800 MHz to 1000MHZ) are used. Reflections typically occur at lithologic changes, subsurface discontinuities, and internal soil structures such as: top of bedrock surfaces, soil and rock stratification, water table, (and several others of no interest to this report). The depth of GPR penetration is site-specific, being limited by the attenuation of the electromagnetic energy. Signal attenuation is controlled by four different mechanisms listed below, any or all of which may be present at a site: scattering losses, conduction losses, water losses and clay loss.”

A paraphrase of the report’s lengthy discussion of signal attenuation is as follows. Scattering losses are caused by the interaction of radar waves with buried objects, conduction losses occur where the radar waves interact with mineralized water, and clay losses occur where the radar waves interact with electrochemically-charged clay particles. In this situation, there are very few buried objects, there is no mineralized water, and clay occurs at depth, mostly beyond the range of the device. As a result, radar waves suffered little attenuation in this study (Blasland, Bouck, and Lee, 2001, p. 1.1-1.2).

Main Points of Interpretation

*GPR records and vibracore logs demonstrate that the sand seen along the beach, in dune swales and on the lee side of the dunes is 10 feet thick or less and that the thickness is highly variable (Figures 2, 3, 4). Sand thickness beneath dunes was not determined but is approximated by dune relief.

*C14 dates at four locations indicate that deposition of sand has continued at or very near the modern shoreline location for at least 1290 years.

*Modern sands rest on glaciolacustrine- or bay muds, till (?) or rock(?) eroded during a lower stand of lake level more than 1290 years ago.

*Some of the modern dunes developed above older topography, perhaps dunes.

Main features of the GPR Records and Vibracores

Modern sands: the top unit of the GPR records; its the complexity and composition – This unit appears in all GPR records and it is sampled by all of the vibracores. The GPR records, both elevation- and horizontally corrected are characterized by faint reflectors. Vibracore descriptions (Gabel and Willis, 2000 as reported in Report of ELOSTS Activities for 2000) show the top unit to be made up of fine sand arrayed in thin, ill-defined strata. Small amounts of gravel are found in the top unit at Sandy Island Beach and Selkirk/Salmon River.

Size analyses of surficial samples from 5 of the 6 GPR sites (Woodrow and Singer, TNC report, 1999) and of sands from the vibracores demonstrate them to be fine-grained with little variation. Earlier reports on the grain size of the modern sands seen along Lake Ontario's south shore give similar results (Coch, 1969; Sutton, Lewis, and Woodrow; 1972, Weir, 1977; and Rukavina 1999).

Sands in the top unit appear to be draped across older topography at Black Pond (Fig 2) and Southwick Beach State Park (Fig 3) and perhaps at Selkirk/Salmon river (Fig 4).

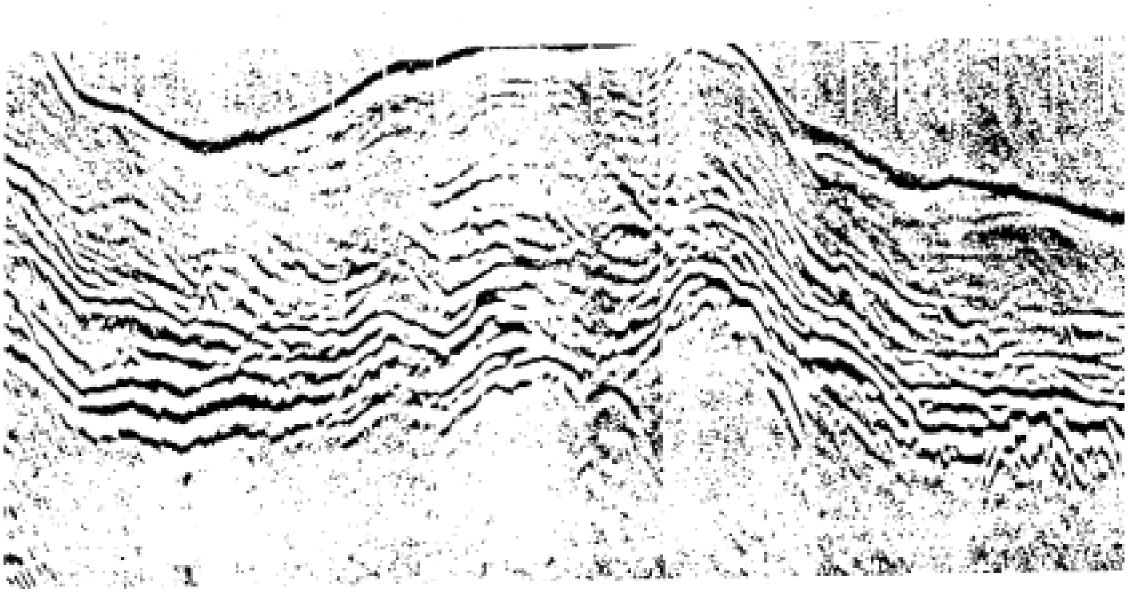

Figure 2a. GPR record with elevation correction.

