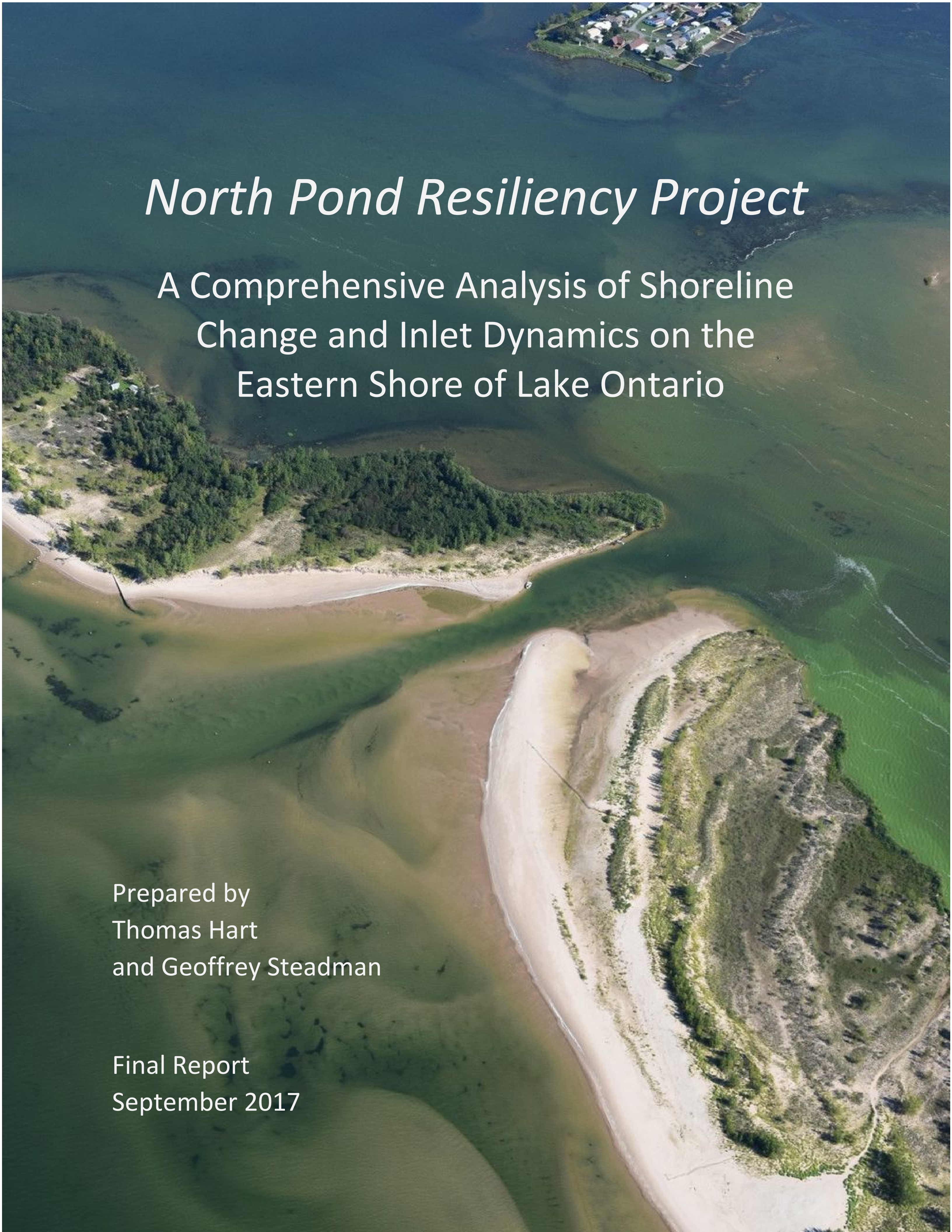

North Pond Resiliency Project

A Comprehensive Analysis of Shoreline Change and Inlet Dynamics on the Eastern Shore of Lake Ontario

Prepared by
Thomas Hart
and Geoffrey Steadman

Final Report
September 2017

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This project was prepared for Oswego County Soil and Water Conservation District supported with funds provided by the Environmental Protection Fund under the authority of the New York Ocean and Great Lakes Ecosystem Conservation Act and administered through New York Sea Grant in partnership with New York State Department of Environmental Conservation.

Foreword

Starting in 2015, NYS Sea Grant has had the opportunity to coordinate and focus several initiatives for the Eastern Shore of Lake Ontario, all with a goal of furthering our understanding of this remarkable resource. The first was to track historic storms, along with the extent of damage and flooding associated with each of these storms, from 1950 forward. A second was to revisit shoreline photomonitoring, where imagery was taken at documented stations to create a catalog that can be used to compare shore conditions over time at the same place and from the same vantage. The third initiative investigates climatology as it relates to the eastern shore and explores how long-term climate change may affect the area with preliminary results suggesting warmer and wetter weather which was certainly the case in 2017.

It gives me great pleasure to introduce the fourth initiative: the North Pond Resiliency Project. This project was conducted with a goal to enhance the resiliency of a coastal community in response to shoreline change affecting the North Pond Inlet and the coastal barrier between Lake Ontario and North Pond. How does this project add to enhanced resiliency? Expanded knowledge of shoreline change over both long and short timeframes can help understand the natural processes that drive this remarkable area of shifting sand dunes, dynamic inlets and retreating shorelines. How this physical system is used by people who live and work here and what actions we take to modify the coast are at the heart of the project through integration of ecosystem-based management principles.

Knowledge gained in this project will help guide science-based decisions by public officials and resource managers to implement the policies and recommendations suggested for the North Pond barrier-pond ecosystem. This report does not provide all answers for how to manage this resource. What it does provide is a basis and framework within which management questions can be thoughtfully addressed, and then endorsed and implemented by the Town of Sandy Creek, State of New York, and other stakeholders.

On a personal note, I'd like to acknowledge both Geoff Steadman and Tom Hart for this work. It goes far beyond all expectations in the supporting grant. It truly represents a culmination of their collective effort, interest and professional commitment to this area for over 30 years. The work presented represents a turning point in establishing much needed attention and management action. Armed with this new information, it is time for us each to step up and carry well-reasoned stewardship forward for this unique resource. It is my sincere hope that in reading this report, you will be personally inspired and help carry the vision forward.

David White
New York State Sea Grant

Abstract

The goal of the North Pond Resiliency Project (Project) is to enhance resiliency and integrity of the natural ecosystems and coastal communities in the North and South Ponds Resource Management Area (RMA) on the eastern shore of Lake Ontario.

The RMA encompasses about four miles of Lake Ontario shoreline and the largest barrier-pond ecosystem on the Lake's New York shore. Valuable for human cultural and recreational activities, the RMA also contains a wealth of natural resources including a unique ecological system of barrier beaches, sand dunes, wetlands, embayments, nearshore lake waters, and coastal shore lands. While the Lake's powerful natural forces are the predominant influence controlling the area, human activity is also a major factor. Both affect recreational, residential, and commercial development by influencing water levels and quality, habitat, shoreline integrity, and other conditions. Consideration is given to public infrastructure, community functions, and natural coastal resources, and to continued preservation, restoration, and improved management in accordance with ecosystem-based management (EBM) principles.

A fundamental question is: "How much shoreline change has occurred and can we better understand and manage this change?" To provide an answer, a comprehensive review of historical cartographic and photographic records, inlet locations, and relevant literature was conducted. Records were compiled from 1895 forward with historical aerial photography beginning in 1938. Fourteen sets of historical imagery from 1938 to 1995 were rectified for use in geographic information systems along with fifteen sets of digital orthoimagery from 1994 through 2015. From these, 25 shorelines were produced for a change analysis encompassing 1895 to 2015. In addition to shoreline change, volumetric illustrations and measurements were accomplished using three sets of LiDAR data and one 1948 bathymetric survey.

Four major inlet locations are identified and up to 27 individual instances where inlets formed. During the Project's period of record, the shoreline retreated from three to seven meters per year, resulting in 80 to 280 meters in net shoreward movement over 120 years. Formation of filled inlet features and the more recently formed shoal on the pond side of the current inlet account for nearly two million cubic yards of sand added to the barrier complex, roughly corresponding to the loss of beachfront sands. The size of the shoal and its rate of formation suggests most of the sand was deposited in the first ten years, with 20 percent of the volume added over the past 15 years. A vulnerability analysis identifies weak points on the north barrier spit indicating reduced resiliency and likelihood of new inlet formation.

Resource management issues include erosion of high dunes and beachfront on the coastal barriers and potential for closure of the current inlet. Long-term town or agency EBM policies are needed to mitigate environmental and economic impacts associated with these issues. The Project Report presents twenty-five findings and ten recommendations for EBM planning, and concludes with suggested planning approaches for establishing more detailed public policies and preparing an inlet management plan.

Preface

The Eastern Lake Ontario Dune and Wetland System (DWS) is remarkable for its geology, living resources, and as a place for people. Few areas are comparable. On the Canadian side of the lake, Sand Bank Provincial Park shares some of the same geologic history, as does Weller's Bay National Wildlife Area farther west on the Canadian shore. Together, these two areas are similar in size to the DWS. Each Canadian area has an inlet, but they're stabilized by jetties. Lake Erie's sand dune landscapes are found at Presque Isle State Park and Long Point, its Canadian companion directly across the lake. In these locations, longshore currents have sculpted coasts with overlapping recurved shores and dunes, with each new shore being cast further east. In the case of Presque Isle, the natural landforms are masked by development and engineered structures. Sleeping Bear Dunes National Lakeshore in Michigan, and Indiana National Lakeshore are also two outstanding sand landforms. Each is a celebrated destination - they are the most popular National Park destinations in their respective states.

Although there are other dune landscapes in the Great Lakes, the DWS at the eastern end of Lake Ontario is unique. Here on the Great Lake whose water level changes more than all others and whose deep waters make it less susceptible to freezing over than the others, the shore is exposed to prevailing westerlies and storms that can rush unimpeded across open surface waters for nearly 180 miles. It is in this extreme environment where snow falls nearby more deeply than anywhere else east of the Rocky Mountains that the sand dunes of eastern Lake Ontario formed. An abundant sheet of sand left by the retreating glacier 12,000 years ago filled the Lake's eastern basin and provided the raw material to allow wind, waves, and water to create a singular combination of beaches, dunes, ponds, and wetlands.

This report focuses on the largest barrier-pond ecosystem on the New York shore of Lake Ontario—the North and South Ponds area—and the most dynamic feature of the DWS—the North Pond Inlet. At the start of this project, more than one person stated, "the lake will do what it wants to do," recognizing the overwhelming force of nature the lake presents and perhaps stating a fatalistic (or well-informed, depending on your viewpoint) view of the limitations of human intervention to stabilize and otherwise manage this environmental system. But what is it that the system, and most particularly, the inlet, is likely to do? That's where the focus of this study lies. Our objective is to increase understanding of the physical history and processes shaping the system so that we may better, though imperfectly, anticipate what the future may hold. By improving our knowledge, we can help define the scope of possibilities and try to address one of the most fundamental questions of interest to governmental agencies, public officials, and landowners alike: "To protect the DWS for the enjoyment of future generations, to what extent should we try to influence the natural forces affecting it?"

It's not only the physical environment that makes this region remarkable. Its cultural history is also extraordinary. We began this project by reading about the people who have lived here and about their experiences on the eastern shore and, particularly, in North Pond. The Sandy Creek Town Hall holds a wealth of historical information, including copies of the Sandy Creek News from the 1800's forward. Stories of marriages, births, and deaths, and the experiences of lifetimes fill page after page of local news. News of horses and carts, and their load limits according to the grade of local roads, were replaced by automobiles and the new hazards that accompanied them. Stories of sailing sloops and their wrecks along with fishermen with nets laden with whitefish were replaced with stories involving recreational motor-boating on the pond and lake. Prominent are heroic stories of those who saved others from drowning. Destinations on the lake's eastern shore drew thousands of people in the 1800's and still do today. The underlying theme of many historical accounts is the attachment of the people who lived here to this special place shaped by glaciers and Lake Ontario in the north country of New York.

