Eastern Lake Ontario Sand Transport Study (ELOSTS): Final Report on Sediment Transport Patterns and Management Implications for Eastern Lake Ontario

A Report and Technical Appendix submitted to
The Nature Conservancy

by
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EXECUTIVE SUMMARY

To provide a basis for decisions concerning management of the Eastern Shore of Lake Ontario, study of important aspects of that region were carried out over the period 1998-2002. Personnel carrying out the projects came from the NY colleges and universities, Environment Canada, and consultants. Studies addressed lake currents, sediment type, distribution, internal structure and thickness in the lake and on the barriers; size variation of sand on the lake floor and on the beaches; water level in North Pond as a guide to short-term lake-level variations; shoreline evolution as seen in charts, maps and aerial photographs; and carbon dating of sediments to provide a chronology for the changes observed.

Major findings include:

- The barrier beach/dune complex between Stony Point and the Salmon River mouth was established at least 1290 years ago.
- Most of the sand, both offshore and onshore, is inherited from earlier, higher stands of lakes in the Ontario Basin. Little sand is being added to the system at present.
- The sand sheet offshore is a few meters thick. Its boundary on the south is off the Salmon River, on the north off Black Pond and lakeward at a depth of approximately 100 ft (30 m).
- Sand deposited on the pond side of the barrier and on the pond side inlet-mouth bars is lost to the system for decades or centuries.
- Sand is not accumulating on the lake floor off Black Pond, nor is it being transported to the deep lake.
- The lack of sand accumulation off Black Pond suggests that sand must be moved south during winter storms to offset the northerly transport evidenced during summer months.
- Changes in sand grain size both offshore and on the beaches and the geometry of most of the shoreline indicate sand movement to the north. The geometry of the inlet-mouth bars abutting the north side of Montario Point and at Deer Creek suggests sand movement to the south.
- The position of the barrier beach/dune complex at North Pond has changed little over the past 150 years while the inlet has moved several times. A similar pattern of shoreline stability and inlet movement is also indicated on the barrier system between Montario Point and Southwick Beach State Park.
- The internal structure of the barrier system suggests that inlet-movements occurred much earlier than 150 years ago and were normal over its entire existence.
- Currents over the study period showed net water movement toward the north with few southerly excursions. Currents over the winter are unknown but with strong winds from the NW, southerly currents and water movement can be expected.
- Internal waves capable of lifting sand are suggested by some of the current data taken late in the summer season.
- Lake level changes a few inches on a cycle of several hours.

These findings lead us to the following management suggestions:

1. **If sand must be dredged or otherwise moved, retain it within the system.**
    - It is important that dredged sand be returned to the barrier system. Dredged sand should be returned to the beach or the base of the dunes.
    - Stabilize dunes with vegetation and limit access to them.
    - Avoid dune blowouts.
    - Encourage the activities of the DUNE COALITION and like-minded groups.

2. **Monitor the system.**
    - Monitor shore profiles and bathymetry in the nearshore, inlets and inlet mouth bars.
    - Monitor lake levels by a recording "tidegauge" such as a DATALOGGER.
    - Establish collaborations between state and federal agencies to monitor the lakeshore, wetlands, and lake bottom at intervals of a decade using SHOALS technology and rectified aerial photographs.
    - Establish a monitoring program with advice from agency personnel or a consultant and administer it via personnel from a local university or college, a research entity or a non-profit.
    - Report on monitoring promptly and to the public. Provide easy access to the data.

3. **Arrive at management decisions openly.**
    - Devise a management plan including elements already in place and others to be devised. Parts of the management plan ought to be implemented over the short-term (days – one year). Examples: dune restoration/protection, inlet monitoring; and the long-term (more than one year). Examples – land-use planning, wetland monitoring.
    - Develop a Management Advisory Board with interested citizens and agency personnel as members.
    - Hold open meetings. Inform the media. Publish meeting summaries on an Eastern Shore Management Plan website.

INTRODUCTION

The Eastern Shore of New York is one of the few locations on New York's Lake Ontario shore where recreation is possible on a sandy beach (Figure 1 a, b). There, the shore is marked by long barrier beaches, many with dunes and wetlands arrayed in an attractive mosaic of environments, complex both in their development and interrelationship and subject to change both naturally and as the result of human activities.

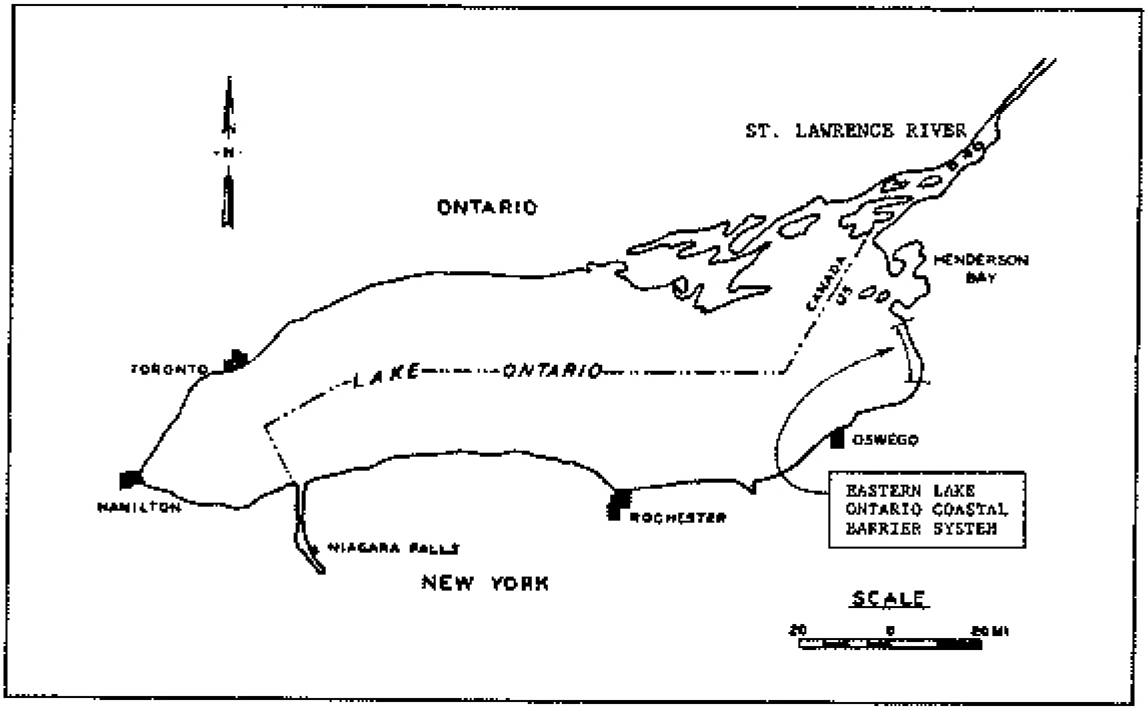

Figure 1a. Location map. Streams enter Lake Ontario in New York at Niagara, Rochester, and Oswego.