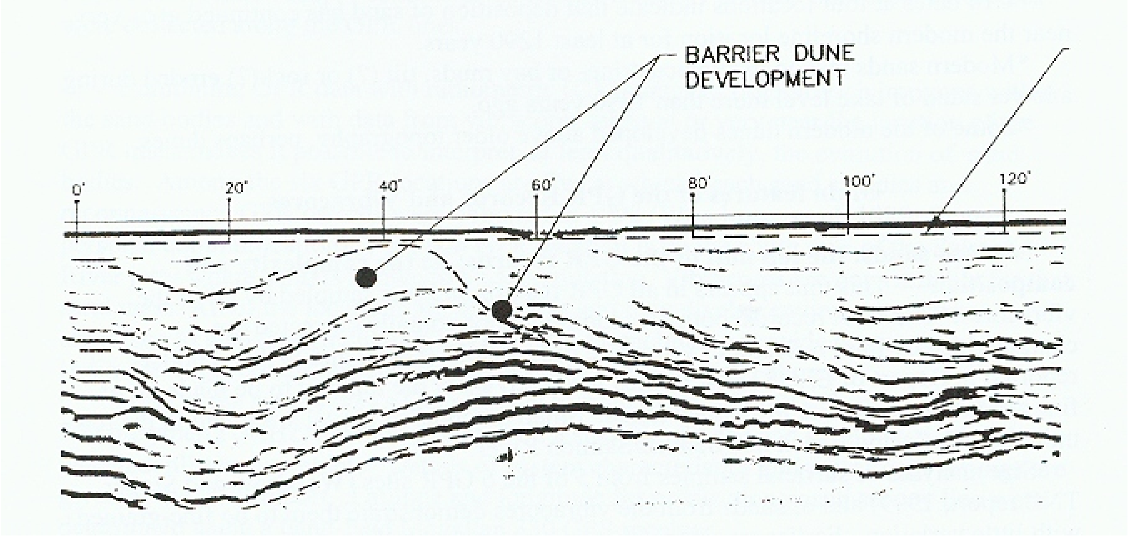

Figure 2b. Black Pond. GPR record without elevation correction. Modern sand over older, dunes.

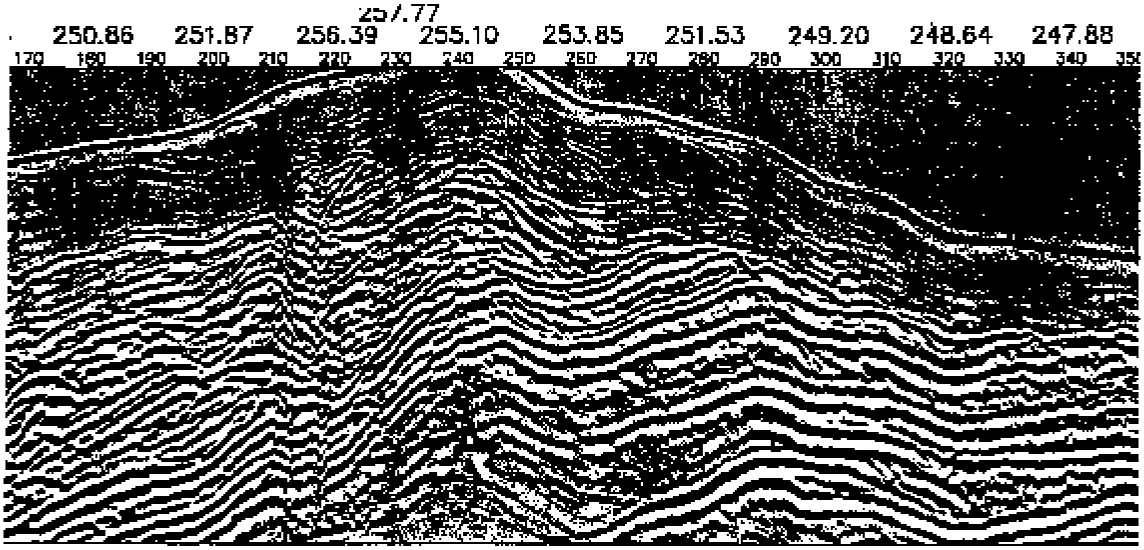

Figure 3a. Southwick Beach State Park. GPR record with elevation correction.