Over the past 32 years we've been fortunate, and feel privileged, to have learned first-hand how many people drawn to the DWS by its natural environment also committed themselves to being good stewards of that environment. They've worked hard to make others aware of this unique area, what it means to live here, and what it takes to preserve its resources and values for future generations. Some original members of The Ontario Dune Coalition have passed on, joining the remarkable history of this place, but always will be remembered for their vision and inspiring dedication. They provided the Coalition's foundation. Drayton Grant was first chair of the Coalition and led a fledgling organization that continues to play a large role in shaping the future of the DWS. Jean Wetsig represented local landowners on the Coalition and is remembered for her passionate concern for this place she called "our dunes." Tony Kotz, another local landowner, was a landscape architect and a chair of the Coalition. Among many other things, he determined the feasibility of making Sandy Island Beach a public park and then designed Sandy Island Beach State Park. Tom Cutter was a planner for the St. Lawrence Eastern Ontario Commission. He provided many years of technical expertise to advance our knowledge and understanding of the natural forces shaping the DWS. Finally, Tom Jones, Sandy Creek Regional Planning Board member and owner of the long-time, family-run Jones Marina, knew this area and its history better than anyone. Much of his life was dedicated to protecting the dunes, beaches and wetlands of the DWS. He guided the acquisition and protection of Sandy Pond Beach and helped plan the development of Sandy Island Beach State Park. Each of these people contributed to their community, made it better, and set an example for all of us who would hope to do the same. This work is dedicated to them.

Thomas Hart
Voorheesville, New York
13 September 2017

Geoffrey Steadman
Westport, Connecticut

North Pond Resiliency Study

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List of Acronyms and Abbreviations

BMP: Best Management Practice
CEHAA: Coastal Erosion Hazard Areas Act
CMP: New York State Coastal Management Program
CNY RPDB: Central New York Regional Planning and Development Board
DCR: New York State Department of State Division of Coastal Resources
DEC: New York State Department of Environmental Conservation
DOS: New York State Department of State
DWS: Eastern Lake Ontario Dune and Wetland System
EBM: Ecosystem-Based Management
ELODC: Eastern Lake Ontario Dune Coalition
ELOST: Eastern Lake Ontario Sand Transport Study
EPA: U.S. Environmental Protection Agency
FWS: U.S. Fish and Wildlife Service
GIS: Geographic Information System
GLAA: New York's Great Lakes Action Agenda
IJC: International Joint Commission
IMSA: North Pond Inlet Management Study Area
LiDAR: Light Detection and Ranging
LWRP: Local Waterfront Revitalization Program
NPS: Nonpoint Source of Pollution
OPRHP: New York State Office of Parks, Recreation and Historic Preservation
Plan: Inlet Management Plan
Project: North Pond Resiliency Project
RMA: North and South Ponds Resource Management Area
SEQRA: State Environmental Quality Review Act
SIBSP: Sandy island Beach State Park
SUNY: State University of New YorkSWCD: Soil and Water Conservation District
TNC: The Nature Conservancy
USACE: U.S. Army Corps of Engineers
WMA: Wildlife Management Area

Introduction

This report presents the results of the North Pond Resiliency Project (Project) conducted in the period January 1, 2015 to August 18, 2017 with funds from New York's Great Lakes Basin Small Grants Program provided by New York Sea Grant in partnership with the New York Department of Environmental Conservation (DEC).

The Project's principal goal is to enhance the resiliency of coastal communities in response to shoreline change affecting the North and South ponds barrier-pond ecosystem on the eastern shore of Lake Ontario in the area of special environmental concern known as the Eastern Lake Ontario Dune and Wetland System (DWS). In this regard, the project advances Goal 7 of New York's Great Lakes Action Agenda (GLAA) coordinated by the DEC Great Lakes Watershed Program to "enhance community resiliency and ecosystem integrity through restoration, protection, and improved resource management."

In addition, the project supports the following numbered priority actions to achieve Goal 7 of the GLAA: No. 7.1 (coastal property and ecosystem vulnerability analysis); No. 7.2 (identification of "soft" shoreline protection techniques); No. 7.4 (development of coastal restoration and resilience strategy); No. 7.6 (technical assistance to shoreline communities for improved shoreline stewardship); No. 7.10 (creation, restoration, and preservation of natural shoreline protections); and No. 7.18 (promotion of coastal stewardship on public and private lands).

For this Project, coastal resiliency is considered with respect to public infrastructure, community functions, and natural coastal resources. In this context, resilience is the measure of the ability of the affected communities (towns of Sandy Creek and Ellisburg) to accelerate recovery and reduce the amount of resources, including public expenditures, needed to completely restore municipal services, public infrastructure, and community functions damaged by natural hazards. Those hazards include but are not limited to, flooding, erosion, and wind hazards caused by coastal storms, high lake levels, and other weather and climate-related events and phenomena. Resilience is also the measure of the ability of the natural environment, when affected by those same hazards, to continue to provide ecological functions and natural resource values.

Project Study Area

The North and South ponds barrier-pond ecosystem, also called the North and South Ponds Resource Area in two “Dunes Reports” prepared by the New York State Department of State DOS), is the largest barrier-pond ecosystem on Lake Ontario’s New York shore. This ecological system of barrier beaches and sand dunes, wetlands and embayments, nearshore lake waters, coastal shore lands, and local community residential and marine-related recreational development is subject to ongoing modification by intense storm events, significant ice formation and processes, normal and ongoing hydrologic and climatologic forces, and human activities. Modifications influence water levels and quality, native habitats, and shoreline integrity, as well as recreational, commercial, residential, and other beneficial uses and the local economy. [1]

Within the ecosystem, the North Pond Inlet provides the hydrologic connection between Lake Ontario and the North and South ponds. Five different inlet locations have been identified since the early 1800’s. Recently, the barrier beach system has been the subject of significant restoration initiatives through construction of dune walkovers, beach grass planting, and management of human uses to the extent that substantial dune formations are now found on the coastal barrier. The Project has assessed restoration efforts to date, including construction of dune walkovers and beach grass planting initiatives, leading to dune and beach restoration. Assessments of coastal resiliency are based in part on the Project’s estimates of volumetric change on the coastal barrier.

Defined for the Project, the North Pond Inlet Management Study Area (IMSA) is coincident with the North and South Ponds Resource Area and includes public and private lands on the coastal barrier and the most dynamic sections of the larger Dune and Wetland System.

Issues and Opportunities

High dunes on the North Pond coastal barrier, some of which rise 50 to 70 feet above the beach, are subject to ongoing erosion with no source of replenishment. Historical inlet locations provide graphic evidence of an active history of inlet formation and migration. Most significantly, the inlet’s recent and current geomorphology indicate that it is tending toward closure. In 2017, Town of Sandy Creek officials, resource managers from a number of agencies and organizations, local residents, and marina managers are concerned about the potential

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[1] See the 1989 report New York’s Eastern Lake Ontario Sand Dunes: Resources, Problems and Management Guidelines and the 2007 report New York’s Eastern Lake Ontario Dune and Wetland System: Guidelines for Resource Management in the 21st Century. These two reports are known as the “Dunes reports.”

economic and environmental impacts of inlet closure, including impacts on water quality in the pond (several creeks drain into the pond from the eastern Lake Ontario watershed) and on the water-dependent businesses requiring navigation access to Lake Ontario. However, no long-range town or agency plan or policies currently exist regarding maintaining the inlet in its present location or, should the inlet close, to guide decisions concerning possible re-opening of an inlet to connect the pond with the lake. The need for an inlet management plan to enhance coastal resiliency was well illustrated in January of 2014 when inlet closure caused by an ice jam resulted in a two-foot rise in North Pond water level and significant flooding. More recently, record high Lake Ontario water levels in the first half of 2017 further emphasized the need for community resiliency in response to flood hazards. In addition, the Inlet Management Study Area, with the combination of tributary flow and its Lake-dominated inlet, may constitute an area particularly susceptible to flooding and erosion under more varied climate conditions.

While the ecological integrity of the barrier beach system has improved due to the above-noted restoration initiatives, the complex effects of inlet conditions continue to present management issues and influence the resiliency of the barrier beaches, coastal wetlands, and near shore upland surrounding North Pond. This well-defined ecological area presents an opportunity to: 1) assess dune restoration outcomes and needs using both natural and green infrastructure combined with community stewardship and education initiatives; 2) evaluate inlet formation processes and migration over time to better support management actions; 3) determine historical and anticipated rates of shoreline change and the extent to which inlet variation accounts for change; 4) identify and assess environmental, economic, and cultural issues associated with modified exchange of water between the lake and Pond; 5) identify available inlet management methods; and 6) prepare coastal management policies and other recommendations for consideration and endorsement by the towns of Sandy Creek and Ellisburg, New York Coastal Management Program administered by the Department of State, and other stakeholders. Each of these elements relate well to the above-noted priority actions to achieve GLAA Goal 7.

It is anticipated that the Project's identification and assessment of available shoreline management methods will be used to leverage other sources of funding for implementation of specific resiliency measures, including preparation and implementation of the recommended inlet management plan. The Project also provides justification for implementing shoreline management approaches for similar projects beyond the North Pond IMSA.

Project Need

The need for the North Pond Resiliency Project was identified in a number of reports and studies addressing North Pond and the larger Dune and Wetland System, including: a) the 1989 report *New York's Eastern Lake Ontario Sand Dunes: Resources, Problems and Management*

Guidelines (1989 Dunes Report) funded and published by the New York State Department of State Division of Coastal Resources (DOS DCR); b) the 2007 report *New York's Eastern Lake Ontario Dune and Wetland System: Guidelines for Resource Management in the 21st Century* (2007 Dunes Report) also funded and published by the DOS DCR; c) the 1989 "Sandy Pond Resource Management Study Final Report" for the Town of Sandy Creek; and d) the 2002 report "Eastern Lake Ontario Sand Transport Study: Final Report on Sediment Transport Patterns and Management Implications for Eastern Lake Ontario" prepared for The Nature Conservancy (TNC). The need for the proposed project is also supported by the Town of Sandy Creek through its ongoing effort to adopt a comprehensive town plan.

The Project serves to advance the Stewardship Vision for Resource Conservation and Beneficial Use set forth in the 2007 Dunes Report, including the Vision's ideals for: active management of areas and resources; recognition of ecological systems; effective shoreline management; educational and scientific use; and effective response to changing conditions. In addition, insofar as the Project has advanced planning for management of the North Pond Inlet, it has advanced Element 16 ("Prepare a Management Plan for the North Pond Inlet") of the Stewardship Vision Implementation Strategy presented in that same report.

Project Methods and Procedures

Achieving the Project's principal goal of enhancing community resiliency in response to shoreline change requires application of ecosystem-based management (EBM) principles and expanded knowledge of the causes and impacts of shoreline change. That knowledge, developed through the Project, is intended now to guide science-based decisions by public officials and resource managers and form the basis for new EBM-based policies and recommendations for the North and South ponds barrier-pond ecosystem, including development of an Inlet Management Plan, for endorsement by the Town of Sandy Creek, State of New York, and other stakeholders. In addition, Project findings and recommendations were developed to be applicable to resource management initiatives in other Great Lakes locations. Following procedures used previously in other planning, education, and outreach initiatives concerning the Dune and Wetland System, Project procedures involved assembly and review of existing sources of information; on-land and aerial reconnaissance; identification and involvement of stakeholders; public meetings; and report preparation.

Shoreline change analysis focused on the inlet and coastal barrier was conducted with respect to: 1) long term change based on historical aerial photography and existing maps that precede available photography; 2) recent change based on available orthoimagery; and 3) potential topographic volumetric change based on LiDAR data and prior topographic mapping data. A long baseline of shoreline change was developed based on historic aerial photography reaching back to the late 1930's and progressing at approximately 10 year intervals. Older photography was scanned and registered to current orthoimagery. Existing maps predating available aerial photography were evaluated to extend the time record for inlet location, and more recent orthoimagery was assessed to create a series of high accuracy shorelines. Shoreline sets from both long-term and more recent sources were used to calculate change using existing methods and software. Availability and application of recent LiDAR data sets were evaluated to provide potential volumetric change analysis, additional shoreline change references, and validation metrics. Data analysis applied available software and methods to determine shorelines and volumetric change.

Based on these analyses, shoreline dynamics on the North Pond coastal barrier, including the inlet, were characterized with an assessment of the extent of sand mobilization and identification of areas of significant progressive change.

Objectives, Activities, Outputs, and Outcomes

The project was guided by objectives to: 1) identify and assess environmental, economic and cultural issues associated with shoreline change and barrier island dune restoration outcomes in the North Pond Inlet Management Study Area, including, but not limited to, changes affecting the coastal barrier and the exchange of water between the lake and pond through the North Pond Inlet; 2) determine anticipated rates of shoreline change, including changes associated with inlet and coastal barrier migration; 3) encourage and increase public interest, support, and participation for Ecosystem-Based Management principles and implementation of the Project's recommendations; and 4) prepare findings and recommendations for coastal resiliency and inlet management for consideration and endorsement by the Town of Sandy Creek, New York State Office of Parks, Recreation and Historic Preservation (OPRHP), New York State Department of Environmental Conservation, New York Coastal Management Program, and other stakeholders.

Eleven project tasks were carried out to achieve the Project's principal goal and objectives.