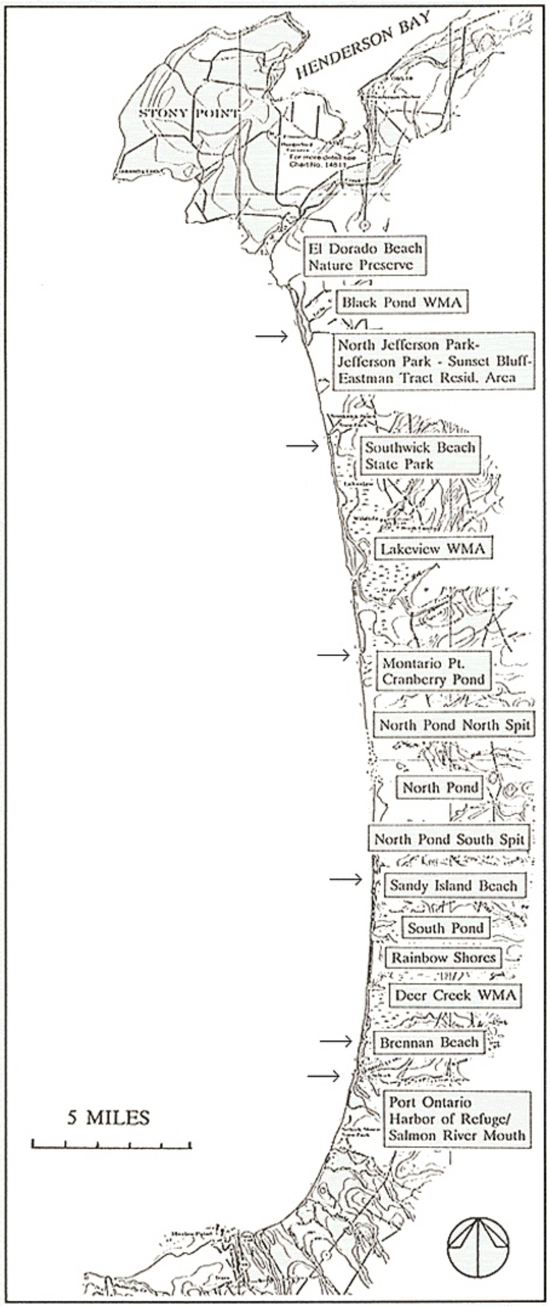

Figure 1b. Locations along the Eastern Shore. Arrows locate positions of ground-penetrating radar transects and onshore vibracores.

The Eastern Lake Ontario Sand Transport Study (ELOSTS) was undertaken to understand both the origin, movement, and fate of sand on the beaches, in the dunes and offshore and the evolution of the shoreline as a basis for decisions about coastal management. Sand on the beaches and offshore was studied by conventional grain-size analysis, echo-sounder (RoxAnn), vibracore, ground-penetrating radar, subbottom seismic profiler, side-scan sonar. Underwater video was used at several locations off the Salmon River and diver observations were obtained at a few locations. Data on currents were obtained with a recording current-meter and limited data on lake levels were obtained with a DATALOGGER©. Shoreline evolution was studied using topographic maps, bathymetric charts and aerial photographs and preliminary study of beach profiles. Shoreline evolution and sediment dynamics were placed in a time framework by 16 radiocarbon dates. Results from those studies and a discussion of methods, instrumentation and personnel are contained in a series of reports to The Nature Conservancy in 1999, 2000, and 2001. The recent report is included here as a Technical Appendix. Taken together, results from the studies provide a history of the eastern Lake Ontario sedimentary system at time scales of tens, hundreds and thousands of years useful as a basis for decisions about coastal management.

Data were collected between late Spring and early Fall each year from 1998 through 2001. Two attempts to collect data on lake currents during winter months resulted in loss of one instrument and serious damage to another, which served to dissuade us from further attempts at data collection during those times. Thus, our conclusions most fully represent the situation during the warmer months.

This report is divided into three sections: **Findings, The Future of the Eastern Shore,** and **Advice to Managers**. **Findings** are presented in four, bulleted subsections enabling a reader to move quickly to the section of greatest interest. The subsections are: **Overview**, **Origin of the Sand**, **Distribution and Thickness of the Sand**, and **Movement of the Sand.**

FINDINGS

Overview

Dunes, sandy and gravelly barrier beaches and the offshore sand sheet of the eastern shore of Lake Ontario make up a sedimentary system which is the result of shoreline and lake floor evolution spanning 12,000 years since the retreat of Pleistocene glaciers. Sand presently found on the beaches and lake floor is largely inherited from the shores of predecessor lakes, which occupied the Lake Ontario basin while the gravel is more likely a local erosion product. Little sand is being added to the lake from upland or in-lake sources today. Topographic maps, bathymetric maps and aerial photographs demonstrate that the present-day barriers and dunes have occupied their present position for at least 140 years. An exception to this record of stability is the shifting of pond-inlet positions, which, at North Pond, has occurred at least three times in the last 100 years.

At most locations, sand in the beaches and offshore sand sheet moves northward and onshore from shore-parallel bars during the warmer months while in the colder months sand apparently moves southward and offshore into shore-parallel bars. During storms, sand moves either north or south along the beaches and on the lake floor depending on the direction of wave-driven longshore drift and offshore during storms into shore-parallel bars. Gravel *(particles >2 mm diameter, typically 5-10 cm in diameter in this situation)* tends to reappear on southerly beaches after storms.

If lake level remains within the management range of the past 60 years (1.5 m/5 ft) and if climate remains about as it has been for the past century, then the geometry and placement of the shore will look in the future much as it does today. On the other hand, when lake level is at one of the extremes of the management range, noticeable local changes in shoreline position will occur. Lower lakes levels will be accompanied by wider beaches, less exposed gravel in southerly reaches and development of beach berms and dunes. Higher lake levels will see narrower beaches, more gravel in southerly reaches and increased erosion of beach berms and dunes and, rarely, relocation of inlets. Individual storms occurring during extremes of lake level will accentuate the changes. Relocation of inlets will most likely occur at times of high lake level during storm events.

Sand may be moved from the beaches to two locations: pond-side, inlet-mouth bars and dunes. The 100 year record of stability in shoreline position indicates that sand supply about equals sand loss under the present climatic and management regimes.

At a time scale spanning decades and with assumptions about climate, lake level, land use, and shoreline armoring, coastal managers can be confident that the shoreline overall will remain at its present position. A single storm or episodes of high or low lake levels within the management range will yield the local effects noted above but those effects will not be permanent. Shoreline change may occur over hours or days (storms) or months (lake level) with recovery taking months or years but the record of the past century makes clear that recovery to a close approximation of the previous shore geometry and position can be expected.

Origin of the sand

Major Points:

- **Sand accumulations are rare along the American shore of Lake Ontario both on beaches and offshore.**
- **Several potential sources of the sand are known but their contributions are small.**
- **Streams entering the lake do not provide much sand or gravel.**
- **Wave erosion and mass-wasting of shoreline bluffs yield muddy gravel to the beach where waves quickly concentrate the gravel**.
- **Erosion of glacial sediment and bedrock on the lake bottom yields little sand.**
- **A scenario of sand origin.**
    - **If appreciable amounts of sand are not now being introduced to the eastern shore….then where did the existing sand come from?**
    - **Evidence of older sand-rich shoreline sediments is found up on land and down in the lake.**
    - **We conclude that small amounts of sand are being added to the sedimentary system from upland, shoreline and in-lake sources and that small amounts are being removed to dunes and inlet-mouth bars.**
    - **Summary**

- **A novel idea on sand origin and sand movement offered at a public meeting has sand sources in the deep lake and transport of sand to deep water.**

- **Shell debris makes up a sizable fraction of the sand at northern locations along the beach and offshore.**

- **How about the gravel?**

Sand accumulations are rare along the American shore of Lake Ontario both on beaches and offshore. The only significant sandy beaches are located on the west side of jetties at the Genesee River, Irondequoit and Sodus Bays and on the south side of the jetty at the Salmon River (Figure 1a). The largest mass of beach sand is found along the eastern shore between the Salmon River and Stony Point, the ELOSTS study area (Figure 1b). Quantities of sand on the lake floor occur as sediment masses *(deltas)* at the mouths of the Niagara and Genesee Rivers but neither the Salmon River nor the Oswego River has a delta. Away from the deltas, thin sand patches of limited surface extent are found at a few locations but only along the eastern shore is there an extensive sand sheet (Figure 2) Even there, the sand mass is mainly less than 2 m thick and it is distributed unevenly (Figure 3). McClennen, working from subbottom profiles, calculates the eastern shore sand mass to contain 245,000,000 m^3 (320,000,000 yds^3) of sand. Back-of-the envelope calculations indicate that erosion of shoreline bluffs and sediments on the lake floor account for less than 20% of this mass.