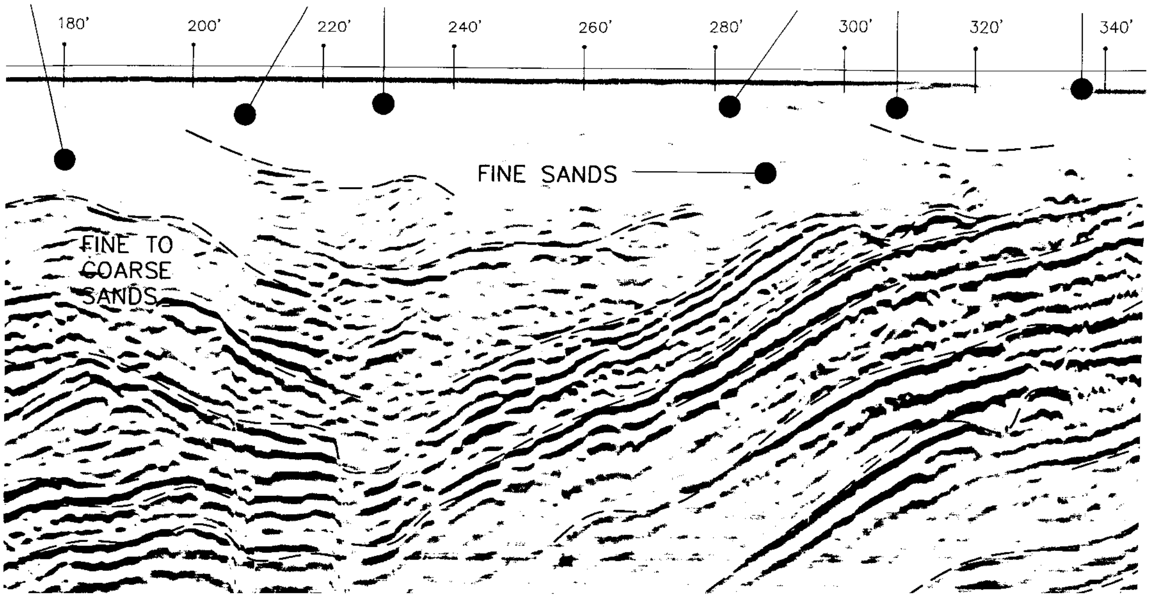

Figure 3b. Southwick Beach State Park. GPR record without elevation correction. Modern sand covering older dunes or channel-fill.

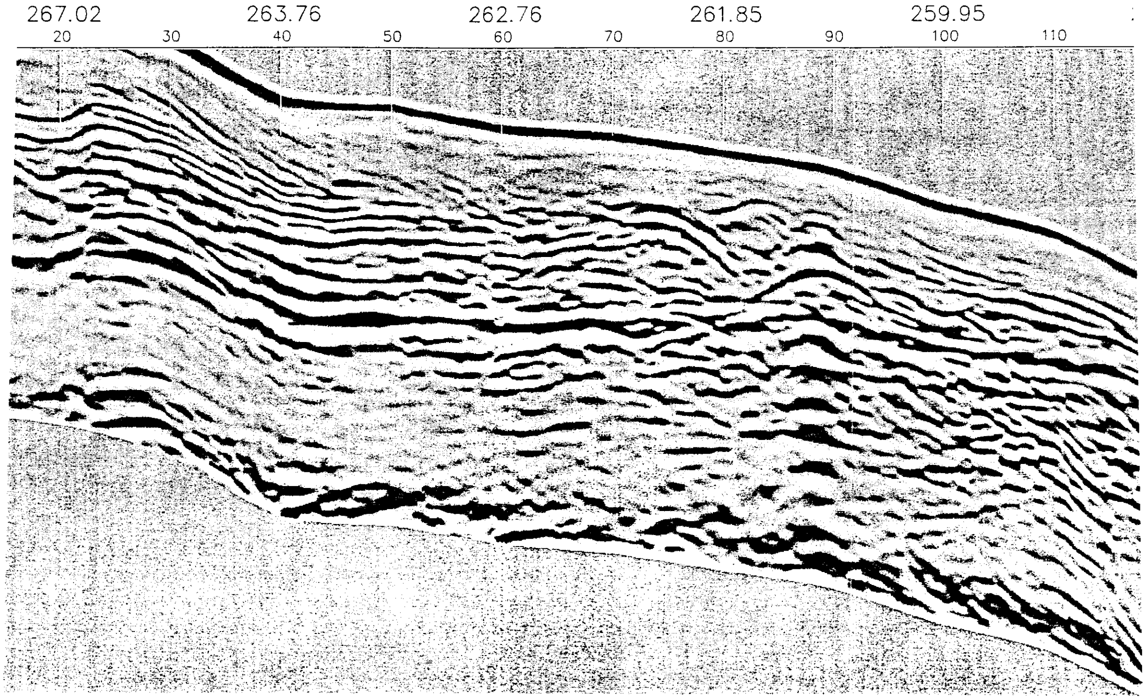

Figure 4a. Selkirk-Salmon River. GPR record with elevation correction.