1. *Project Initiation*, including: formation of the project management team; initial team meeting; adjustments to scope of work as needed; delineation of the IMSA; discussion of potential issues and management questions; and identification of existing sources of information, knowledgeable persons, and stakeholders.
2. *Reconnaissance and Mapping*, including: land and water site visits to inlet, pond, coastal barrier, and other affected locations, including site visits to observe winter ice conditions, channel dredging operations, and beach and boating recreational uses; aerial photo surveys on September 18, 2015, August 8, 2016, and June 12, 2017; and GIS base-mapping.

3. *Identification of Ecosystem-Based Management Issues and Planning Considerations*, including environmental, economic, and cultural issues and considerations pertinent to inlet management and coastal resiliency planning.

4. *Literature Review and Interviews*, to develop information needed to address EBM issues and planning considerations through existing sources of information and personal communication with knowledgeable persons, including May 21 and 22, 2015 public informational session in the Sandy Creek Town Hall.

5. *Draft Report on Existing Conditions*, including sections on: natural features and conditions (concerning the inlet, Lake, pond, tributaries, and watershed, for example); land- and water-uses; the "institutional framework" for resource management (e.g., relevant laws, agencies, programs); and resource management issues.

6. *Shoreline Change Analysis*, including long-term change, recent change, and potential topographic volumetric change, through application of historical aerial photography, available orthoimagery, and LiDAR data.

7. *Draft Findings and Recommendations*, including, characterization of shoreline and inlet dynamics with an assessment of the extent of sand mobilization and areas of significant progressive change; and recommendations for EBM policies for coastal resilience and preparation of an inlet management plan.

8. *Draft Presentation Maps*, to present geographic-based findings and recommendations, including shoreline change analysis.

9. *Public Meetings*, to: present draft findings, recommendations, and maps; and to obtain public comments and promote public interest, support, and participation, including meetings of the Eastern Lake Ontario Dune Coalition and the September 21, 2016 Eastern Lake Ontario Dune-North Sandy Pond Channel Resiliency Workshop sponsored by New York Sea Grant in Altmar, New York.

10. *Final Report with Maps and Graphics*, including sections on: existing conditions; the institutional framework for resource management; issues and planning considerations; shoreline change analysis and findings; project methodology; findings and recommendations; and sources of information.

11. *Public Outreach*, including preparation and distribution of materials to maintain and increase public interest, support, and participation for advancement of EBM and development of effective policies and measures for enhancing coastal resiliency in the North Pond barrier-pond ecosystem.

Personnel and Collaboration

The Project Team included Co-Principal Investigators Geoffrey B. Steadman and Thomas F. Hart, Jr., and Project Director John DeHollander. Mr. Steadman has conducted Eastern Lake Ontario Dune and Wetland System planning and research projects for the past 30 years for the New York State Department of State Division of Coastal Resources and others. Mr. Hart, formerly an official at the DOS DCR and New York State Department of Health, is a consulting scientist and lecturer at Skidmore College in GIS and Environmental Science. He has also taught remote sensing at the University of Albany. Mr. Hart developed and applied the Project's analytical methods for shoreline change analysis. He was project manager for the 1987 DOS DCR study and is a former Chairman of the The Ontario Dune Coalition (TODC), now the Eastern Lake Ontario Dune Coalition (ELODC). Mr. DeHollander, formerly District Manager of the Oswego County Soil and Water Conservation District, is an original member of TODC, former chairman of TODC's technical committee, and current Vice Chairman of the ELODC. He has over 38 years of natural resource conservation experience. In addition, Joe Chairvolotti, current District Manager of the Oswego County Soil and Water Conservation District, and Dave White, New York Sea Grant, Recreation and Tourism Specialist and Associate Director, Great Lakes Research Consortium, provided direction and assistance for the Project. David Klein, The Nature Conservancy, aided in acquiring Baird studies and provided valuable commentary. Wendy Leger, National Hydrological Services / Meteorological Service of Canada, Environment and Climate Change Canada, provided access to data collected in 2001 and 2002 for the IJC LOSR studies. Sandy Bonanno, former chair of the ELODC provided access to reports and data from the McClennan studies. Students from Mr. Hart's Advanced Spatial Analysis class in Fall of 2016 participated in collection of GPS and depth readings for the Inlet Shoal at North Pond. Ron Fisher and Kathy Goodnough provided access to both the barrier beach and shoals for photographic surveys and GPS measurements, as well as their extensive personal knowledge of historical and current conditions. Heather Wietzner and Brittney Rogers, NYS Sea Grant, assisted in early phases of online document access and mapping. Steve Smith, Cornell University, provided access to and expertise in online mapping ESRI products.

Collaboration and partnerships throughout the Project were developed and maintained through the ELODC, a voluntary alliance of representatives of governmental agencies, not-for-profit organizations, and private landowner associations with interests and responsibilities concerning the DWS. The ELODC's mission is to "promote and support the protection, stabilization, restoration, and optimum public use of eastern Lake Ontario sand dunes and related land and water resources while respecting the rights of private property owners." Among its activities, the ELODC promotes the development and sharing of information, provides technical assistance for land management projects, and provides a forum for public comments and discussions concerning use and conservation of the DWS. Since its formation in 1985 as TODC, the ELODC has provided coordination and support for all the above-noted resource planning and management initiatives addressing North Pond and the DWS. Through its quarterly meetings and the ongoing involvement of its members as project stakeholders, the ELODC provided input and coordination throughout the Project.

An Ongoing Process

The North Pond Resiliency Project was planned and implemented as part of an ongoing process of stewardship initiatives to guide beneficial use and conservation of the eastern Lake Ontario Dune and Wetland System. Experience in the DWS has shown that effective stewardship of coastal resources must be recognized as an ongoing process to be maintained as conditions and circumstances change, as specific initiatives may be successfully completed, and as new and significant issues arise. In addition, it is well recognized by local, state, and federal agencies and officials as well as private groups with interests in the DWS that the success of stewardship initiatives depends in large part on knowledge and information, including but not limited to knowledge and information concerning resource conditions and values, natural processes, resource use and development, and the institutional framework for resource management (the applicable laws, regulations, and agencies, for example). Experience in the DWS also has resulted in significant appreciation of the complexity of natural processes affecting the system. Part of the ongoing process of stewardship is the process of expanding the base of information on which to base management decisions and initiatives, especially as conditions and circumstances change. Through the Project's scientific research, that base of information has been expanded.

In addition, the Project provides an educational benefit by helping increase the awareness and understanding of individuals and groups concerning natural resource functions and values and ecologically-based management efforts. The Project also demonstrates how research should be designed to have practical applications for science-based management decisions and for other resource management purposes.

Institutional Framework

This section describes the institutional framework for natural resource management in the North Pond Inlet Management Study Area (IMSA), part of the larger Eastern Lake Ontario Dune and Wetland System (DWS).[2] That framework consists of a number of agencies and private organizations as well as many laws, regulations, plans, and programs that affect the use and conservation of the coastal resources in the IMSA and DWS, including barrier beaches, sand dunes, embayments, wetlands, and the nearshore waters of Lake Ontario. Governmental agencies at the town, county, state, and federal levels have roles and authorities affecting the IMSA and DWS. Private organizations, including conservation and educational organizations, also have significant interests. In addition, the general public and private landowners in and near the IMSA have significant rights and interests that are part of the institutional framework

Town Agencies and Authorities

The North Pond Inlet Management Study Area is largely within the jurisdiction of the Town of Sandy Creek in Oswego County. The northernmost part of the area is within the Town of Ellisburg in Jefferson County. Town authorities in the IMSA are influenced by a number of state laws that enable, require, or restrict the types of authorities that the towns may carry out. Both towns, along with the Town of Richland just south of the IMSA, participate in stewardship initiatives in the Dune and Wetland System and are members of the Eastern Lake Ontario Dune Coalition (ELODC). (See page 10.)

In both Sandy Creek and Ellisburg, the principal executive and legislative body is the town board. The town boards are responsible for the general management and control of town finances and have power to acquire land for public purposes. The boards may also enact, amend, and repeal various ordinances, laws, and regulations, including but not limited to, a building code, local law controlling design and installation of septic tanks and other waste

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[2] Some of the information in this section is from the 2007 report New York's Eastern Lake Ontario Dune and Wetland System: Guidelines for Resource Management in the 21st Century. The information in this section is not intended to be a comprehensive review of all agencies, organizations, laws, regulations, and programs directly and indirectly affecting the IMSA and DWS. The institutional framework for resource management in the IMSA and DWS is subject to change from time to time. Persons affected by or otherwise interested in the institutional framework should consult the web sites and other sources of information listed in this report and contact the appropriate agency or organization directly for information on the status of current laws, regulations, and programs.

disposal systems, zoning and subdivision regulations, and regulations concerning the operation of vessels on navigable water.

Sandy Creek has a planning board (Sandy Creek Regional Planning Board) as well as a code enforcement officer responsible for ensuring compliance with the town's sanitary code and issuing building permits, but the town has no zoning or subdivision regulations. In Ellisburg, the Town Board acts as the planning board and the town has adopted zoning regulations enforced by a zoning enforcement officer. Neither town has prepared a Local Waterfront Revitalization Program (LWRP) authorized by Article 42 of the New York Executive Law. Ellisburg has assumed local responsibility for implementing the state's Coastal Erosion Hazard Areas Act (CEHAA). Under the State Environmental Quality Review Act (SEQRA), the Town of Sandy Creek has designated all of the area west of New York Route 3 including the North and South Ponds area and the IMSA as a "critical environmental area." As a result, any private or governmental development proposal within this area is automatically a "Type 1" action under SEQRA. (See the following section on State Agencies and Authorities.) The town, acting through its Planning Board and with assistance from the Central New York Regional Planning and Development Board (CNY RPDB), has prepared a draft comprehensive town plan for development and land-use (Town of Sandy Creek 2013).

The Town of Sandy Creek, with jurisdiction over most of the largest barrier-pond ecosystem on the New York shore of Lake Ontario (the North and South Ponds ecosystem) historically has assumed an active role for sponsoring or otherwise participating in a number of stewardship initiatives in the DWS. The town, for example, conducted a special study of the area of the ponds (the "Sandy Pond Resource Management Study"); has served as the required municipal applicant for several governmental grants awarded for resource management initiatives in the DWS; and has participated with other agencies and organizations on those initiatives. In addition, through a number of actions and decisions over an extended period of time, the town has demonstrated its support for maintaining the North Pond Inlet channel. In 2016, its highway department conducted a maintenance dredging project by excavating sand from the channel in an effort to maintain safe and efficient navigation between North Pond and Lake Ontario.

County and Regional Agencies and Authorities

Much of the North Pond Inlet Management Study Area is within Oswego County. The northernmost part of the IMSA within the Town of Ellisburg is part of Jefferson County. The legislative body in each county is the County Legislature, responsible for enacting county laws and overseeing county government operation. County-based agencies with roles and responsibilities in the IMSA include the planning departments, sheriff's departments, and soil and water conservation districts in each county as well as the Oswego and Jefferson County

Environmental Management Councils and the Oswego County Health Department. The county planning departments, soil and water conservation districts, and emergency management councils are all members of the Eastern Lake Ontario Dune Coalition and participate in stewardship initiatives in the Dune and Wetland System.

The primary function of the county planning departments is to provide technical assistance on planning and development matters to local governments including, for example, assistance relative to the formulation and enactment of local land-use controls and assistance for meeting the requirements of state and federal programs. Both counties have developed county land-use plans. The Oswego County Comprehensive Plan recognizes the opportunities for beneficial uses that are provided by the DWS and the need for proper planning of those uses to avoid adverse impacts on the system's natural resources. Among the prominent county planning initiatives that have addressed the IMSA and DWS, the Oswego County Department of Planning and Community Development administered, in conjunction with Seaway Trail, Inc., the 1997 Sandy Island Beach Park Feasibility Study that preceded the establishment of Sandy Island Beach as first a county park and then later a state park—Sandy Island Beach State Park. (See page 7.) In addition, in 2000 the Oswego County Highway Department dredged (excavated) sand from the North Pond Inlet channel in an effort to maintain safe and efficient navigation in the channel.

The primary objectives of the Soil and Water Conservation Districts (SWCDs) in both Oswego and Jefferson counties concern the protection of soil and water resources and the agricultural resources dependent on soil and water. In the DWS, the SWCDs have provided technical assistance to concerned landowners regarding the establishment of appropriate erosion control measures. Among the SWCD's contributions to stewardship initiatives in the IMSA and DWS, the Oswego County SWCD has provided leadership for the activities of the ELODC and developed and supervised the Eastern Lake Ontario Coastal Watershed Restoration Project of which the DWS has been one element. In addition, the Oswego County SWCD applied for and received the grant of funds from the New York Sea Grant Small Grants Program (see page 6) to conduct the "North Pond Resiliency Project" and administered work on the Project as undertaken by the consultant team.