Several potential sources of sand are known. They include sand coming from: 1) weathering, erosion, and transport of soils, glacial sediments, glacial-lake sediments and bedrock, 2) mass-wasting or freeze/thaw effects *(solifluction)* acting on lakeshore bluffs and cliffs of glacial sediments and bedrock, 3) erosion of lake-bottom sediments and bedrock by wave action and wave-driven currents. Of these sources, erosion of bedrock and soils must be the ultimate source of sand over geologic time but that source provides only modest additions to the eastern shore sedimentary system today as explained below. Similarly, Rukavina (1972) concluded that erosion of glacial sediments is the primary source of sand seen along the modern Lake Ontario shore in Ontario and New York.

Another likely source of the sand is the material originally massed along the 12,000 year old shoreline of glacial Lake Iroquois, remnants of which remain at elevation well above the present lake level. That shoreline is marked by unique topography and numerous sand/gravel quarries on hillsides 60-100m (200-300 ft) above present lake level and surrounding all of Lake Ontario in New York and Ontario (Muller and Prest, 1985).

Streams entering the lake transport little sand and gravel. In the New York part of the Lake Ontario watershed, streams flow at low gradients, drain wetlands and lakes and are dammed or canalized. Low-gradient valleys, wetlands, dams and lakes trap all but the finest sediment. As an example, much of the Oswego River is canalized and dammed. Outside of its canalized sections, the Oswego River flows through wetlands and it drains the central Finger Lakes. As a result, it carries only fine sediment to the lake where it is swept into deep water. In contrast, the Niagara River’s swift, turbulent flow moves all grain sizes. Gravel is deposited in the lower reaches of the river and sand is moved to the delta bypassing the shore.

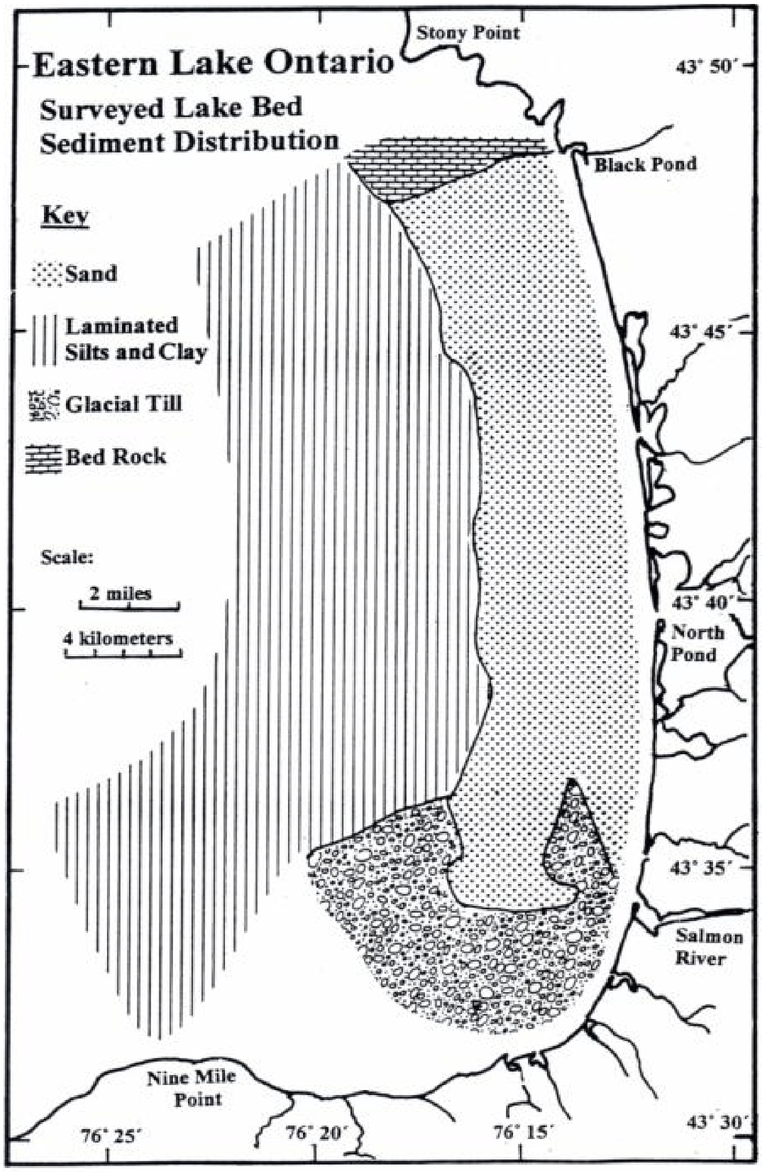

Figure 2. Distribution of sediment types based on subbottom profiles and side-scan sonar records.

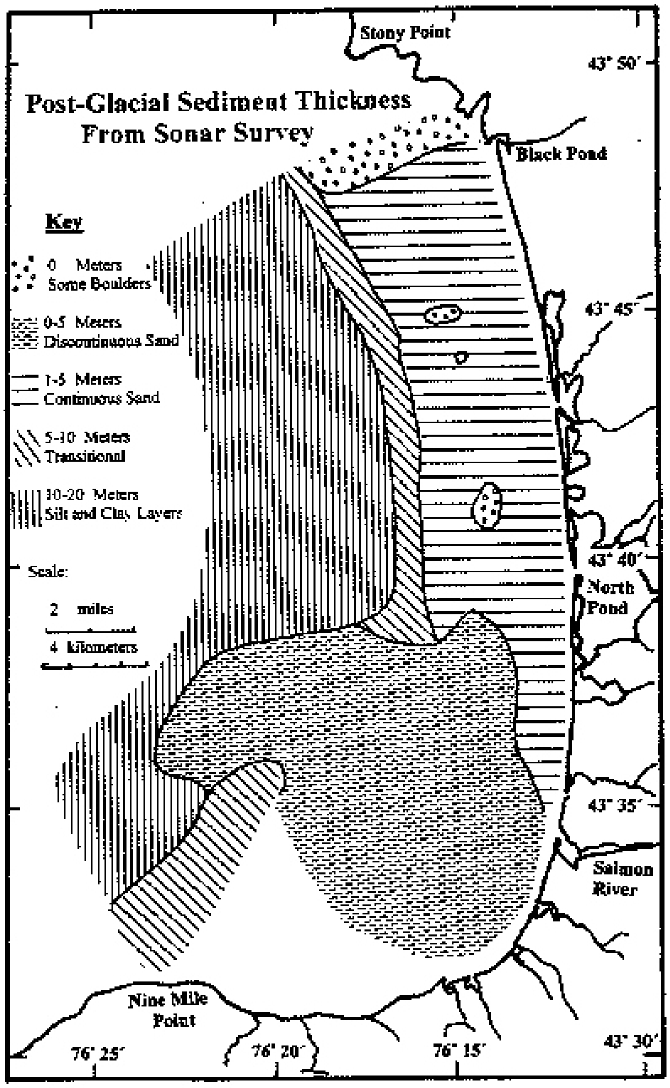

Figure 3. Post-glacial sediment thickness based on subbottom profiles.

Wave erosion and mass-wasting of drumlins yield muddy gravel to the beach where waves quickly concentrate most of the gravel and remove finer sediment to the deep lake. At many locations along the southern and eastern shore of Lake Ontario, shoreline bluffs have been cut into drumlins *(glacially-streamlined hills made up of silty, gravel-rich glacial sediment known as* *<u>till</u>)* (Pinet, McClennen and Moore, 1998, Woodrow, McKinney, Cortes, and Williams, 1990). Especially during times of high lake level, shoreline bluffs are subjected to wave erosion, which steepens the cliff face and undercuts it leading to cliff collapse. This process places on the beach an unsorted mass of gravel-rich clayey sediment, which contains less than 30% by weight of sand-sized particles. Solifluction and attendant debris flows introduce the same kind of material to the beach, some arrayed as alluvial fans at gully mouths. Sorting by waves quickly works on these products of mass-wastage, concentrating gravel on the beach with some sand while the silt and finer sediments are dispersed offshore to the deeper parts of the lake.