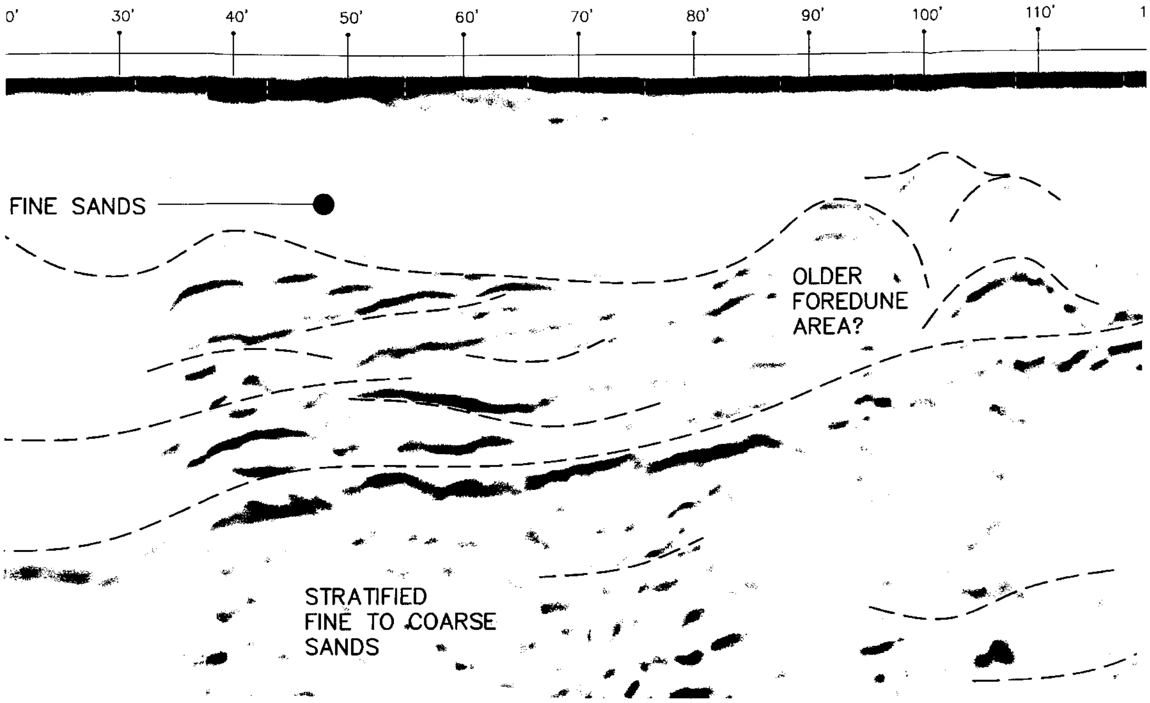

Figure 4b. Selkirk/Salmon River. GPR Record without elevation correction. Modern sand draped across older dune sands.

Sands appear to rest on eroded bedrock at Black Pond (Fig 2). By way of contrast, sands in the top unit at Montario Point (Fig 5) and Sandy Island Beach (Fig 6). appear to fill in older channels, the channel-filling sand being approximately 7 m thick. Older topography covered by the sand of the top unit at Selkirk/Salmon River is interpreted by Wagner as being itself made up of fine sand. If so, the Selkirk/Salmon River location is the only GPR site at which older dunes were preserved.

Composition of the sand was not a focus of this study, but on quick inspection, the sand appears to be made up mainly of quartz and particles of fine-grained rocks with particles of limestone, dolostone and chert especially common. An appreciable amount of dark minerals more dense than quartz ("heavy minerals") is called for to explain the color streaks seen in some beach sands. Analysis of the heavy minerals might lead to the ultimate source of these sands but we were unable to carry out such an analysis given the reallocation of funds for radiometric dating and more detailed shoreline analysis. Coch (l967), Weir (1977), and Trask (1976) provide information on heavy minerals in the southern and eastern shore sands of Lake Ontario.

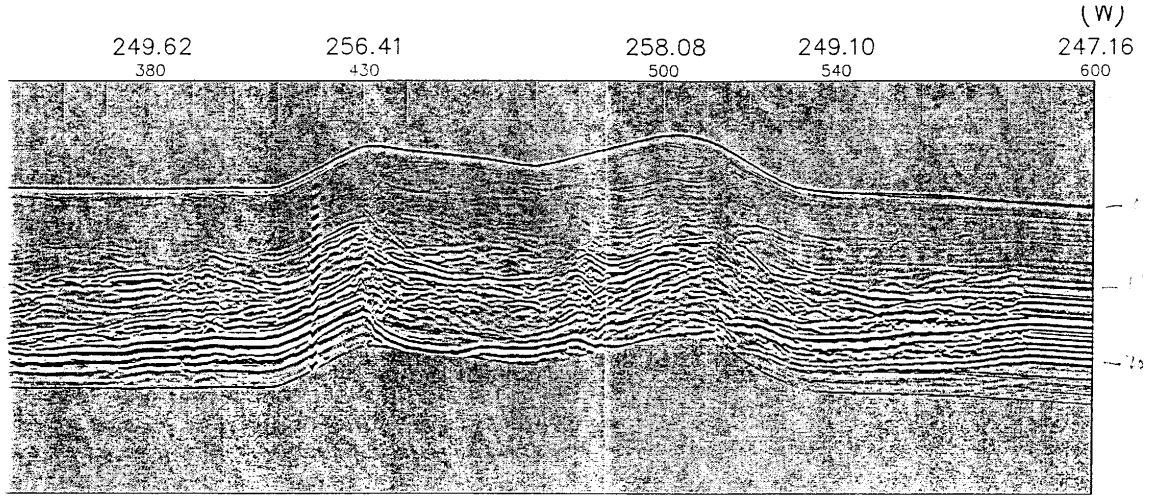

Figure 5a. Montario Point/Lakeview. GPR record with elevation correction.