The Oswego and Jefferson County environmental management councils are county-authorized citizen advisory boards. Their primary functions are to advise citizens and local government officials on matters affecting the management of each county's natural resources.
The Oswego County Health Department conducts inspections of sewerage facilities for conformance with standards established by the New York State Department of Health, including inspections of residential facilities in and near the IMSA

The Oswego and Jefferson County sheriff's departments have law enforcement authorities in the IMSA and DWS, including authorities for enforcement of the state Navigation Law (with

respect to vessels operating in North Pond and the North Pond Inlet, for example) and any local laws that might be enacted pertaining to boating. The sheriff's departments share law enforcement jurisdiction with the state police and other state law enforcement agencies, including the law enforcement divisions of the New York State Department of Environmental Conservation (DEC) and Office of Parks, Recreation and Historic Preservation (OPRHP).
In addition to the above-noted agencies of county government, the Central New York Regional Planning and Development Board (CNY RPDB) is a regional public agency involved with stewardship initiatives in the DWS. The CNY RPDB was established by five central New York counties, including Oswego County, and provides planning services to communities in the region including, for example, assistance to the Town of Sandy Creek for preparation of the town's draft comprehensive plan for development and land use. The CNY RPDB is a member of the ELODC.

State Agencies and Authorities

On the state level, a number of agencies, laws, regulations, and programs affect the Inlet Management Study Area and Dune and Wetland System. The principal State of New York agencies with roles and responsibilities affecting the IMSA and DWS are the Department of State (DOS), Department of Environmental Conservation, and Office of Parks, Recreation and Historic Preservation. These agencies are members of the Eastern Lake Ontario Dune Coalition and have long participated in stewardship initiatives in the DWS. Other state agencies are also involved and there are numerous state laws, regulations, and programs that affect the system, including state grant programs such as those authorized by the Environmental Bond Act and Environmental Protection Act used to fund a variety of stewardship initiatives. The DOS, DEC, OPRHP and other state agencies serve on the Ocean and Great Lakes Ecosystem Conservation Council charged with coordinating programs and activities to help protect and restore the state's coastal ecosystems. The Council was established by the New York Ocean and Great Lakes Ecosystem Act of 2006.

Department of State

The DOS, through its Division of Coastal Resources (DCR), administers the New York State Coastal Management Program (CMP) and coordinates activities essential to the program's implementation. Authority for the CMP was established by the New York Waterfront Revitalization and Coastal Resources Act (Article 42 of the New York Executive Law) which enables the state to manage its coastal resources pursuant to the provisions of the federal Coastal Zone Management Act. The CMP covers the New York shores of lakes Ontario and Erie, the Niagara and St. Lawrence rivers, New York City, Long Island, Long Island Sound, the tidal portion of the Hudson River, the Atlantic shoreline, and associated coastal embayments.
The CMP establishes 44 management policies to carry out the legislative intent that a balance be established between economic development and coastal resource protection in the state's

coastal area. Under the CMP, each coastal area municipality may prepare a Local Waterfront Revitalization Program based on local needs and objectives for promoting beneficial waterfront development balanced with resource protection in accordance with the CMP policies. (Noted above, neither Sandy Creek nor Ellisburg, the two towns with jurisdiction in the IMSA, have prepared LWRPs as of 2017.) Pursuant to its responsibilities for administering the CMP, the DCR's major roles pertinent to resource management in the DWS include: review of proposed development activities for consistency with the CMP; designation of special resource areas; and provision of planning and funding assistance for special projects.

All major actions proposed in the coastal area of New York State by federal agencies or by entities requiring federal permits (from the U.S. Army Corps of Engineers (USACE), for example) must be consistent with the management policies established in the CMP and in any applicable LWRP that may have been prepared. The DCR evaluates the consistency of federal activities with the policies set forth in the CMP. If a proposed action is judged inconsistent by the DCR, a permit cannot be issued. In addition to federal activities, state agency initiatives are also required to be consistent with the CMP and any applicable LWRP.

Under the provisions of the Waterfront Revitalization and Coastal Resources Act, the DOS is responsible for assuring the protection of coastal fish and wildlife habitats, scenic areas, and agricultural lands of statewide significance. With regard to significant fish and wildlife habitats, state regulations establish criteria applied by the DEC to evaluate habitats which then may be designated by the New York Secretary of State as "significant coastal fish and wildlife habitats." Significant habitats have been so designated in the DWS, and the system is recognized as containing one of the highest concentrations of designated habitats in the state as well as some of the highest valued habitats.

The DCR has provided substantial funding for a number of special projects to advance stewardship initiatives in the DWS, notably the 1989 report "New York's Eastern Lake Ontario Sand Dunes: Resources, Problems and Management Guidelines" and the 2007 report "New York's Eastern Lake Ontario Dune and Wetland System: Guidelines for Resource Management in the 21st Century." These are known as the two "Dunes Reports." The 2007 Dunes Report identified preparation of a management plan for the North Pond Inlet as a priority project for implementing a recommended "Stewardship Vision" for resource conservation and beneficial use of the DWS. In addition, the DCR supported: the Eastern Lake Ontario Sand Transport Study, including a shoreline change component and an assessment of littoral conditions in the vicinity of the IMSA, conducted with funds provided under the Environmental Protection Act; and the Eastern Lake Ontario Coastal Watershed Restoration Project conducted as part of the state's Great Lakes Coastal Watershed Restoration Program. The DCR also promotes ecosystem-based management (EBM) planning for the eastern Lake Ontario watershed pursuant to the New York Ocean and Great Lakes Ecosystem Act.

Department of Environmental Conservation

The DEC has both resource management and regulatory responsibilities in the IMSA and DWS. Management responsibilities are directed toward managing fish and wildlife resources and focus on the three state wildlife management areas and designated “natural area” in the DWS. Regulatory responsibilities include permit authority over activities affecting freshwater wetlands and navigable waters; authority for protecting water quality and coastal erosion hazard areas; and other authorities. The several maintenance dredging operations in the North Pond Inlet conducted by Oswego County, the Sandy Pond Channel Maintenance Association, and the Town of Sandy Creek in the period 2000 to 2016 were conducted in accordance with permits issued by the DEC.

North of the IMSA, the Black Pond and Lakeview wildlife management areas (WMAs) in Jefferson County are managed by DEC Region 6. South of the IMSA, the Deer Creek Wildlife Management Area in Oswego County is managed by DEC Region 7. The DEC’s environmental conservation officers have law enforcement authority for enforcing the management rules and regulations established by the DEC for these areas. In conjunction with its responsibility for managing the WMAs, the DEC also implements the Eastern Lake Ontario Marshes Bird Conservation Area (BCA) program to conserve the diversity of bird species using the area and to promote research and management of those species. The BCA encompasses the three WMAs nearby the IMSA.

The DEC has proposed designating all state-owned land in the DWS as a natural heritage area. In coordination with the DOS and OPRHP, the DEC also prepares the New York State Open Space Conservation Plan which recognizes the exceptional natural resource values and opportunities for recreational use provided by the public lands in the DWS. In addition, the DEC in 2017 continues to pursue development of a Watershed Action Plan for the southeast Lake Ontario watershed, including the IMSA and DWS, that will serve to implement the state’s Comprehensive Wildlife Conservation Strategy.

The DEC has the major responsibility for protecting natural resources in the coastal area of the state and exercises this responsibility through a number of regulatory programs authorized by state legislation. For example, the DEC reviews proposed development activities with the potential for significant environmental impact in accordance with the requirements of: the *State Environmental Quality Review Act*, which establishes a comprehensive review process applicable to all actions of state and local agencies and private interests that may have significant effects on the environment; the *Freshwater Wetlands Act*, which authorizes the DEC to map and classify freshwater wetlands and regulate their use and development; the *Stream Protection Act* whereby the DEC regulates dredging and filling in navigable waters and adjacent wetlands; the *Water Pollution Control Act*, whereby the DEC assigns state water quality classifications to streams and water bodies and has adopted water quality standards for each class of waters, including the streams and water bodies in the DWS; and the *Coastal Erosion Hazard Areas Act* whereby the DEC has mapped erosion hazard areas and adopted regulations (to be implemented by the DEC, affected county, or local government) to control certain activities and development in these areas, including the "natural protective feature areas" mapped in the IMSA and DWS.

The DEC also administers state grant programs including those authorized by the Environmental Bond Act and Environmental Protection Act and which can be used by municipalities to fund projects for land preservation and improvement projects and other stewardship initiatives in the DWS. In addition, the DEC cooperates with the DOS DCR to administer funds available through the National Oceanic and Atmospheric Administration's Great Lakes Coastal Watershed Restoration Program.

The DEC also provides support, in partnership with New York Sea Grant, The Nature Conservancy (TNC), and OPRHP, for the Eastern Lake Ontario Dune Steward Program. Through this program, the dune stewards interact with visitors to the WMAs, the state parks, and TNC's El Dorado Nature Preserve on the northern edge of the DWS during the period May through Labor Day, providing information, monitoring use, assisting resource managers with maintenance of the areas, and otherwise promoting environmentally sound use of the public recreation areas in the DWS.

Office of Parks, Recreation and Historic Preservation

The main responsibility of the OPRHP is to operate and maintain a statewide system of parks and historic sites and to meet the recreational needs of the people of New York State. The State Parks and Recreation Law authorizes the OPRHP to acquire, establish, operate, and maintain state parks, parkways, historic sites, and state recreational facilities.

The OPRHP establishes rules and regulations for state park use, including rules and regulations for Sandy Island Beach State Park in the IMSA and nearby Southwick Beach State Park to the north of the IMSA and Selkirk Shores State Park to the south. These parks are managed and their rules and regulations are implemented by regional OPRHP offices. Sandy Island Beach and Selkirk Shores state parks are within the jurisdiction of the Central New York Regional Office; Southwick Beach State Park is within the jurisdiction of the Thousand Islands Regional Office.

As part of its efforts to manage the state parks in accordance with its goals for conservation and enhancement of DWS resources, the OPRHP provides support, in partnership with the DEC, New York Sea Grant, and TNC, for the Eastern Lake Ontario Dune Steward Program.

The OPRHP is also responsible for marine and recreational vehicles programs and facilities and for administration of the state's Navigation law. The OPRHP's Bureau of Marine and Recreational Vehicles has general responsibility for boating safety in New York State and provides funding and training for marine law enforcement as well as boating education programs. Also, under the Navigation Law and New York Town Law, no local law or ordinance pertaining to the regulation of vessels and/or the establishment of a vessel regulation zone can take effect until it has been submitted to and approved by the Commissioner of Parks, Recreation and Historic Preservation. The OPRHP maintains the aids to navigation that currently mark the navigation channel between North Pond and Lake Ontario in the North Pond Inlet.

The northern part of Sandy Island Beach State Park, formerly managed by the DEC as the Sandy Island Beach Natural Area, and known locally as Sandy Pond Beach, encompasses the sand flats adjacent to the North Pond Inlet. The OPRHP therefore has an important role in all actions concerning inlet management, including placement of dredged material from channel maintenance operations, and managing habitat for threatened and endangered bird species affected by inlet management activities.

Other State Agencies

Other state agencies also have roles and authorities that may affect resource management in the IMSA and DWS. These include, but are not limited to: the *Office of General Services* which is the proprietor of state lands, including lands under water and can issue grants, easements, and leases for private use of submerged lands within the public domain including those generally below mean low water in Lake Ontario (see the later section on the General Public); the *Department of Health* which enforces the Public Health Law and state Sanitary Code; the *DOS Codes Division* which administers the state's Uniform Fire Prevention and Building Code that provides the minimum requirements that must be met in local building codes; and the *Tug Hill Commission* which is responsible for studying the Tug Hill region east of Lake Ontario and recommending means for protecting the region's environment and strengthening its economy, and which in 2017 is assisting the DOS DCR, in partnership with TNC, in the development of an ecosystem-based strategic management plan for the Sandy Creek watershed which drains into the DWS nearby the IMSA. This effort is known as the Sandy Creeks Ecosystem-based Management Demonstration Project.

Federal and International Agencies and Authorities

The U.S. Army Corps of Engineers and the U.S. Environmental Protection Agency (EPA) are two federal agencies with significant roles and responsibilities in the Inlet Management Study Area and Dune and Wetland System. Both agencies are members of the Eastern Lake Ontario Dune Coalition. In addition, other federal agencies, including the U.S. Fish and Wildlife Service (FWS), have authorities affecting the IMSA and DWS, and the authority of the International Joint Commission (IJC), including authority affecting the water level of Lake Ontario, is also significant.