Along the eastern shore, gravelly sediment is exposed to erosion only in low cliffs at Montario Point and in the barrier bars south of Sandy Island Beach (Fig 1b). At Montario Point, armoring of shore by walls and abutments restricts erosion while south of Sandy Island Beach, gravel is moved along the beach and over it during storms. Elsewhere along the eastern shore, sand is introduced to the beach by wave erosion of dunes and the beach berm during high lake levels.

Not all glacial sediment found in beach cliffs is gravelly, however. On the south shore, between Rochester and Oswego, at Chimney Bluffs State Park (Figure 1a), glacial-lake clays with very little gravel have been eroded into low cliffs. Only the gravel remains on the beach as the clay is eroded and then transported lakeward.

Erosion of glacial sediment and bedrock exposed on the lake bottom yields little sand. Glacial sediment containing little sand is broadly exposed on the lake bottom only over the southern part of the ELOSTS study area and is exposed in patches elsewhere. What sand remains after erosion of the glacial sediment may be moved shoreward but most is arrayed in isolated patches.

Sandstone, limestone and dolostone are exposed on the lake floor west of the ELOSTS study area and at the north end of it near Black Pond as eroded, south-sloping surfaces broken by vertical fractures (Figure 1b). These durable rocks yield boulder gravel whether under erosive attack by waves, wave-driven currents or ice scour. Side-scan sonar records of the bedrock surfaces off Black Pond and elsewhere in Lake Ontario show them to be strewn with boulders, which inhibit erosion.

How about the gravel? Gravel is not often found on eastern shore beaches and when it is, it is often unwelcome. Gravel is found behind the shore armoring at Montario Point, at Sandy Island Beach Park and along the barrier bar south of it and along the beaches north of the Salmon River jetties (Figure 1b). Gravel is also known in small patches on the Lake floor off of Montario Point, as a common feature on and around rock outcrops offshore from Black Pond and in large patches on eroded glacial sediment off the Salmon River and further south and west.

Some beach gravel may have moved with the sand from the Iroquois shoreline, but the greater size of gravel particles inhibits such transport. Instead, most of the beach gravel must be derived locally and mixed with the sand as the sand shifts from place to place. Gravel was previously transported to the shore by the Salmon River before it was dammed. Currently, gravel is provided directly to the beaches by the erosion of till and other glacial sediment like that at Montario Point and Selkirk Shore State Park (Figure 1b).

Gravel found in the offshore at the south end of the ELOSTS study area as wells as to the west must have been available for mixing with sand as lake level rose. That gravel likely came from erosion of glacial topography as lake level rose across the area now covered by the sand sheet.

A scenario of sand origin

If appreciable amounts of sand are not now being introduced to the eastern shore except locally and episodically at eroding dunes and beach berms, then where does the bulk of the sand come from? About 80% of the eastern shore sand sheet is unaccounted for by modern sedimentary processes. Instead, it looks to be a relict sand mass. Sutton, Lewis and Woodrow (1972) provided an hypothesis about origin of the sand sheet in terms of shoreline evolution since the last of the Pleistocene glaciers about 12,000 years ago. They hypothesized that the sand presently found along the south shore of Lake Ontario and especially the eastern shore, is inherited from sand introduced to the lake basin during retreat of the continental glaciers.

The hypothesis of Sutton, Lewis, and Woodrow (1972) also defined on land and on the lake bottom the positions of sandy shorelines developed since the retreat of the glaciers. The earliest shoreline is that of proglacial Lake Iroquois *(a proglacial lake has one shore against a glacier with drainage from the lake controlled by the position of the glacier)*. The Iroquois shoreline is located at elevations as much as 100 m (300 ft) above present lake level.

The lake surface dropped from Iroquois levels to levels now submerged under lake Ontario over a very short time as the ice-barrier in the St. Lawrence valley was breached (Anderson and Lewis, 1985). The resulting lake surface elevation was low enough that marine waters entered the upper reaches of the St. Lawrence Valley almost reaching the Ontario Basin. The drop in lake level appears to have been stepwise spanning a few hundred years at the most and perhaps much less. This relatively rapid change in lake level left the sandy sediments of the Iroquois shoreline vulnerable to erosion. Some were moved downslope to the new lake level by streams and then by longshore drift to the east along the new shore. That is, Lake Iroquois sand “followed” the movement of post-Lake Iroquois, pre-Lake Ontario shorelines. In eastern Lake Ontario, lake level rise and isostatic rebound* have brought the older sands, with relatively minor modern additions, to their present position.

**Isostatic rebound refers to the Earth’s surface rising to a position approximating what it was before continental glaciers weighed it down. Glacial ice was thicker from south to north across the Ontario basin. Rebound is, as a result, greater in the north. The south-to-north contrast in rebound causes the lake basin to be tilted southward, which results in the southward displacement of both the north and south shores. Over time, the north shore shallows while the south shore floods.*

Evidence for older sand-rich shorelines is found both up on land and down in the lake. Linear hills paralleling US Rte 11 a few km east of the present shore are cut by numerous sand/gravel quarries that expose the sediment, structures and topography of coastal barrier bars that surrounded part of the former glacial Lake Iroquois. This pattern of upland sand-gravel quarries marks the Iroquois shoreline both in New York and the southern part of the Province of Ontario (Muller and Prest, 1985).

Sediments from the shoreline of lower, post-Iroquois lake levels are illustrated in the offshore vibracore records (Woodrow, et al, 2001). Three of the cores penetrate well-rounded gravel mixed with sand, approximately 26 m (80 ft) below present lake level.

These sediments look very much like those found on beaches of the modern shoreline and are located at the position Sutton and others (1972) hypothesized as that of an earlier lake shoreline. The gravelly sands found in the vibracore are responsible for a weak but readily observable seismic reflector in the subbottom profiles, which extends from offshore of the Salmon River to offshore of the inlet at North Pond (Figures 2, 3).

Rukavina's RoxAnn survey (1999) disclosed abrupt changes in bottom profile, which may represent lower lake levels, but they have not been correlated with the earlier lake levels reported above.

These data indicate that the ancient shore was flooded as climate became more humid after glaciation and the lake basin tilted southward in response to isostatic rebound. The ancient beach deposits sampled by the vibracore are now buried under a few meters of sand and rest, in turn, on more sand. These sands are thought to have been introduced to the lake by a predecessor Salmon River, Sandy Creek and other local streams, and the Oswego River which eroded the Lake Iroquois shoreline sands and glacial till. These upland sands were supplemented by sand derived from local erosion of shore bluffs and glacial sediment on the lake floor as lake level dropped and then rose. Following lake level drop from the Iroquois position and subsequent rise to its modern position, sand was moved first lakeward, then landward as a beach/dune complex.

The amount of sand now introduced from all sources is approximately balanced by the amount of sand removed to dunes and inlet-mouth bars. Although we cannot assess sand inputs and outputs quantitatively, they appear to be in balance on a regional scale. This is suggested by the distribution and thickness of sand deposits both on the beach and in the offshore and by the relatively slight change in shoreline topography and location as shown in maps and aerial photographs over the past 140 years. Inlets through the barriers are the only impermanent feature if the experience at North Pond is typical (Figure 3). Inlets there remain at one location for about 30 years before shifting position.

Summary:

1) The ultimate source of the bulk of the sand seen in beaches, dunes and offshore sand sheet is erosion of local uplands.

2) Much of the sand was first deposited as beach ridges on the shoreline of glacial Lake Iroquois at positions higher than those of the modern lake.

3) Through a series of changes in shore position spanning the last 12,000 years, Lake Iroquois sands were moved downslope by stream flow and dispersed along the shore by longshore drift. As the position of the shore changed, sand derived from the erosion of glacial sediments along the shore and lake bottom was added to the Lake Iroquois beach sediment.