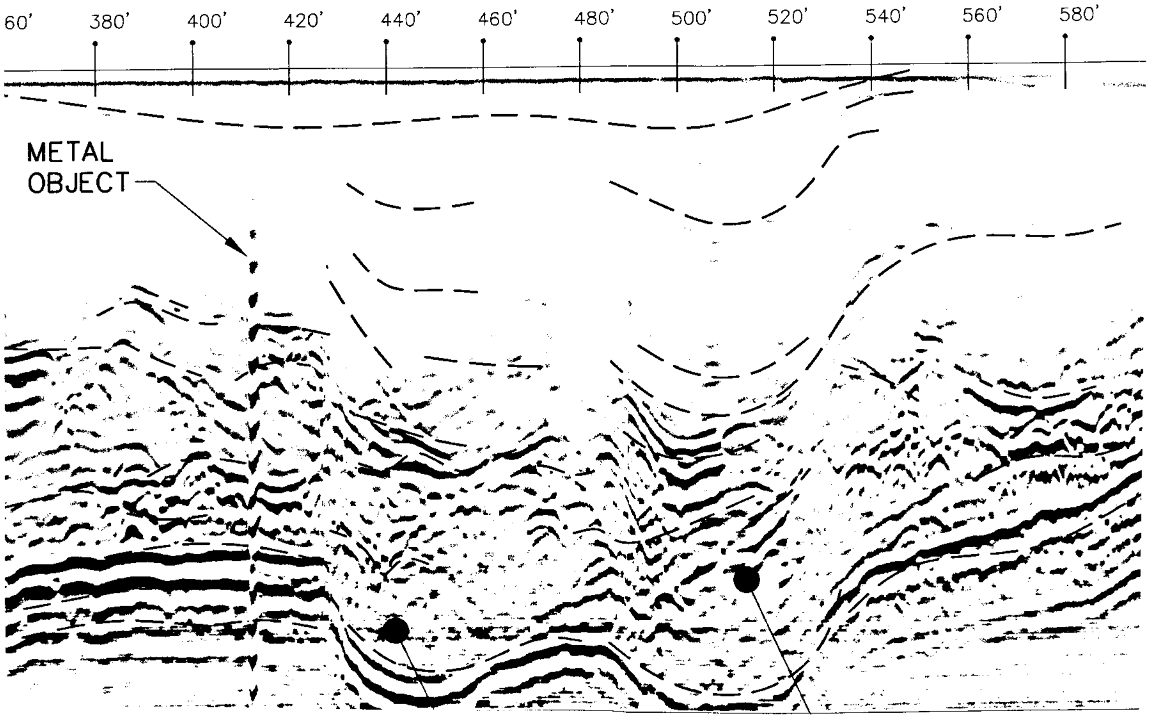

Figure 5b. Montario Point/Lakeview. GPR record without elevation correction.

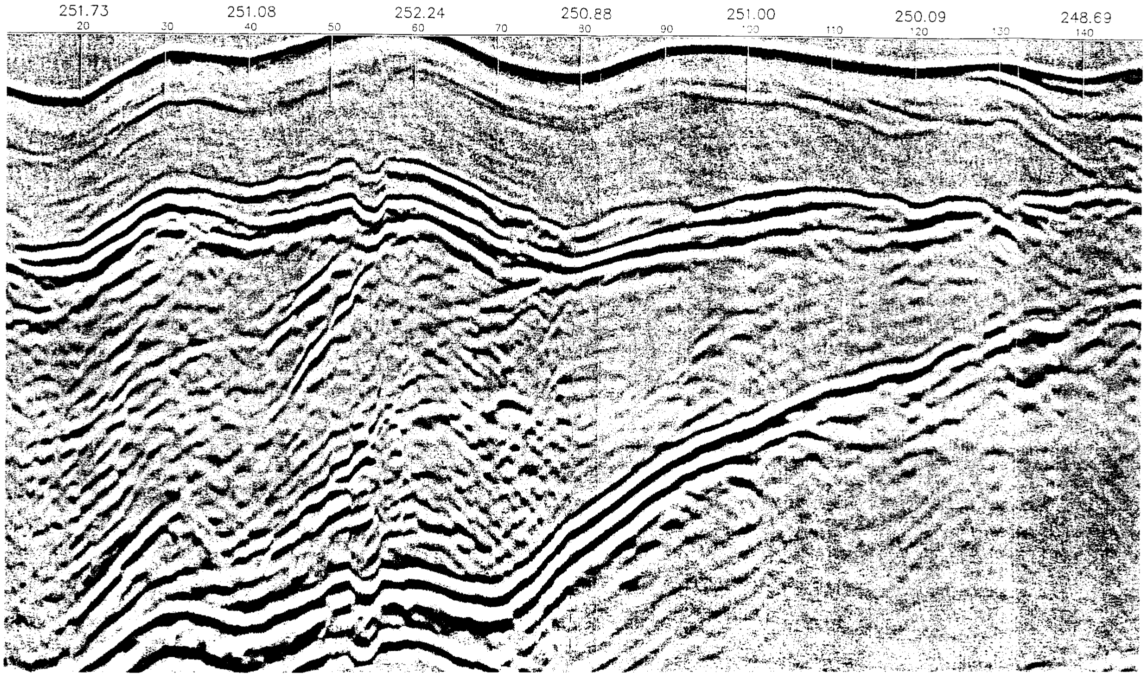

Figure 6a. Sandy Island Beach, lakeside. Lake to the right. GPR record with elevation correction. Modern dunes over channel-fill.