U.S. Army Corps of Engineers

The IMSA and DWS are within the jurisdiction of the USACE's Buffalo District with headquarters in Buffalo, New York. The USACE regulates structures in or affecting navigable waters of the United States as well as excavation (e.g., dredging) and deposition of materials in navigable waters. The USACE is also responsible for evaluating applications for Department of the Army permits to deposit dredged and/or fill material into waters of the U.S., including adjacent wetlands. These regulatory programs, originating from Section 10 of the River and Harbor Act of 1989 and Section 404 of the Clean Water Act of 1977, do not directly address the upland portions of the IMSA and DWS but instead focus on the navigable waters, aquatic habitat, and wetland areas in the DWS. In general, a permit must be obtained from the USACE for any filling of wetlands and navigable waters; placement of structures in navigable waters; and dredging and disposal of dredged materials. The several maintenance dredging operations in the North Pond Inlet conducted by Oswego County, the Sandy Pond Channel Maintenance Association, and the Town of Sandy Creek in the period 2000 to 2016 were conducted in accordance with permits issued by the USACE.

The USACE is also responsible for constructing and maintaining federal navigation projects such as channels, jetties, and anchorage basins authorized by Acts of Congress. The one federal navigation project affecting the DWS is the Port Ontario Harbor of Refuge Project at the mouth of the Salmon River to the south of the IMSA. Under its authority to assist communities in small navigation improvements, the USACE previously conducted an appraisal of the feasibility of establishing a dredged, federally maintained channel to provide improved navigation access between North Pond and Lake Ontario. That appraisal determined that the benefits of such a project did not justify its cost.

The USACE has several programs through which planning assistance may be provided on matters subject to USACE authority. For example, the Engineer Research and Development Center (ERDC) assists USACE districts with navigation project planning and dredged material disposal planning, and the Planning Assistance to States (PAS) program may be used to provide planning and engineering assistance as requested by a state. The USACE's Detroit District provides monthly bulletins on Great Lakes water levels, including information and forecasts on long-term lake levels.

U.S. Environmental Protection Agency

The EPA has several responsibilities affecting the IMSA and DWS; these are related primarily to maintaining water quality values and include responsibility for reviewing and commenting on applications submitted to the USACE for permits to dredge and/or fill aquatic areas. In addition, the EPA provides funds for stewardship initiatives, including water quality initiatives to be developed and applied on a watershed-wide basis. The EPA's Great Lakes National Program Office provides funding pursuant to the federal Clean Water Act to advance national goals to restore and maintain the chemical, physical, and biological integrity of the Great Lakes Basin. One such Great Lakes Ecosystem Protection Grant, for example, was provided to The Nature Conservancy to support TNC's Eastern Lake Ontario Conservation Initiative involving a variety of research, planning, and monitoring to help achieve long-term conservation of the DWS. EPA funds have also been used for site-specific projects including construction of the handicapped accessible dune walkover structure at Sandy Island Beach State Park.

Other Federal Agencies

Several other federal agencies also have roles and authorities affecting the IMSA and DWS. These include the *U.S. Fish and Wildlife Service* (FWS) which reviews permit applications submitted to the USACE and then comments on potential impacts to fish and wildlife and which has recognized the DWS as containing especially significant waterfowl habitat. The FWS also has important responsibilities for implementing the federal Endangered Species Act. To the extent that North Pond Inlet management plans, including channel dredging projects, would affect species protected by that Act, such plans must be approved by the FWS. For example, recent plans for maintenance dredging of the inlet channel, including placement of dredged material, have required FWS approval in accordance with the Endangered Species Act due to potential impacts on the federally endangered piping plover.

In addition, the *National Park Service* administers the National Natural Landmarks Program which includes the Lakeview Wildlife Management Area; the *Federal Emergency Management Agency* administers the National Flood Insurance Program; and the *National Oceanic and Atmospheric Administration* administers the Federal Coastal Zone Management Program and administers the Great Lakes Coastal Watershed Restoration Program whereby federal funds are provided to Great Lakes states, including New York, to support projects that protect and restore coastal resources in Great Lakes watersheds.

International Joint Commission

The IJC was established by the Boundary Waters Treaty of 1909 between the United States and Canada to prevent and resolve disputes over the use of the two countries' shared waters. The IJC oversees regulation by the International Lake Ontario - St. Lawrence River Board of the outflow of Lake Ontario through the St. Lawrence River. A five-year study by the Board in 2000 examined the effects of water level and flow variations in the Lake Ontario-St. Lawrence River system. Options were developed for a revised plan of outflow regulation intended to provide the most desirable balance among all user groups and interests in the system, including navigation and resource protection groups and interests. Input for the study, which has given additional credence to the effects that regulation of the outflow of Lake Ontario can have on the shoreline of the IMSA and DWS, was provided from all interested parties, including members of the ELODC. The IJC held a series of public hearings prior to adopting Regulation Plan 2014 for Lake Ontario and the St. Lawrence River to regulate Lake Ontario outflows. Implementation of this plan must comply with the IJC's December 8, 2016 Supplementary Order effective January 2017. The Board also has responsibilities to communicate with the public about water levels and flow regulation, and to monitor and assess the performance of the regulation plan.

Conservation, Education, and Other Not-for-Profit Organizations

In addition to the various local, county, state, and federal agencies with roles and authorities affecting the Inlet Management Study Area and Dune and Wetland System, several conservation and education organizations also have active roles and authorities, most notably the Eastern Lake Ontario Dune Coalition, New York Sea Grant, and The Nature Conservancy. Several other organizations are also involved.

The Eastern Lake Ontario Dune Coalition

Formed in 1985, the ELODC is a voluntary alliance of private property owners' associations, not-for-profit organizations, local governments, and state and federal agencies, all of whom have an ownership, regulatory, or management interest in the DWS; many also have programs and authorities affecting the IMSA The mission of the ELODC is to "promote and support the protection, stabilization, restoration, and optimum public use of eastern Lake Ontario sand dunes and related land and water resources while respecting the rights of private property owners." Among its activities in pursuit of its mission, the ELODC promotes the development and sharing of information, provides technical assistance for land management projects, and provides opportunities for public comments and discussions concerning the use and conservation of the DWS.

Not-for-profit members of the ELODC include TNC, Onondaga Audubon Society, Seaway Trail, Inc., and the Friends of Sandy Pond Beach. State member agencies include the New York State Department of State acting through its Division of Coastal Resources. Other state agency members of ELODC are the Department of Environmental Conservation and Office of Parks, Recreation and Historic Preservation. New York Sea Grant is also a member. Federal members include the U.S. Army Corps of Engineers, U.S. Environmental Protection Agency, and U.S. Fish and Wildlife Service. Town and county agencies are members; so too are private landowner associations (see the following section on Private Landowners).

The ELODC has established standing committees to address issues regarding resource management in the DWS, including committees to address educational, technical, and legislative matters as well as the concerns of private landowners. The Snow Memorial Library in Pulaski, New York serves as a repository of information assembled by the ELODC. Although the ELODC is not able to accept funds for resource management initiatives, its member agencies and organizations have applied for and received grants to support a number of resource management initiatives to advance stewardship goals in the DWS. Representatives of the ELODC's member agencies and organizations provide leadership for those initiatives and otherwise actively participate in them.

New York Sea Grant Program

The New York Sea Grant Program is established under the National Sea Grant Program which provides funds to state institutions for marine research, education, and advisory services. The program also receives operating funds from the State of New York. Program goals include the conservation, proper management, and balanced use of marine resources. The program provides science-based information to agencies, organizations, and officials making and influencing decisions for the wise development, management, and use of coastal resources. Toward this end, the program has been involved, through extensive research, information exchange, and public education and outreach programs, with a variety of stewardship initiatives in the DWS. The program's office at the State University of New York College at Oswego provides leadership for the ELODC and has participated in all of the major stewardship initiatives that have affected the DWS since ELODC's formation in 1985.

Stewardship initiatives in the DWS for which the Sea Grant Program has provided leadership, organization, and technical assistance include the preparation and distribution of numerous fact sheets, publications, and visual-media presentations to provide educational information on a variety of topics to local residents, town officials, visitors to the system, and the general public, including the interpretive guidebook “Sand, Wind, and Water”; planning and design of interpretive signs throughout the system; organization and management of public meetings and workshops to review ongoing research and the results of completed stewardship initiatives

in the system; establishment and maintenance of the Eastern Lake Ontario Dunes and Wetlands web site (www.seagrant.sunysb.edu/elodune/ELODC); distribution of information concerning the potential impacts of Lake Ontario water level regulation; and development (as an element of the Eastern Lake Ontario Coastal Watershed Restoration Project) of educational materials for private landowners concerning use and conservation of the DWS.
The Sea Grant Program also coordinates the Eastern Lake Ontario Dune Steward Program in partnership with the Department of Environmental Conservation, Office of Parks, Recreation and Historic Preservation, and TNC. In addition, the "North Pond Resiliency Project" was made possible by a grant of funds from the New York Sea Grant Small Grants Program to the Oswego County Soil and Water Conservation District.

The Nature Conservancy

TNC is a national conservation organization whose mission is to preserve natural diversity by protecting lands and waters supporting the best examples of all types of natural environments. A membership organization, TNC's interest in the DWS extends beyond its ownership and management of its El Dorado Beach and Selkirk Fen preserves. TNC has long recognized the ecological significance of the DWS and is concerned with the protection of rare natural communities and species as well as biological diversity in the system. Through active involvement of its Central and Western New York Chapter in the ELODC, TNC has long supported informed management and conservation of the system and has participated in all the major stewardship initiatives since ELODC's formation in 1985.

The DWS is an important area of focus of TNC's Great Lakes Program. To help achieve this program's goal of protecting biodiversity and the integrity of ecological systems throughout the Great Lakes basin, TNC's Great Lakes state chapters, including the Central and Western New York Chapter, continue to work on projects to address various threats to the basin's natural systems. In this regard, TNC promotes conservation initiatives that address not only specific resource locations but also the larger ecological systems of which the locations are part.
The Great Lakes Program includes work to better assess biologically significant areas and expand the scientific knowledge of how key ecological systems function. The eastern Lake Ontario area is one of the demonstration project areas selected by TNC for development of locally based efforts for Great Lakes ecosystem conservation.

Some of the major stewardship initiatives in the DWS for which TNC has provided leadership and/or funding include: initial purchase and subsequent transfer of the properties that would become Sandy Island Beach State Park, including the Sandy Pond Beach Natural Area; development and administration of the Eastern Lake Ontario Sand Transport Study and the Eastern Lake Ontario Conservation Initiative; and development of, and ongoing participation in, the Eastern Lake Ontario Dune Steward Program. In addition, TNC is a partner with the DCR and Tug Hill Commission in the Sandy Creeks Ecosystem-based Management Demonstration

Project and has served on two International Joint Commission technical committees to review the potential environmental impacts of Lake Ontario water level regulation.

Other Organizations

Other organizations with active interests in the IMSA and DWS include: the *Onondaga Audubon Society*, a chapter of the National Audubon Society and member of the ELODC, which promotes the wise use and conservation of DWS resources, including the protection of habitat for all bird species in the system; the voluntary organization *Friends of Sandy Pond Beach*, another member of the ELODC, originally formed to assist with management of the Sandy Pond Beach Natural Area (now part of Sandy Island Beach State Park) and which has developed, applied, and shared significant technical knowledge with regard to the use of beach grass planting for dune stabilization and the use of property management techniques to guide visitors in sensitive resource areas; the *Sandy Pond Channel Maintenance Association* formed by water-dependent businesses and residents to raise and apply funds for maintenance of the navigation channel in the North Pond inlet, and which has obtained the necessary permits and conducted and supported maintenance dredging in the channel in the period 2004-2016; *Seaway Trail, Incorporated*, a member of the ELODC, whose mission is to increase tourism revenues and enhance the economic well-being and quality of life in the Seaway Trail corridor that connects historic communities and scenic landscapes along Lake Ontario, the St. Lawrence River, Niagara River, and Lake Erie, and which has provided funding support for a number of stewardship initiatives in the DWS, including the Sandy Island Beach Park Feasibility Study that preceded the establishment of Sandy Island Beach as first a county park and then later a state park; and a number of *Colleges and Universities* that conduct research in the DWS, including but not limited to Youngstown State University, Colgate University, Cornell University, Hobart and William Smith Colleges, the State University of New York (SUNY) at Buffalo, SUNY Oswego, the SUNY College of Environmental Science and Forestry at Syracuse, and Syracuse University, which have participated in such research initiatives as the Eastern Lake Ontario Sand Transport Study and the National Science Foundation-funded Lake Ontario Biocomplexity Project, and whose students may participate in a number of initiatives, including the Dune Steward Program.

The Public

The general public has important rights to use the navigable waters and public recreation areas in the Inlet Management Study Area and Dune and Wetland System and the navigable waters of Lake Ontario. Consistent with the Public Trust Doctrine (the body of law pertaining to waters subject to the ebb and flood of the tide as well as navigable freshwaters) individuals and groups generally do not own the navigable waters, plant and animal life inhabiting those waters, and the submerged lands in Lake Ontario and the Dune and Wetland System (with the exception of submerged lands in the North and South ponds which, according to the New York Office of General Services, were conveyed by the state to private interests in the 1700's). The State of New York owns these resources and holds them in trust for the benefit of all State residents.