4) Finally, Lake Ontario approached its modern level and the shoreline took on the pattern we see today.

Novel ideas about sand origin and movement offered at public meetings have sand sources in the deeper lake and transport of sand from deep water to shore. We see no evidence for a sand source at depth in the lake. Earlier investigations by members of the study team and those of many other workers (for example, Hutchinson, Lewis, and Hund, 1993) have shown a lakeward grading of sand into silts and silty clays in the deeper lake. Gradation is apparent in the subbottom records where the surface reflector becomes less well-defined with increasing water-depth. Below the sand surface, deeper reflectors are weak and widely spaced nearshore. In deeper water where the surface reflector becomes less well defined, strong, close-spaced reflectors typical of silts and clays dominate. Gradation from sand to silt and silty clay with increasing water depth is also seen in the size analysis data (ELOSTS, 2000) and in results from the ROXANN study (Rukavina in Woodrow, *et al.*, 1999). The depth and distance from shore at which the sand/silt gradation takes place is a zone hundreds of meters wide starting at depths of about 30 m (100 ft) and located 3-4 km (2.5 miles) from shore.

There can be no doubt that wave-related currents generated during strong storms and that currents generated by internal waves mobilize sediment in the shallow part of the lake. Current-meter data and the loss of current meters during the winter months suggests strongly suggest as much (Woodrow , et al 1999, 2000, 2001; Technical Appendix, this report, 2002). But, without sand at depth the question of the effectiveness (or not) of surface storm waves or internal waves to transport sand shoreward is moot.

Shell debris makes up a sizable fraction of the sand at northern locations on the beach and offshore. Shell material is an obvious but trace component of the sand. Most notable are the shells of zebra and quagga mussels both whole and as sand-sized fragments. Exceptional quantities of shells and shells material occur along the shore near Black Pond (Figure 2). There, shells and shell fragments make up entire strata within beach sand, thick bands of shells on the beach and as much as 30% of some samples offshore. Zebra mussels selectively colonize any hard, stable surface on the lake bottom and they are very common on bedrock, till and gravel surfaces. Concentrations of their shells in the sand along the beach near and offshore from Black Pond most likely reflect mussel colonization of the bedrock exposures known to exist on the lake bottom there.

Distribution, Thickness and Age of the Lake-bottom Sand Mass

Major Points:

- **A lake bed sand sheet extends offshore for five km (3 miles) to 10 km (6.5 miles) and to depths of about 30 m (100 feet) to 45 m (150 feet)**
- **The nearshore sand sheet covers somewhat more than 100 km^2 (~70 miles^2) and has a variable thickness depending on location and the roughness of the underlying surface.**
- **Radiocarbon ages indicate that deposition of the offshore sand sheet began as much as 8400 years ago, that the barrier system was established at least 1290 years ago and perhaps as much as 2470 years ago.**

A lake bed sand sheet extends offshore for about five km (3 miles) to 10 km (6.5 miles) and to depths of about 30 m (100 feet) to 45 m (150 feet). Its slope steepens offshore. Subbottom profiles, side-scan sonar records collected on several hundred km of tracks (Figure 3), the ROXANN survey (Rukavina in Woodrow and others, 1999) samples collected for grain-size analysis (Woodrow and Singer in Woodrow, et al, 2000) and earlier studies by Canadian workers reported by Rukavina (1999) provide the bases for determining sediment distribution and post-glacial sediment thickness. Deeper than the 30-45 m (100- and 150-ft) isobaths, sediment on the lake floor is silt and clay, which the subbottom profiles indicate to be thinly layered. These fine sediments extend below the lake floor to the limit of seismic penetration (tens of m/~100 ft). The total volume calculated for this nearshore sand mass is approximately 320 million cubic yards.

Although the lakeward edge of the sand sheet everywhere grades to mud, the north and south end of the sand sheet are quite different. On the north, opposite Black Pond, the sand sheet abruptly ends at a dam-like, bedrock outcrop (Figure 2). Bedrock at this location rises nearly to the lake surface as shown on the bathymetric maps and extends almost to the shore. On the south, the limit of the lake bed sand sheet is less clearly defined, but we place it offshore from the Salmon River mouth (Figure 2). There, and for a few km to the north, the sand sheet is broken into patches by bathymetrically rough exposures of eroded glacial till to depths as great as 45 m (150 ft) and up to 10 km (6.5 miles) offshore.

Nearshore, the surface of the sand mass slopes at less than 30 ft/3000ft (10m/km), a value comparable to that for slopes on beach surface slopes detected in the GPR data. With those slopes, a change in lake level of 0.6 m (2 ft) will produce 35-87 feet (10-21m) of beach widening. Further offshore, the slope on the surface of the sand mass steepens and, at least as indicated in the RoxAnn data, it changes abruptly at several locations suggesting a lower lake level (Rukavina, 1999).

The nearshore sand sheet covers somewhat more than 90-100 km^2 (~70 miles^2) and has a variable thickness depending on location and the roughness of the underlying surface. The surface extent of the sand sheet calculated from analysis of subbottom profiles is approximately 100 km^2, which closely resembles the 91 km^2 determined by Rukavina (1999) who worked with the RoxAnn acoustic sea-bed classification system and aerial analysis by GIS. Comparability of the values determined by these two methods suggests that the estimates of the surface extent of the sand are reasonable.

Analysis of the subbottom profiles also indicates that the surface sand sheet is most commonly 2 to 3 m (6-10 ft) thick but may be as much as five to 6 m (15-20 ft) thick. The vibracores (ELOSTS, 2001) confirm both the sand and its thickness as deduced from subbottom survey records. Sand on the lake bottom is mobile at least on an annual basis. This interpretation is based on 1) the disclosure by side-scan sonar surveys, diver observations and underwater videos of sand-waves, ripples, parabolic-shaped masses of zebra mussels and scoured masses of gravel and cobbles and 2) current-meter data illustrating near-bottom turbulence and increased turbidity (Woodrow, *et al.*, 1999, 2000; Steinglass and McClennen, 1999; Woodrow, McClennen and Beaulieu, 2001).

Radiocarbon ages indicate that deposition of the offshore sand sheet was underway at least 8400 years ago, that the modern barrier system was in existence at least 1290 years ago although wetlands developed (behind barriers?) 2400 years ago. Wood and shell material associated with gravelly sand obtained in vibracores offshore from the Salmon River and North Pond demonstrate deposition 6540-8400 years ago of gravelly sand typical of the modern lake beaches. Two dates on peat resting on gray mud at the Rainbow Shores Bog (Figure 1b) indicate establishment of wetlands there by 2380 and 2470 years ago. Wetland development likely requires a barrier beach to forestall removal of the wetland plant mass by waves from the open lake so it is likely that a barrier beach/dune complex was established then. We have no dates on material at the base of a modern dune because that material is beyond the reach of the vibracore. Dates on plant debris within the dune sands at Black Pond and at the wetland edge of the dunes at Southwick Beach State Park demonstrate active dunes at those locations over the time period 1290 – 345 years ago.

These dates lead to the following synopsis. A beach/dune complex was in place along the eastern shore by 8400 years ago at locations as much as 26 m (80 ft) below the modern lake level. That beach/dune complex moved landward as lake level rose and reached a position near the modern one by approximately 2500 years ago. Wetlands developed behind the barrier partly filling estuaries, which resulted from lake level rise. Wetlands continued to develop and expand behind the barrier as dunes built on it and the eastern shore took on its modern appearance. A period of dune stabilization with growth of plant material took place about 1290 years ago.

Wetlands, the beach/dune complex including inlets, and the offshore sand sheet continue to change but over a more limited area than in the past.