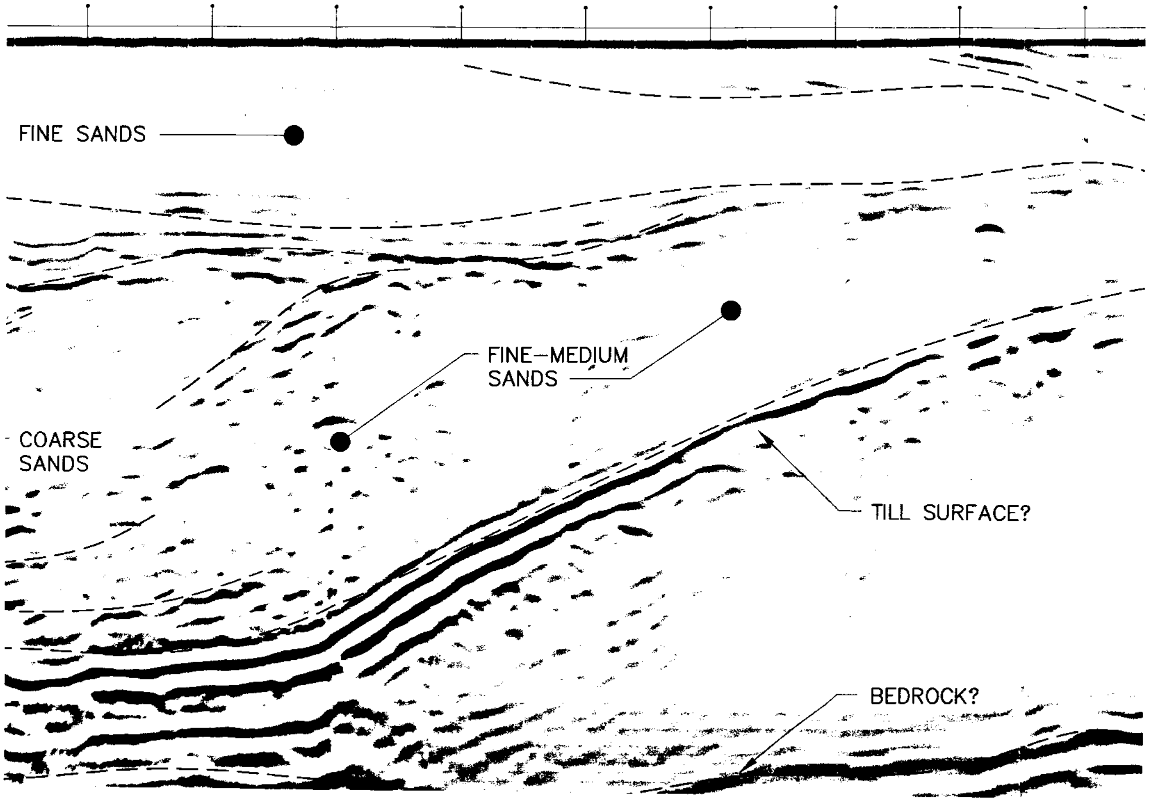

Figure 6b. Sandy Island Beach, lakeside. Lake to the right. GPR record without elevation correction.

Also apparent to the casual observer is the increase in the number of mussel shells and shell debris incorporated into the sands as one moves north along the shoreline. Mussel shells and shell debris comprise an appreciable fraction of the sand on the beaches north of Southwick Beach State Park. Whatever the actual amount, shell material is a major addition to the shoreline sand, especially in the north.

Middle unit - As compared to the top unit, the middle unit is made up of a more diverse suite of sediments in a variety of arrrangements. The age of these sediments is greater than 1290 yrs BP.

In the GPR records, reflectors of many types are apparent and their arrangement suggests a history more complicated than that represented in the top unit. For example, the middle unit at Sandy Island Beach is represented in the GPR record (Fig 6) from the beach side of the modern dune as a 20-foot deep channel filled with sand. In contrast, on the pond side of the dune about 600’ feet to the east illustrates a different situation. There, the middle unit is represented at the top by weak, inclined reflectors thought to represent slip faces of a duneadvancing into the marsh while at the bottom, strongly defined, nearly horizontal reflectors are interpreted as interbedded sands and muds (Fig 7).