The rights of the general public for use of navigable waters, including the waters of Lake Ontario and in the IMSA and DWS, are generally classified under three major headings: 1) transportation and navigation; 2) recreational activities; and 3) commercial and consumer use of "sea products" (e.g., fishing). The use of public waters for navigation is the central and essential public right and generally takes precedence over other rights. The public has the right to pass and repass on navigable waters without interference or obstruction.

To the extent that members of the public can gain access to navigable waters without trespassing on the adjoining uplands of private landowners (see below) they may use navigable waters for recreational purposes, including boating, fishing, swimming, and related activities. When discussing public rights for use of navigable waters, questions concerning the public's right of access to these waters are particularly important. Where title to the land adjoining navigable waters is in private ownership, the property owner may deny access across his or her land to the Public Trust area. Described below, the right of access to public waters is one of the most significant rights associated with the ownership of lands bordering navigable water; possession of this right distinguishes the waterfront property owner from members of the public.

Private Landowners

Certain rights - referred to as riparian or littoral rights[3] - are inherent in the ownership of lands bordering navigable water. One of the most important of these rights is the right of access to navigable water. A property owner's littoral/riparian right of access to a navigable water course is totally distinct from the right of the general public to use that water body or water course. New York courts have held that the owner of upland property adjacent to navigable water has certain exclusive yet qualified rights and privileges in the adjoining submerged land and navigable waters, including the exclusive right to build docks and piers from the upland to reach deep water (often referred to as "wharfing out"). These structures, however, must not unreasonably interfere with the public's right of navigation and must be acceptable under applicable regulatory statutes, including the statutes that protect natural resources. In other words, the exercise of the littoral/riparian right must not interfere with the rights and interests of the state and the general public and with the federal interest in navigation.

Described above, both the Corps of Engineers and the New York Department of Environmental Conservation regulate the construction of docks and piers and other activities in navigable

[3] Regarding water rights law, water rights arise when property either abuts or contains water. If the water in question is flowing (e.g., river or stream) the rights are said to be riparian. If the property is subject to the ebb and flood of the tide, or is located on a lakeshore such as Lake Ontario's, the rights are said to be littoral rights. Despite these distinctions, the terms "riparian" and "littoral" are commonly used interchangeably.

waters. The state and federal regulatory programs help to ensure that the exercise of littoral/riparian rights is consistent with the public's interest in those waters.
A waterfront property owner cannot exclude the public from lawful uses of the Public Trust area adjoining the owner's property. Also, all littoral/riparian rights must be exercised with due regard for the rights of other littoral/riparian owners; the waterfront property owner cannot wharf out from the shore, for example, in a manner that encroaches on the littoral/riparian area of an abutting waterfront property owner.

In the Inlet Management Study Area and Dune and Wetland System, many property owners concerned with the quality of life in their communities are members of landowner associations formed to address issues of common interest including, for example, issues concerning shore protection, fluctuating lake levels, and the use and development of public and private lands. These associations, including the Eastman Place Association, North Jefferson Park Landowners Association, North Rainbow Shores Landowners Association, North-South Sandy Pond Association, Renshaw Beach Association, Sandy Island Beach Property Owners Association, and the Selkirk Beach Association, are all members of the Eastern Lake Ontario Dune Coalition.

North Pond Inlet Management Study Area

This section provides an overview of the physical features of the North Pond Inlet Management Study Area (IMSA) within the larger Eastern Lake Ontario Dune and Wetland System (DWS) in 2017.[4] The IMSA is defined for the purposes of the North Pond Resiliency Project as coincident with the North and South Ponds Resource Area described in the 1989 report *New York's Eastern Lake Ontario Sand Dunes: Resources, Problems and Management Guidelines* and the 2007 report *New York's Eastern Lake Ontario Dune and Wetland System: Guidelines for Resource Management in the 21st Century.* For a more detailed description of conditions in the DWS, the reader may refer to those two reports, known as the "Dunes Reports."

Eastern Lake Ontario Dune and Wetland System

To summarize, the Eastern Lake Ontario Dune and Wetland System is an ecological system of inter-related parts—a unique and valuable natural area in the coastal zone of New York State and the larger Great Lakes—St. Lawrence River system. On the eastern shore of Lake Ontario, the DWS is a natural blend of barrier beaches and sand dunes, freshwater wetlands, creeks, and embayments, nearshore lake waters, underwater lands, and the mainland shoreline. The beaches and dunes form a "coastal barrier" protecting the landward features and resources—including extensive and relatively undisturbed wetlands and other aquatic habitats—from the direct effects of Lake Ontario's waves, currents, and high water. Among the sand dunes are distinct areas of "high" dunes that rise 50 to 70 feet above the beach. These dunes are described as the largest in the state and second largest (behind those on Cape Cod, Massachusetts) in the northeastern United States.

The dunes and other coastal resources of the DWS provide vital natural functions and values as well as opportunities for recreational, residential, and commercial uses. The system's living resources—its plants, fish, and wildlife—are significantly diverse, abundant, and productive.

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4 Some of the information in this section is from the 2007 report *New York's Eastern Lake Ontario Dune and Wetland System: Guidelines for Resource Management in the 21st Century* which includes descriptions of: natural processes affecting the DWS, including, but not limited to, wind, waves, storms, and fluctuating lake levels; its natural history; and the four major "resource areas" traditionally recognized within the DWS.

On the north, the DWS is bounded by Black Pond; on the south by the Salmon River. To the east, New York Route 3 (part of the New York State Seaway Trail) follows the Lake Ontario shoreline and helps to frame, for management purposes, an easily recognized eastern boundary for the system. Offshore in Lake Ontario, the DWS includes the indeterminate zone of littoral sediment transport affecting the shoreline, a zone influenced by fluctuating lake levels and other considerations. The Lake Ontario shoreline of the DWS is slightly more than 16 miles long measured between the Black Pond outlet on the north and the main (south) jetty at the mouth of the Salmon River and Port Ontario Harbor on the south.

For planning purposes, four major "resource areas" have been identified previously in the DWS. These areas were first described in the 1989 Dunes Report and are now well recognized by resource managers and others concerned with use and conservation of the DWS. The resource areas are in large part defined, from north to south, by the substantial aquatic and barrier beach environments associated with Black Pond, Lakeview Marsh, North and South Ponds, and Deer Creek.

Inlet Management Study Area Description

In the central part of the Dune and Wetland System, the North and South Ponds Resource Area centered on North Pond encompasses the largest barrier-pond ecosystem on the New York shore of Lake Ontario. The North Pond Inlet, the most dynamic feature of the DWS, is included in this resource area. The two ponds are hydrologically connected and outflow of both ponds to Lake Ontario is through the inlet. Accordingly, for the purpose of the North Pond Resiliency Project, the Inlet Management Study Area encompasses the well-recognized North and South Ponds Resource Area.

As so defined, most of the IMSA is in the Town of Sandy Creek in Oswego County; the northernmost part is in the Town of Ellisburg in Jefferson County. The IMSA's Lake Ontario shoreline measures about 5.7 miles from the outlet of South Colwell Pond near Montario Point on the north to Rainbow Shores Drive on the south. This distance is about 36% of the total lake shoreline in the DWS.

The Montario Point area, which includes lakeshore residential development as well as Cranberry Pond, is physically separated from the aquatic habitat of North Pond but is included in the IMSA due to the shoreline's direct connection to the north spit at North Pond (see below).

Figure 1: Inlet Management Study Area reference map

North Pond, also known as North Sandy Pond and Big Sandy Pond, has about 2,300 acres of open water with dense beds of submerged aquatic vegetation. The pond's maximum north-south length is almost 3.5 miles; its greatest width is 1.5 miles. The deepest areas of the pond are no deeper than 10-12 feet, but substantial areas of shoaling and submerged vegetation have effectively reduced water depths throughout much of the pond. The entire pond is part of the North and South Sandy Ponds Significant Coastal Fish and Wildlife Habitat Area designated by the State of New York.

Previous investigations as part of the Eastern Lake Ontario Sand Transport Study (ELOSTS) indicated that the pond is gradually becoming shallower due to sediment deposition from tributaries and the coastal barrier.[5] The pond is connected to Lake Ontario by the shifting North Pond Inlet flanked on both sides by barrier spits known as the north and south spits. These barrier formations contain extensive and well-developed sand dune formations, including "high" dunes on both the north and south spits.

Several creeks—Little Sandy, Blind, Lindsey, and Skinner creeks—drain into North Pond from the eastern Lake Ontario watershed. Sizeable areas of emergent wetlands have formed in the lower reaches of these tributaries and in small sheltered bays at the north (Renshaw Bay) and south ends of the pond. Portions of Little Sandy, Lindsey, and Skinner creeks are designated as Significant Coastal Fish and Wildlife Habitat Areas by the State of New York. These streams, among the few free-flowing, coldwater tributaries in the Lake Ontario coastal area, support naturally reproducing salmonid populations. The streams drain from forested headwaters and flow through rural, agricultural and residential areas before they enter the pond.

The length of the coastal barrier from Montario Point south to the North Pond Inlet, including the north barrier spit, is about 2.2 miles. The north spit, which has a maximum width of about 1,200 feet, contains some of the largest sand dunes in the DWS as well as sand flats near the inlet. In the northern part of the spit, seasonally occupied homes have been built in high, vegetated dunes. Further south, high dunes, some with steep, exposed slopes directly facing the lake, extend along the barrier for about three-quarters of a mile. The north spit also

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[5] The ELOSTS included a number of investigations conducted by personnel from New York colleges and universities, Environment Canada, and consultants to address: lake currents; sediment type, distribution, internal structure, and thickness in the lake and on the barrier beaches; size variation of sand on the lake floor and on the beaches; water level in North Pond; shoreline evolution; and carbon dating of sediments. The results of this work, supervised by The Nature Conservancy with funds provided by the State of New York, were presented in the 2002 report "Eastern Lake Ontario Sand Transport Study: Final Report on Sediment Transport Patterns and Management Implications for Eastern Lake Ontario." Although the ELOSTS was not able to address all initial research questions including questions related to shoreline change, it provided much useful information and an important basis for additional research efforts, including the North Pond Resiliency Project

includes the largest wind-caused dune "blow-out" in the DWS. South of the high dunes, the barrier flattens and narrows leading to the undeveloped sand flat, often over-washed by high water, north of the North Pond Inlet. The narrowest portion of the barrier on the north spit may well be the location on the North Pond barrier most vulnerable to being breached in the future as part of the natural process of inlet changes. A portion of the sand flat is state-owned and part of the Sandy Island Beach State Park (SIBSP).

The North Pond Inlet in its current location and the sand flats on either side of the inlet represent the most dynamic section of the coastal barrier in the DWS. Five different inlet locations since the early 1800's have been identified and are graphic evidence of an active history of inlet formation and movement on the North Pond barrier.

The south spit extends for about 2.25 miles from the existing inlet to and including the shoreline of SIBSP. The south spit includes residential areas in addition to the state park. Barrier widths range from about 300 feet to 1,200 feet. The wider sections of the barrier represent recurve spits and deltas associated with historical inlet locations that naturally filled with sand before they closed. The high dunes on the south spit also have steep, exposed slopes directly exposed to the Lake. The high dune area extends about three-quarters of a mile northward from SIBSP and contains mature forest vegetation.

That portion of SIBSP on the north end of the south spit was formerly known as the Sandy Pond Beach Natural Area or Sandy Pond Beach and previously managed by the New York State Department of Environmental Conservation (DEC). Now managed by the New York Office of Parks, Recreation, and Historic Preservation (OPRHP) the former natural area encompasses about 77 acres, including the area actively managed as a bird sanctuary on the sand flats adjacent to the inlet at the north end of the south spit.

This area is managed by OPRHP for the purposes of: a) preserving and restoring sand dune resources; b) protecting vital habitat for migratory and breeding birds; and c) providing public recreation opportunities compatible with conservation goals. A dune walk-over allows visitors who arrive by boat at the traditionally popular "boat beach" on the North Pond side of the natural area to cross over the dunes to reach the Lake Ontario shore. This area is part of the DEC-designated Eastern Lake Ontario Marshes Bird Conservation Area.

In 2015 a pair of piping plovers nested in this area—the first nesting occurrence of this bird on the eastern shore of Lake Ontario in more than 30 years. OPRHP, with assistance from the U.S. Fish and Wildlife Service and other groups and agencies monitored the area and implemented measures to protect these birds whose Great Lakes' population is listed as "endangered" pursuant to the federal Endangered Species Act. Nesting piping plovers were also observed in 2016.