Movement of Sand

Major Points:

- **Sand is moved along the eastern shore, offshore and on the beach, except for sand stranded in the dunes and in old (relict) inlet-mouth bars.**
- **Movement of sand along the shore:**
    - **Salmon River jetties – sand accumulation along the south jetty**
    - **Sandy Island Beach – sand movement to the north leaves a gravel lag**
    - **Inlet at Sandy Creek/North Colwell Pond – No unidirectional longshore current**
    - **Inlets at South Colwell Pond and Deer Creek – sand movement to the south**
    - **Movement of sand across the shore**
    - **Dune accretion and blowouts – sand accumulates in dunes and in ponds**
    - **Inlet-mouth bars and ponds – sand accumulates in bars and ponds**
    - **Movement of sand offshore.**

Sand is moved along the eastern shore both on the beach and offshore, except for sand stranded in dunes, dune blowouts, inlet-mouth bars and ponds. The normal condition is for sand to be moved annually or more frequently in the shallows and on the beach. Waves and wave-driven currents cause longshore drift of sand along the beach and offshore. Wind moves sand from the beach to the dunes at any time. Sand is moved to and from inlet-mouth bars and inlet channels by currents generated in response to rapid raising or lowering of lake level during storms. Sand movement along the beach is evidenced by: changes in beach profiles, observations of beach and dune configurations, trends of grain-size change, and position of inlet-mouth bars (McClennen in ELOSTS, 2001). Offshore, sand is moved by surface, wind-driven waves and wave-driven currents and perhaps by turbulence and currents associated with internal waves. Evidence of sand movement offshore is given by ripples on the sand-sheet surface, development of linear sand bodies, trends of grain-size change, and the character of the contact of sand and glacial sediment as shown in seismic records (ELOSTS, 1999, 2000). There is also a notable lack of silt and clay accumulation over sand to lake depths of about 30 m (100 ft).

Movement of sand along the shore:

Salmon River Jetties – sand accumulation along the south jetty (Figure 1b) **-** A small quantity of sand has accumulated on the south side of the jetties since their construction. Sand looks to be accumulating at the rate of about 1000 m^3 per year. The geometry of that sand mass, wedged as it is against the south jetty (ELOSTS, 2001), indicates that it is derived from further south and west along the shore. The immediate source of the sand is not as clear. Immediately to the south, the beach surface is strewn with gravel and beyond that for about two km (1.7 mile), the shore is armored with a concrete wall. If sand came from along the shore, it came from much further west. There is no obviously identifiable source in that direction. Offshore of the Salmon River coastal segment, glacial sediment (and bedrock?) is exposed on the lake bottom (Figure 2). Erosion of these outcrops can be expected to yield some sand to the shore. Alternatively, sand wedged against the jetty may be what remains from sand in place prior to jetty construction. Construction of the jetties was undertaken because sand bars extended, from time to time, to the north across the river mouth thus restricting navigation and eliminating a harbor of refuge (McClennen in Woodrow, et al, 2000). Development of those earlier sand bars and consequent deflection of the Salmon river mouth-inlet indicates sand transport from the south and west toward the north.

Just north of the jetties is a relict dune field now obscured by homes and a large stand of mature trees but still expressed topographically. It is tempting to think that the dunes are there because substantial amounts of sand were removed by wind from the bars and beaches and moved inland. The jetties have cut off this sand source and it is unlikely that the dunes will be added to because the beaches at their feet are now sand-starved as progressively more gravel has appeared there over time.

Sandy Island Beach: sand movement to the north leaves a gravel lag (Figure1b) **-** This beach has been a popular recreation site since at least the early 20th century and it is now an Oswego County park. Over the past few years, gravel has appeared, been covered and reappeared on the beach. For nearly a century, a dune blowout has been a pathway to transport beach sand eastward to the wetlands surrounding the southern end of North Pond. This dune deposit has extended itself inland as much as 200 m (600 ft). Sand mining limited the rate of eastward-directed dune expansion in early decades of the 20th century. In the past few years sand has been removed from the pond side of the dune blowout and trucked to the beach where it has been used to cover the gravel. Sand relocated to the lakeside of the blowout has been stabilized by vegetation and lines of snow fencing. The beach itself is built on a sand/gravel mass at least 6 feet thick as disclosed in a test hole dug by backhoe near the beach swashline early in 1998. Gravelly sand below the modern beach was confirmed by a vibracore taken at the base of the lakeside of the dune blowout (Woodrow, *et al.*, 2001). Both the test hole and the vibracore displayed a gravelly sand to a depth of 2 m (6 ft).

In addition to the sand movement onto dunes, sand is moving to the north along the beach. South of Sandy Island Beach Park, the shore is gravelly and partly armored; to the north it is all sand (Figure 1b). This leads to the conclusion that, at the Park, gravel is becoming more common and as sand moves north. Most of the shore to the south is gravel, which forms a barrier in front of South Sandy Pond and a wetland. Without a sand source to the south or sufficient transport of sand from the offshore or continuing replenishment from blowout or upland sources, Sandy Island Beach looks to be on its way to becoming a gravel/sand beach like the beach south of it.

Inlet at Sandy Creek/North Colwell Pond: no unidirectional longshore current (Figure 1b) - Between Southwick Beach State Park and Montario Point is a barrier beach/dune complex 8 km (five mile) long making it the longest on the eastern shore. Behind the barrier are North Colwell and other ponds, extensive wetlands, and Sandy Creek (Figure 1b). At about the midpoint of the bar, an inlet provides egress for the waters of Sandy Creek and the ponds. The inlet has not been a focus of our work, the location making access difficult. However, maps spanning about 140 years suggest that the inlet and its mouth-bars, though variously configured over time, have occupied about the same position over the past century. Their changing geometry but persistent location suggests that neither north-flowing nor south-flowing longshore currents prevail at that location or are dominant for long.

Inlets at South Colwell Pond and Deer Creek – sand movement to the south (Figure 1b)- The inlet to South Colwell Pond exists at the southernmost end of the barrier stretching south from Southwick Beach State Park. It has been cut off from time to time as the spit extended south to reach Montario Point and it was reestablished by channels cut through the spit. That this part of the barrier has been subject to inlet shifts is illustrated by the several channel-forms seen in the GPR record from the site and in the topographic maps which illustrate the opening and closing (Woodrow, *et al.*, 2001; Blasland, Bouck, and Lee, 2001). A vibracore from the wetland side of the spit shows it to be made up of sand to the 8 feet (2.5 m) limit of coring (Woodrow, *et al.*, 2001).

The south-trending deflection of the small barrier at the outlet for Deer Creek at Brennan's Beach (Figure 1b) is the only other location along the eastern shore where there is evidence of prevailing southward movement of beach sand. The barrier is less than 30 feet (10 m) wide and of varying length but it is anchored on the north indicating sand transport from that direction.

Movement of sand across the shore

Dune growth and blowouts: stranding sand on land - Dunes may form at any location back of the beach berm where sand blown from the beach is trapped by dune grass and shrubs. Accumulation continues to produce vertical and horizontal dune accretion as long as the wind blows, dune vegetation thrives, and sand is available for transport to the dunes. Dune growth is a major cause of barrier widening. Dunes, once established but cut off from a supply of sand or facing a change in wind direction, may be covered by vegetation. All of the dunes along the eastern shore, no matter their location or size, have a vegetative cover of some kind ranging from the 20 year old scrubby growth on the south spit at North Pond to the mature forests at Black Pond and north of the Salmon River mouth. Development of forests on the dunes attests to their existence at those locations for at least 150-200 years.

On the other hand, reducing the vegetative cover from a dune or removing it entirely renders the dune deposit vulnerable to erosion. Carried to an extreme, wind erosion can turn a tall dune into a deep swale (blowout) as the erosive power of wind becomes more focused on the swale surface and sweeps sand landward into the wetland or pond behind the barrier. Sand movement of this type has occurred at Sandy Island Beach where the dune has been partly restored and revegetated (Figure 1b). It has also occurred on a smaller scale at Black Pond and at several places on the spit north of the Inlet into North Pond (Figure 1b).