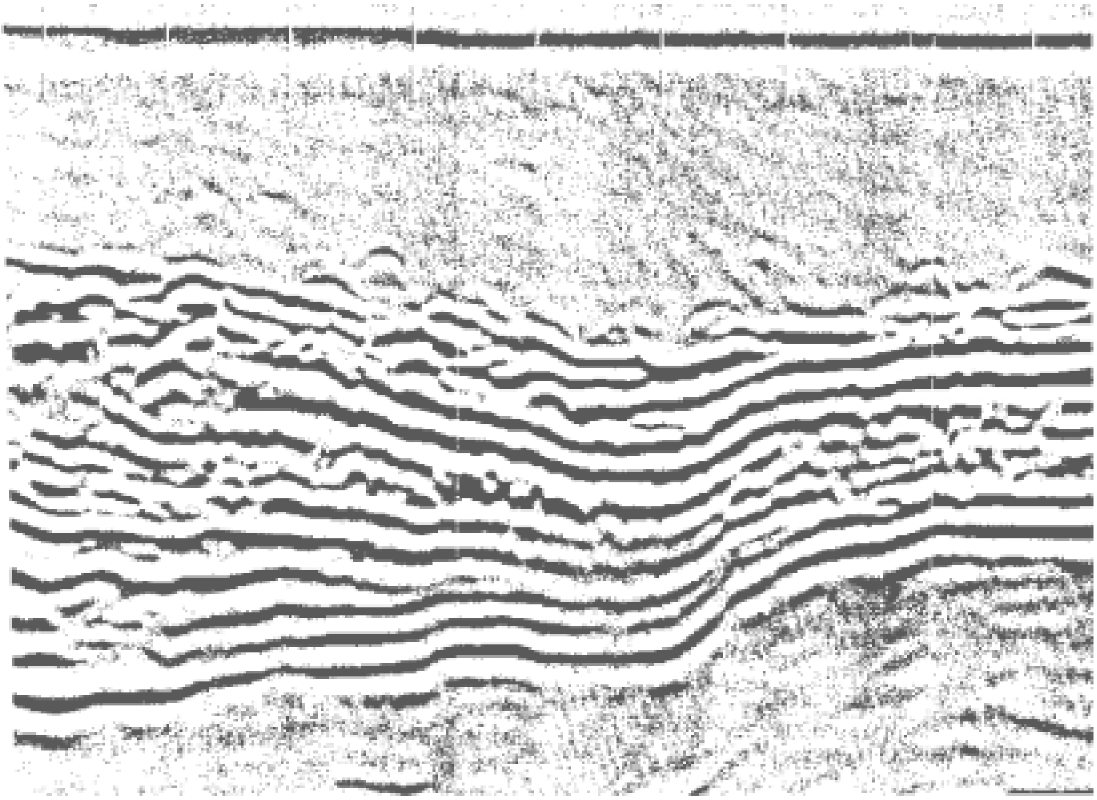

Figure 7. Sandy Island Beach, pond side. Pond to the right. GPR record with no elevation correction. Land surface is horizontal. Modern beach sand covering glaciolacustrine clay.

Another examples of complexity in the middle unit can be seen in the Selkirk/Salmon river (Fig 4) and the Montario Point (Fig 5) GPR records. At Selkirk/Salmon River, the top of the middle unit appears to rise inland where it is covered by modern beach and dune sands. At this location, the middle unit may consist of till given its lack of consistent internal reflectors and strong top reflector. At Montario Point, the top of the middle unit is most clearly defined near the beach end of the record where it appears that small channel forms have been filled with fine sand.

A final example of middle unit complexity, including the record of the unit's lower surface, comes from the sand body south of the Salmon River jetties. There, the middle unit is made up of sand arrayed as imbricate sheets inclined landward. Below them and and 20 feet below the present land surface is a strong reflector (Fig 8). What this surface may be is suggested by the presence in the dredged river channel between the jetties, of a tough gray clay (glaciolacustrine?) about 10 feet below the present lake surface (Jim Walker, Lighthouse Marine, personal communication). The eroded top of this clay is interpreted as the strong reflector seen in Fig 8. In this interpretation, the surface of the clay exposed in the dredged channel equates to the deep reflector beneath the sands south of the jetty. In addition, a quite similar clay was returned in a dredge sample from the lake bottom, about a mile west of the Salmon River jetties. If the top of the clay in the channel, the presently eroding surface of the lake-bottom clay and the deep reflector beneath the south jetty sands are the same, then they form an example of an eroded surface extending lakeward for at least a mile.

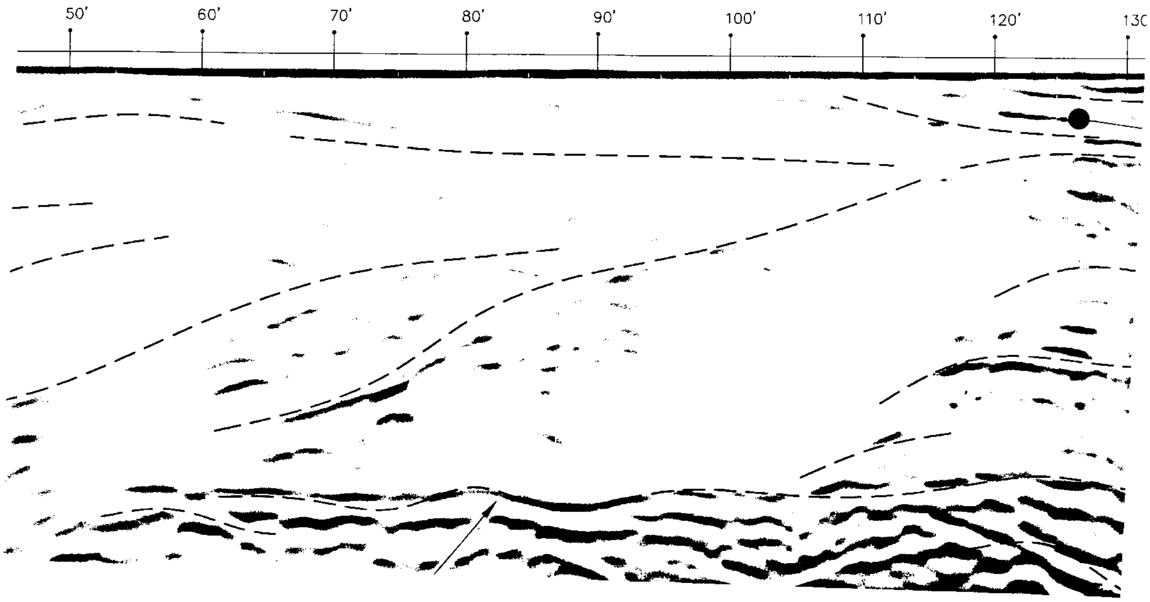

Figure 8. Salmon river jetty. Lake is to the right. GRP record uncorrected for elevation across this surface of low relief. Deep reflector marked with arrow.