Seasonally occupied homes have been built on the south spit, south of the bird sanctuary. While there is no formal road access to these homes, access is possible by small boat from the pond side of the coastal barrier and by walking or driving on the beach on the lake side when the lake level is low enough to permit such access. In an effort to protect property against erosion, some home owners have added riprap and gabion structures at the base of the high dunes.

SIBSP is a major recreational attraction in the eastern Lake Ontario region and one of two state parks (Southwick Beach State Park to the north is the other) in the DWS. The park, managed by the OPRHP in the OPRHP's Central Region, provides opportunities for swimming, picnicking, fishing, nature observation, environmental education, boating, and other recreational activities. Park facilities include a beach pavilion with a community room and bath-house; picnic areas; parking areas; and a "car-top" boat launching area for access to North Pond. Sand dunes in the park have been restored and protected by the OPRHP. Vehicle access to the park is from County Route 15 off Route 3.

Adjoining the park is a substantial state-owned sand dune restoration site managed by the DEC where a large dune "blow-out" previously encroaching into North Pond was stabilized and remediated in conjunction with establishment of the park.

South Pond, also known as South Sandy Pond, contains about 300 acres of open water separated from Lake Ontario by a narrow barrier approximately one mile long developed with seasonally occupied homes near the privately-owned Rainbow Shores Campground. On the south, the pond adjoins an approximately 220-acre wetland that provides habitat for rare plants and exhibits bog characteristics unique in the eastern Lake Ontario region. The wetland is part of The Nature Conservancy's Rainbow Shores Preserve. The pond and wetland are both part of the North and South Sandy Ponds Significant Coastal Fish and Wildlife Habitat Area designated by the State of New York.

There is no direct exchange of water between South Pond and Lake Ontario but the pond is connected to North Pond by a shallow and narrow channel navigable by small boats. The coastal barrier separating South Pond from Lake Ontario is generally 300 to 400 feet wide. The Sandy Island Beach residential area is located on the northern part of this barrier and the Rainbow Shores residential area and campground are found on and near the southern part. The North and South ponds provide vital habitat for both pond and Lake-based fisheries. The abundance and diversity of the fisheries resources in the two ponds provide significant opportunities for recreational fishing. Important habitat for many wildlife species is also provided, with the highest diversity occurring in the largest undisturbed wetland areas in each pond. The coastal barrier between the ponds and Lake Ontario is an integral part of the fish and wildlife habitat.

The barrier spits are heavily used as feeding and resting areas by large numbers of migrant shorebirds and the sand dunes provide valuable resting areas for many migratory bird species. The abundance and diversity of bird species occurring in the IMSA is remarkable and the area is regarded as critical avian habitat and one of the prime bird watching locations in the Great Lakes coastal region.

Excluding the above-noted state-owned property on the coastal barrier, virtually all the land surrounding the two ponds is privately owned and much of it is developed for seasonal and year-round residential use. North Pond, because it is protected from the open waters of Lake Ontario by the coastal barrier, provides sheltered conditions for recreational boating facilities, including seven several privately owned commercial marinas that provide boating access to the pond in 2017.

The shallow and shifting channel through the North Pond inlet provides navigation access to and from the pond and Lake. This channel is subject to natural and ongoing shoaling caused by the longshore movement of sand, changes in lake level carrying suspended sand into the pond, wave overwash, and recurved shore formation.

A substantial deposition shoal known as the Inlet Shoal has formed in North Pond between the inlet and Carl Island. Formed by the movement of sand through the inlet and into North Pond by wind and wave action, the shoal has significantly reduced navigability (water depths in the shoal were less than one foot in many locations when measured in 2016) and water circulation in the pond.

In an effort to maintain a safe navigation connection between the pond and Lake, the channel was dredged by Oswego County in 2000, by the private Sandy Pond Channel Maintenance Association several times in the period 2004-2014, and by the Town of Sandy Creek in 2016. Aids to navigation marking the channel are placed by the OPRHP.

Shoreline Aerial Surveys

To gain an alternative perspective and assess conditions during the study, three aerial photography surveys were conducted. All flights originated at Watertown International Airport using Mike Williams flight service. For each flight, the main photography collection was done by Geoff Steadman using a Nikon D3300 digital camera and backup photography was done by Tom Hart using a Motorola XT1254 android phone.

Oblique photo surveys were performed on: 17 September 2015; 09 August 2016 and 12 June 2017 with 567, 221 and 730 photographs respectively. GPS tracks or simulated tracks were made for each flight to document the location of photographic coverage. The purpose of the first flight was to document conditions at the time of the study initiation. The second flight in 2016 was timed to capture the dredging operation performed at that time, while the last flight in 2017 documented high-water conditions. NYS Sea Grant provided additional funding to assist in collection of the 2017 overflight which was extended to cover from Stony Point to Braddock Bay west of Rochester. Each set of photos is intended to be made publicly available after completion of this study via internet access. Flight lines for each overflight within the Eastern Lake Ontario Dune region are shown for reference (Figure 2).


Figure 2: Flight Lines for 2015 (left), 2016 (middle) and 2017 (right)

Multiple aerial photography collections add to the body of information collected over the last 30 years for each of the reports addressing the Eastern Ontario Dunes. These most recent photography sets provide good reference points for a dynamic system undergoing continuing evolution (Figure 3).

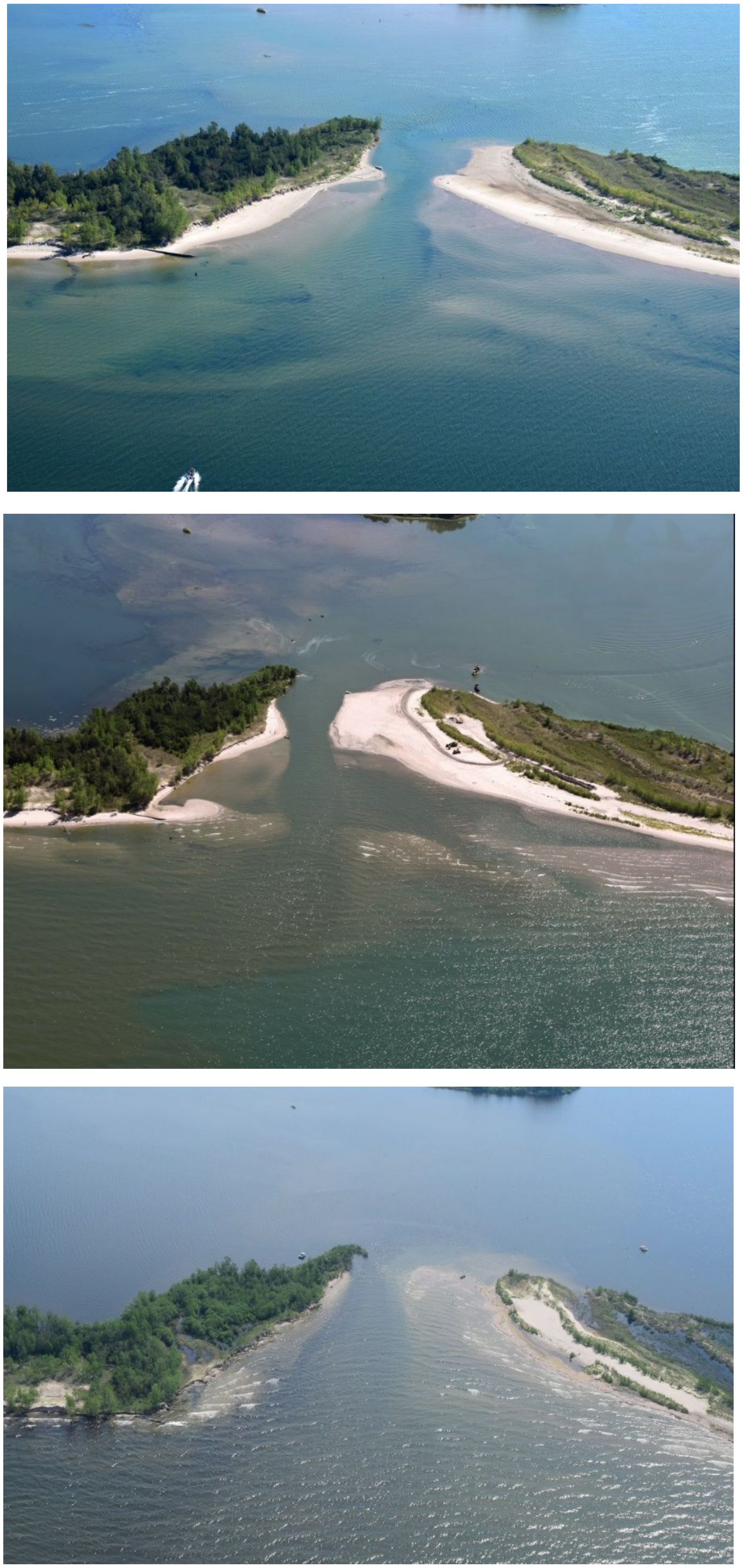


Figure 3: North Pond Inlet in September 2015 (top), August 2016 (middle), and June 2017 (bottom)

Focus on Human Use

An essential element of ecosystem-based management is integration of human use within the study and management considerations (New York State Department of Environmental Conservation 2014). For both North and South Sandy Pond, life in year-round residences and seasonal camps along with water recreation focused on accessing beach front on Lake Ontario have defined the predominant local uses for over a century.

Of the over 1300 parcels located on the Sandy Pond side of Highway 3, and Ouderkirk, Tryon and Rainbow Shores Roads, 310 are listed as single-family residences and 589 are listed as seasonal residences in the town assessor's property roll as represented in the Oswego County assessment roll (Figure 4).

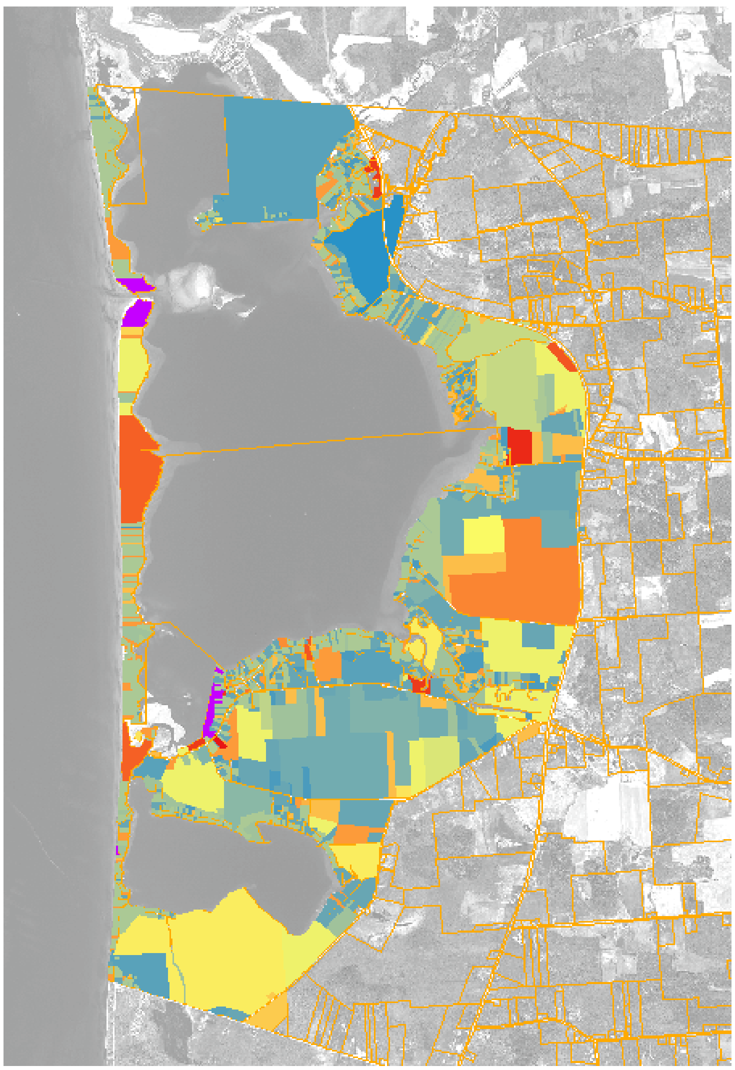


Figure 4: Land uses by property near North and South Sandy Ponds (Oswego County Tax Department).

More complete analysis of land use in the Town, including agricultural uses is available in the Town's draft master plan (Town of Sandy Creek 2013). Those parcels with direct water access to one of the Ponds or Lake Ontario include 150 one-family residential lots, 30 manufactured housing units, and 423 seasonal residential lots (

Figure 5). These parcels were selected using available flood zone maps and excludes large parcels coded as public and underwater lands.