Inlet-mouth bars and ponds: stranding sand in ponds - Inlet-mouth bars form as deposits of sand both on the lakeside and on the pond side of inlets. Lakeside bars move as the inlet moves and serve as a temporary site of sand accumulation. Sand deposited in pond side bars may remain in place for decades or centuries thus removing sand from the eastern shore sedimentary system for periods spanning a lifetime or longer.

The inlet-mouth bars are formed during storms when high-energy waves and elevated lake levels drive currents through the inlets and into the ponds. These currents transport sand toward the pond and deposit it as inlet-mouth bars. The most obvious example is the series of inlet-mouth bars, both presently active and older bars, found along the south barrier of North Pond. We know little about these sand bars other than what can be inferred from the study of aerial photos and maps. In the photographs, paired bars of four former inlets constitute the eastward protrusions *(wide parts)* seen along the pond side of the barrier (see Figures, page 34-35). Each inlet, when replaced by a new one further north, was subsequently filled with drifting beach and dune sands as well finer pond deposits. Vegetation has developed in succession and to a large extent has covered and stabilized the sediments trapped in the former inlets. Maps and aerial photographs partially document the timing of this coastal change over the past century (McClennen in Woodrow, *et al.*, 2001, Woodrow, *et al.*, 2002).

Sediment found in the ponds is probably typified by the organics, silty clay and sand found in North Pond. At locations near the inlet-mouth and along the pond side of the barrier bar, sands predominate. Gravel is found only in narrow zones around shores of islands in the pond and the pond shore. Streams may carry sand or fine gravel during periods of heavy runoff, but most often the streams carry organic-rich mud, the material found over much of the pond floor and described by Leetaru (1976). The thickness of sediment beneath the pond is unknown but it is likely thickest near the barrier.

In effect, the ponds are filling with organic-rich, silty clay and some sand. The sand is blown from the barrier or associated with the inlet-mouth bars with modest additions coming from streams draining into the ponds. Streams and wave erosion of the islands and low bluffs surrounding North Pond provide much of the silt and other fine-grained sediment. Organics are mainly plant debris carried in by the streams, derived from the wetland around the pond and from rooted aquatic vegetation found on much of the pond floor.

With North Pond as the example, all of the eastern shore ponds, wetlands, and pools are accumulating sediment, most of it organic-rich silt or more peat-like sediment. Over the past 140 years, North Pond has shallowed appreciably, as much as a few feet according to McClennen (This report, Technical Appendix). Sand is an important constituent of the sediment in the ponds only near the barriers and inlets.

Another mechanism for transporting silt and sand from the open lake across the barrier beaches into adjacent ponds and wetlands is demonstrated by sediment-containing brown-to-tan ice plastered on the trunks and branches of shoreline trees during winter storms. Field observations by McClennen (unpublished) of this tree-glazing phenomenon have been made at locations along the south shore of the lake. During strong winter storms in sub-freezing temperatures spray from breaking storm waves is blown ashore at elevations of at least 6 m (20 ft) where it coats tree trunks and branches. The content of silt and sand in the glaze ice has been determined in laboratory analyses by melting samples of the ice taken from coastal trees. The brown-to-tan color of the ice is a good field indicator of the amount of sediment contained in the wind-blown spray. This means that sediment suspended in spray may overtop the low vegetation of barrier beaches and dunes and reach the nearby ponds and wetlands. The seasonality of weather with strongest winds and largest surf makes this mechanism of sediment transport onto and across the barrier a mostly winter process, one less likely to be observed.

Movement of sand offshore

A prior hypothesis - Sutton, Lewis and Woodrow (1972) hypothesized that there was a general northward transport of sand along the eastern shore, a trend that, if prolonged, would result in gravel beaches in the south and a sand buildup both onshore and offshore in the north. Results from our most recent research bring that hypothesis into question. We demonstrate the patterns of diminishing grain size and increasingly well-sorted sand toward the north both offshore and onshore called for in the hypothesis but if northward transport of sand is the norm for eastern Lake Ontario, then sand should have accumulated offshore near Black Pond (Figure 2). Such a sand body would likely extend downslope on the lake bottom to deeper parts of the lake following a southwest-sloping bedrock channel located offshore there. Onshore at this location, we might also expect the broadest dune field and the highest dunes as sand accumulated there and on the adjacent beach.

However, the data do not support the hypothesis in at least three ways:

1) There is no broad, thick sand sheet on the lake bottom opposite Black Pond. Instead, side-scan sonar records demonstrate there a wide exposure of bedrock the south-sloping, smooth surface of which is strewn with gravel and much of it covered by zebra mussel colonies (This report, Technical Appendix; Woodrow, McClennen, and Beaulieu, 2001).
2) A significant barrier/dune complex exists at Black Pond but the barrier width and dune heights are unremarkable when compared to barriers and dunes further south.
3) The southwest-sloping channel mentioned above was likely cut by Stoney Creek immediately north of El Dorado as it drained to a lower lake level. If sand were accumulating there, the channel should have long since filled. Instead, it is a clear feature on the floor for some distance into the lake.

Alternatively, if the quantity of sand being moved northward were small, it may have been sufficient only to fill older lake–bottom topography further south leaving only a small fraction of it to reach the area offshore of Black Pont. Evidence of sand-filled channels does exist in seismic records off North Pond but in the absence of more detail about their surface extent and thickness of sand fill and without a quantitative assessment of sand movement, it is not possible to test this alternative.

Sand movement on the lake bottom - While no net northward transport of sand is in evidence, considerable mobility of the lakebed sands is evident at all locations. Side-scan sonar records show sand waves and linear features (Woodrow, McClennen and Beaulieu, 2001). Parabolic scour-and-tail structures and their orientation suggests onshore flow and transport. Video images collected at several places off the Salmon River mouth showed either coarse gravel or sand ripples. Both of these observations are consistent with sand mobility and a high enough energy state to prevent the permanent deposition of silt and clay in water shallower than 30 m (100 feet) (This report, Technical Appendix).

An additional indication of the extent of sand movement on the lake floor at a depth of about 10 m (30 feet) off the inlet to North Pond was provided by the current-meter anchored there. Details about the current-meter array are described in the Technical Appendix and in Woodrow, et al, 2001. The array was approximately 3 m (10 feet) long and included a 600 lb. concrete block about one foot high, the meter, a steel float and connecting cables. When the meter was recovered after a deployment of several months, its concrete anchor and the base of the meter itself were free of zebra mussels to a point more than 1 m (4 feet) above the base of the anchor. Above that point, zebra mussels crowded the instrument surface and the steel float to which it was attached. The distribution of zebra mussels on the array suggests that at least during part of the deployment period the anchor and part of the meter were buried in sand to a depth of more than a meter (3-4 feet).

Finally, the loss of a current-meter array over the winter months of 1999/2000 may indicate sand movement, too. Any of several explanations are possible. In one scenario, the array may simply have been "bounced along" by currents associated with winter storm-waves to a point distant from its original location. Or, breakup of the array resulting from wear of the mooring chains or fittings would have loosed the steel float and dropped the current meter to the floor where it might have been covered by sand. However, the float is distinctive enough (0 .5 m (2 feet) in diameter and painted yellow) that it would have been hard to miss. It ought to have turned up by now if it had it been loosed in this way. An alternative explanation for loss of the instrument is that it was buried by migrating sand bars. If so, the sand bars must have been on the order of 6 feet (2 m) high, if sand around the concrete block had been eroded and the block buried previously. This explanation seems least likely because the array has not reappeared even sand is on the move at that location most of the time.

Sand movement to and from shore-parallel bars – Adjacent to the beaches and offshore of them for at least one km (one-half mile), are shore-parallel sand bars. The bars are observed by people who frequent the beaches and they are partially documented in aerial photographs. It appears that they are closer-spaced, sharper-crested and with heights less than one meter near shore but more widely spaced, round-topped and lower further from shore. They develop in conjunction with higher lake levels and erosion of the beach face, berm and dunes during storm events. Under lower lake levels and calmer wave conditions, sand is transported from the bars back to the beach face rebuilding it and enhancing the size of beach berms. In a general way, the frequency and magnitude of this pattern of onshore - offshore cycling of sand is dictated by lake level, season of the year and storm events. As discussed above, the near permanent storage of sand in, on and around barrier inlet-bars removes some beach sand from this relatively rapid and frequent cycling of sand between beaches and offshore bars. Only a few of the aerial photographs available to us were obtained under the right weather and light conditions to record offshore sand bar development over time making it impossible to assess either quantitatively or with time the development of these bars.