Bottom unit – Reflectors interpreted as a bedrock surface or the surface of eroded glacial sediment are seen in all of the GPR records but without confirmation by vibracore interpretation of them must be viewed as speculative. In each case, interpretation of the reflector is based on its strength and position at the lowermost, noisy edge of the record.

Bedrock and till are thought to make up the bottom unit beneath the sections at Black Pond. The deepest reflector is very strong, persistent and nearly horizontal near the shore but more irregular near the Pond. Offshore at this location, bedrock is exposed on the lake floor at depths like those of the deep reflector seen in the GPR records. Given the E/W trend (strike) of the strata in this region, the bedrock exposed on the lake floor projects into the position seen in the GPR record. Further inland, the deep reflector is irregular suggesting an eroded surface of glacial sediment.

In the other GPR records, the deep reflectors either are irregular suggesting surfaces eroded into sediment or are so indistinct that they cannot be picked with certainty. At Sandy Island Beach (lakeside, Fig 6) or Montario Point (Fig 5), erosion has produced channels. Deep reflectors are ill-defined at Southwick Beach, Sandy Island Beach (pond side), and Selkirk/Salmon River. At those locations, the record is too noisy to provide a basis for interpretation or the reflector is outside the range of the GPR. At all three locations, Wagner interprets the bottom parts of the GPR records as fine sand like that presently seen on the beaches and in the dunes. If so, the middle unit at those locations is notably more sandy than it is elsewhere and/or the top unit is thicker than interpreted.

The age of these deposits – Superposition and C14 dates provide a tentative time framework for sand deposition. Vibracores appear to penetrate the strong reflector found at the top of the middle unit both near Black Pond (Fig 2, core dw2b), and at Sandy Island Beach (Fig 6, spb2). C14 dates greater than 1250 yrs. bp on organic sediments sampled by these vibracores at positions thought to be at or just below the strong reflector near Black Pond indicate the age of the top of the middle unit. A second core from Black Pond 300 feet to the east on the pond side of the barrier and vibracores from Southwick Beach State Park and Mantario Point (Fig 5, dw1b, swb2, mp3) show sequences similar to those seen in vibracores dw2b and spb2, that is, sand over organic-rich sediment. However, C14 dates on peaty sediments from the vibracores taken at Black Pond (pond side), Southwick Beach and Montario Point are 345 and 790 years BP, much younger than dates from organic-rich sediments at the top of the middle unit at Black Pond (beach side) and similar-appearing sediments near Black Pond. These dates demonstrate that sand deposition began at or near the present barrier location 1290 yrs bp, that it continued through 790 and 345 yrs BP, and so on to the present day.

Summary and Conclusions - Within the limits of the data available, the sequence of sedimentary deposits along the barrier system can be divided into three units. At the top are the modern beach and dune sands usually less than 10 feet thick except under the dunes where dune height approximates unit thickness. A middle unit, the thickness of which varies greatly but which is nowhere more than 30 feet thick, is made up of organic muds interbedded with sand. The middle unit rests bedrock or glacial sediments. The thickness of the bottom unit cannot be determined with the techniques employed in this study.

It is apparent from the sequences seen and the C14 dates on them that sandy beaches, perhaps with dunes and developed as a barrier system, have been a feature of this coastline for as long as 1290 years. That date compares with the situation at Sandbanks Provinical Park, Province of Ontario on the north side of Lake Ontario. There, Law (l989) reports that a beach/dune complex was developed enough by 1280 years bp to support forests.

Evolution of the Eastern Shore barrier system continues to the present day, a pattern developed much earlier when the shores of glacial Lake Iroquois were marked by sandy beaches and bars. The Iroquois shoreline is partly preserved in New York State and the Province of Ontario at locations hundreds of feet above Lake Ontario. Local examples of these old shore features and sediments can be seen in abandoned sand quarries strung along both sides of US route 11 through Oswego and Jefferson Counties. Since Oroquois time, the barrier system has migrated with lake level, starting from the Iroquois high stand and dropping to positions now drowned in tens of feet of water along the south shore of Lake Ontario (Sutton, Lewis, and Woodrow, 1972; Woodrow, Sutton and Rukavina, 1965).

Earlier and lower stands of Lake Ontario and its predecssor lakes may have seen a sandy eastern shore develop as rivers brought down some of the older Iroquois sediments and erosion of lake bottom sediments provided additional sand. Streams ancestral to modern-day Sandy Creek, the streams now flowing into North Pond, and the Salmon River, to name a few, likely flowed further west to lower shorelines of Lake Ontario. There, they deposited sand and gravel which was shaped by waves into a barrier system. Today, the channels are flooded (North Pond) or are filled by sediment as suggested in seismic records described by Steinglass and McClennen (1999) and sand from the earlier, barrier system is likely to have been incorporated into the modern barrier system.

Uncertainties about some aspects of the barrier/beach system and its evolution reflect the nature of our database. We are confident, however, both about the broad outline of sedimentary history described here and about the patterns of modern shoreline change described elsewhere in this report by McClennen. Results from these projects provide a strong basis for management decisions about the Eastern Shore.

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