The Future of the Eastern Shore

Analysis of photographs, maps and old charts dating back to the mid 19th-century shows overall stability in coastal location but shifts in the locations of river and pond inlets. From decade to decade or even year to year, changes in the shoreline are influenced by lake level and occasional storm events. Slow infilling of the ponds behind the barriers also appears to be a continuing process associated with storm washovers, wind transport of sand past the dunes, and inputs from streams. Some dunes are relict in that they are now covered with mature woodlands.

The future of the Eastern Shore is evidenced in its history as depicted in the Technical Appendix. Over the next few decades, we predict that minor shoreline fluctuations will occur with changes in lake level. When the lake is high, beaches will narrow as the shoreline moves landward. At low water levels, beaches will broaden as the shore moves lakeward. Beach widths of tens of meters (50-100 feet) or more will be the norm, the width at any location being a reflection of lake-bottom slope. The inlet at North Pond will continue to shift location during exceptional storms at periods of high lake level.

Sediment deposition in and around river and pond inlets may force periodic dredging in order to maintain navigation, particularly during periods of lowered lake levels.

Dunes will grow vertically and horizontally under the influence of weather, vegetation and land use.

Beaches immediately north of the Salmon River and those at Sandy Island Beach will continue to steepen and become more gravelly as sand is moved from them, some into the local dunes. This would be an excellent location for placement of any dredged materials.

Sand in the offshore will be arrayed in shore parallel bars, sand patches the positions and dimensions of which will vary with the season and wave climate. The extent of the sand sheet will vary with lake level.

Masses of mussel shells will form on any hard ground (rock, till, boulders).

Advice to Managers

We do not claim to be coastal managers although we have talked with such personnel about the problems they are asked to solve. What follows is meant to provide a context for management decisions.. Some of the issues presented below are discussed in two publications: Pinet and McClennen (1997) and Woodrow, McClennen and Bonanno (2000).

1. **If sand must be dredged or otherwise moved, retain it within the system.**

General: There is not much sand found along the Lake Ontario shoreline….. anywhere. What is on the beach, in the dunes and in the shallows is likely to be all that will be available during a lifetime. Husband it.

If sand must be dredged, return it to the beach face or the beach berm, preferably at the upcurrent end of longshore drift such as on the south end of Sandy Island Beach and north of the Salmon river jetties. Sand dredged from the North Pond Inlet would be placed on the beach south of the inlet to take advantage of longshore drift and the ease of access to that location.

Stabilize dunes with vegetation and limit access to them. Mining dune sand, allowing dirt bikes or ATV's access to dunes, permitting people and their pets to wander over them will put dune vegetation at great risk. Damaging or removing the vegetation greatly increases the chance of blowouts and movement of the dune landward. Sand moved into dunes or, by blowouts, to wetlands is sand lost to the beach system for centuries. Planting dune vegetation, banning the cutting of vegetation and sand mining, refusing access to wheeled or tracked vehicles, denying construction on dunes, and maintaining paths through or wooden walkways across dunes will assure dune well-being.

The value of the dune system is made evident by the existence of dedicated group of interested citizens and officials working as The Ontario Dune Coalition. Their efforts should be encouraged and publicized.

2. **Monitor the system.**

General: Homeowners keep a careful eye on their property and the property of their neighbors. Marina operators know a great deal about boat use, boat traffic and the condition of inlets, creek and ponds. Park managers are vigilant about the facilities and land under their jurisdiction. Summer camp operators and hotel owners ensure the comfort of their patrons. But, nobody monitors what isn't theirs. That is, no agency or group of people pulls together observations and anecdotes about the wetlands, ponds, shore and nearshore and formulates an action plan to meet challenges posed to those features.

The compact nature of the eastern shore, the diversity of its habitats, the interest of local citizens, the relatively uncomplicated nature of its political context, and the expertise available in the region, make it a natural place to develop a mechanism for monitoring and taking action when called for.

Monitor shore profiles to document change Beach profiles can be expected to evolve in response to changing lake levels, weather events and changing climate. Collecting and analyzing profiles will provide a basis for management decisions made in response to changes. To be of value, shore profiles should extend from permanent markers located well landward of the dune crest to a depth of a few feet in the lake (when/where possible). Relating beach profiles to lake levels and weather effects (storms, ice-cover) would be of great value in arriving at a quantitative model of sediment movement. The basis for such a program of monitoring is in place. The Nature Conservancy has surveyed benchmarks as a basis for profiling at six locations. Other sites could be established at modest expense. Beach profiling can be carried out by almost anyone using a consistent and systematic measurement and recording technique.

Obtaining, analyzing and archiving profiles are the task to be done. Perhaps a collaborative effort between citizen groups, non-profits, agencies and local colleges and universities could take on that job.

Monitor pond levels by a recording "tidegauge" such as a DATALOGGER$^{\text{Ò}}$. These data are necessary for the development of models of sediment transport through inlets and streams and for the development of pond-shore flooding maps. **During storms,** ponds are subject to rapid depth change and sediment influx. Water entering from the lake carries sand, which accumulates on the inlet-mouth bars. At the same time, stream water introduces sediment of many sizes plus organics and chemicals, which spread more widely over the pond floor. In a direct way, pond level variation reflects sediment influx to the pond.

Monitor bathymetry in the nearshore, inlets and inlet-mouth bars by depth-sounder to provide information on zebra mussel distribution and sediment movement**.** Recording depth-sounders and GPS are found on only a few powerboats. Enlisting as volunteers those boat owners whose craft are so equipped to record bathymetry will provide valuable information for quantitative assessment of sediment transport and the effect of a major component of the benthos.

Establish collaboration between state and federal agencies to monitor the lake shore, wetlands, and lake bottom at intervals of a decade using SHOALS technology and rectified aerial photographs. Of necessity, this would be part of an effort along the entire Lake Ontario shoreline, Canadian and US. If it were undertaken by NYS alone, then the Lake Erie shoreline would be included. Canadian interests might share costs as is being done with the IJC study currently underway.

Establish a monitoring program with advice of agency personnel or a consultant and administer it via personnel from a local university or college, a research entity or a non-profit organization. Monitoring could be at a high level incorporating all of the activities listed above or at a lower level involving only one or a few of them. Resources and personnel would dictate the scale of monitoring. Organizations which might administer such an effort include: The Office of New York Sea Grant at SUNY Oswego, a department or groups of departments at SUNY Oswego, the USGS at Oswego/Cortland, The Great Lakes Research Consortium, and the Cornell Field Station at Bridgeport, NY.

Datasets like those to be developed as part of the monitoring process are likely to be of great interest to faculty and students at local colleges and universities. A distribution list might be developed to put these data in the hands of those most likely to use them.

Report on monitoring results promptly and regularly and provide easy access to the data. Reports should be available within days of data collection via a well-maintained web site. A yearly report might be printed and distributed if resources are available.

3. Arrive at management decisions openly.

A plan of shoreline management that may infringe on some people's activities is likely to be of great interest to the public. It is important that such a plan be arrived at in a way that is at least understood and accessible even if the plan adopted is the subject of disagreement. Any management plan will likely include elements implemented over the long-term (decades or longer) and short-term (weeks, months, as much as 10 years).

A Management Advisory Board (MAB) something like the Dune Coalition and made up of interested citizens, elected officials, etc, should offer advice to shoreline managers about issues arising. MAB meetings should be open to the public and advice to managers should be made available to the public. The MAB may advise but binding decisions will be the responsibility of elected officials or entities empowered by public officials.

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