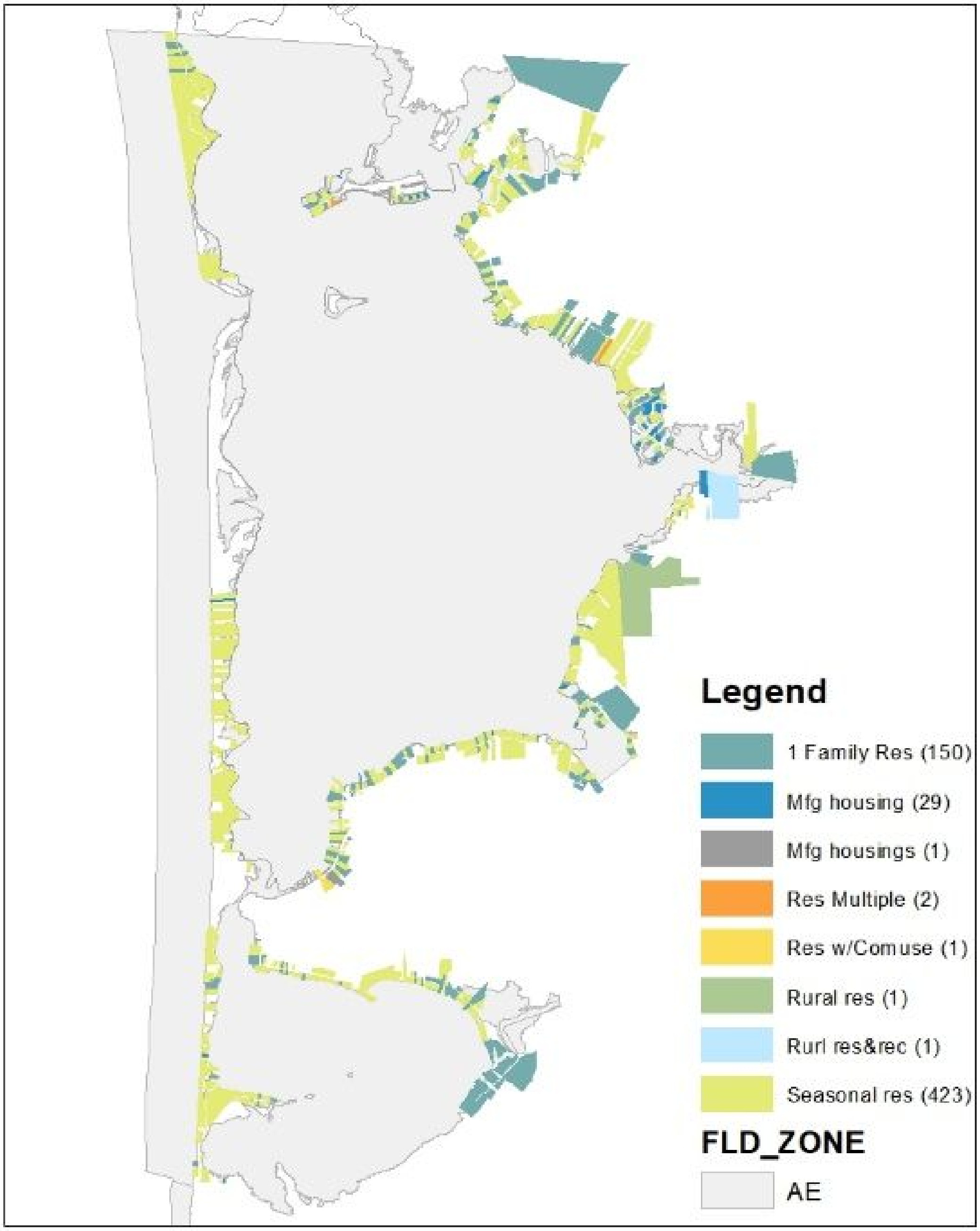


Figure 5: Land uses immediately adjacent to North and South Sandy Ponds.

The Town identified household sanitary waste treatment as a significant issue. Many of the shore-adjacent parcels either have no treatment (55-gallon barrel holding containers) or septic systems of unknown character. Ten-percent of Town survey respondents indicated that they have no treatment of household sanitary waste and 58% of respondents support the need for an inventory of failing septic systems. The Town draft plan indicates the need to focus on this issue with public support. Water quality is an important issue in the Ponds and elevated levels of phosphorous nutrient above State pollution levels have been documented in Sandy Pond (Makarewicz 2010). New York State DEC and US EPA provide information on water quality impairment for North Sandy Pond. The 2012 North Pond report from EPA's My Waters Mapper lists four causes of impairment (Algal Growth, Mirex, Phosphorous and PCBs), while the 2014 report narrows the concerns growth to phosphorous, dropping two Lake-wide issues (Mirex and PCBs) and algal growth (which should be added again in the next revision). The listed probable sources are habitat alteration, on-site treatment systems and other sources (U.S. EPA 2014). Algal blooms are a continuing issue and are indicative of elevated phosphorous levels. In both 2015 and 2016, blue-green algae blooms were documented in the southern half of North Sandy Pond in overflight photography taken for this study (Figure 6, Figure 7, Figure 8). Sources for phosphorous are likely both near shore residences and camps without septic treatment and agricultural practices in upstream lands. Aerial photography clearly shows the hydrologic separation of the waters north of Carl Island and the inlet shoal from the rest of the Pond, even with light winds from the south in 2015.

Figure 6: Blue-green algae bloom limited to the south end of Sandy Pond, September 2015

Figure 7: Blue-green algae bloom limited to the south end of Sandy Pond, August 2016

Figure 8: High water level in June 2017 with no evidence of algal bloom. Direct comparisons with 2015 and 2016 conditions are not possible as this image preceeds those by two months.

Recreational boating is a substantial human use in the study area, complementing the approximately 600 residential homes and seasonal camps near and along the shoreline. Marinas and combined marina, RV camping and mobile home businesses are significant means of accessing the Ponds and Lake. There are at least eight marina businesses or private clubs providing approximately 400 slips. Marinas all have boat launch and marine facilities such as fuel and boat services.

Marinas and an estimate of slips are as follows: Reiter's Marina (20 slips); Seeber Shores Marina and Campgrounds (40 slips); Greene Point Marina & Mobile Home Park (80 slips); Burt Goodnough's Marina East (20 slips); Brennan's Bay (60 slips); Bayview Marina (50 slips); Sandy Pond Marina (100 slips); Jones Marina (40 slips).

Most residences on ponds include docks and boats. A shorefront parcel normally has its own dock - a lot without a dock is an exception. Boats berthed at shoreline residences may add another 600 vessels to the 400 from marinas. How many boats launch at marinas (all have for fee launch services) or at the State boat launch was not determined, but with 7 marinas and one large capacity state launch, an additional 50 boats would be a conservative estimate for busy boating times. In addition, boats may transit from Salmon River (6.3 miles to the south) or from Stony Point (7.8 miles to the north), to access Sandy Pond or Lake-fronting beaches depending on wave conditions.

Pond depth is a limiting factor for boating within the Ponds itself, with deeper draft boats having to avoid shoaled areas, depending on lake level and season. Smaller numbers of sailboats, paddle craft, jet skis and small boats use the pond directly, however the main boating use is accessing the inlet and beaches fronting the Lake. Boaters access beaches at boater's beach on the backside of the southern barrier or along inlet beaches when wave conditions do not allow direct lake access through the inlet channel. The amount and importance of recreational boating cannot be understated, as fair-weather days attract many boaters to the pond and lake beaches (Figure 9). The maximum boating use occurs on holidays and during a loosely organized "Party on the Pond" event documented in several videos (Figure 10, Figure 11, Figure 12).

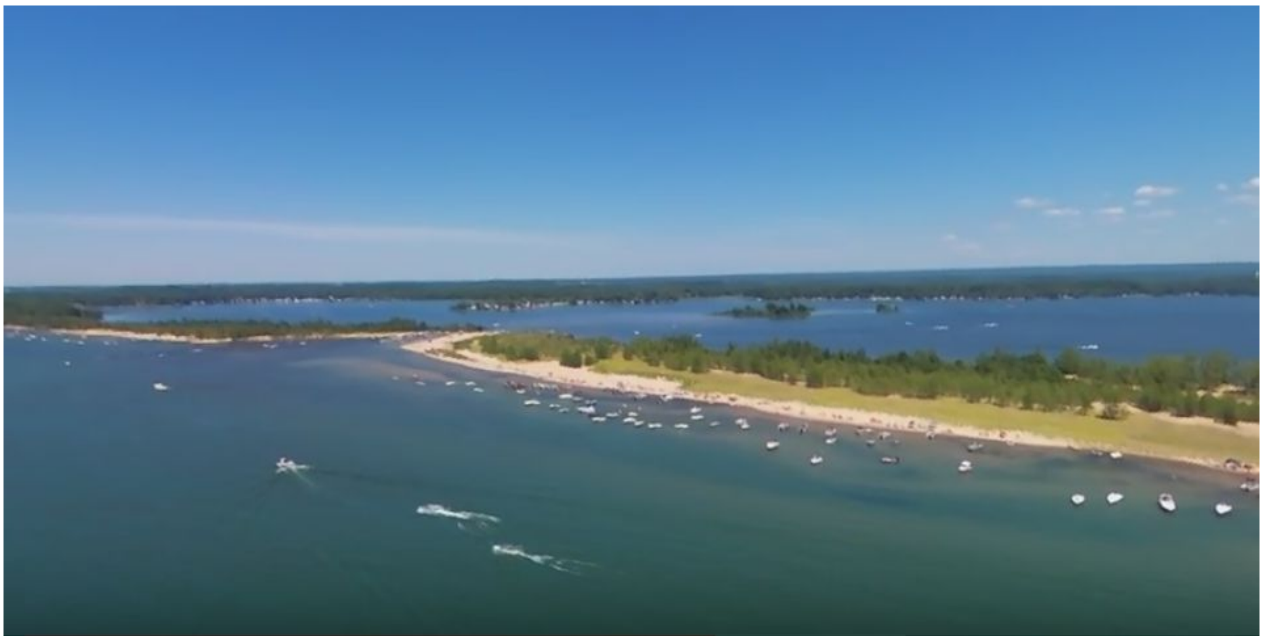


Figure 9: Typical Sandy Pond beach boater use, July 2016 (Youtube still from Modus Operandi https://www.youtube.com/watch?v=_cg6phePc2U)

Figure 10: Sandy Pond beach party, July 2015 showing fair-weather Lake-side beach mooring (Youtube still image from S. Prockup; https://www.youtube.com/watch?v=h6aib0IWvLw)

Figure 11: 2016 Sandy Pond party (Youtube still image capture from S. Procock https://www.youtube.com/watch?v=8rEJ0EkKV0U)

Figure 12: 2016 Sandy Pond party access with higher wave state on Lake Ontario (Youtube still image capture from S. Procock https://www.youtube.com/watch?v=8rEJ0EkKV0U)

Natural Resources Focus

Natural resources have been well-documented in the areas. North and South Sandy Ponds were designated as a Significant Coastal Fish and Wildlife Habitat in 1987 under the NYS Department of State's Coastal Management Program based on information and evaluation by the NYS DEC Habitat Unit the ((NYS Department of State 1987). North and South Sandy Ponds were recognized as the largest barrier-bay ecosystem on Lake Ontario, with several vulnerable species including Common Tern, Least Bittern, Black Tern and historical records for Piping Plover, and endangered species. Fish spawning and nursery values were also noted, along with values to migratory bird species. Human uses of natural resources included recreational fishery and birdwatching. Tributaries flowing to Sandy Pond have also received State designation under the same program based primarily on their value as salmonid habitat (NYS Department of State 1987)

In 2015 and 2016, Piping Plovers returned to the Eastern Shore of Lake Ontario for the first time since last successfully nesting in 1984. The preferred nesting habitat was in the recently formed south spit beach area above wave action heights. Specific nesting sites were on elevated areas of beneficial disposal sands from prior inlet dredging in 2013. Prior to Piping Plovers arriving the area was established as a bird sanctuary with boundaries set each year based on beach form and bird use. The main purpose was to provide feeding and loafing areas for migrating shorebirds and Common and Caspian Terns. The area favored by Piping Plovers gave new meaning to the bird sanctuary in 2015, with string fencing demarking the area and a substantial public education program administered by NYS Parks and Recreation Department. In 2016, one pair of piping plovers nested, but the chicks were lost to fox predation in early July as reported by Irene Mazzochi of NYS DEC (ELODC 2016). Substantial documentation exists for efforts by NYS Parks and Recreation, NYS DEC, Audubon New York, US F&W Service and others regarding management and protection of Piping Plovers at North Sandy Pond's Sandy Island Beach Park and is not reviewed further in this report, save for discussion of inlet dredging plans.

More recent evaluation of natural resources was conducted in association with proposed inlet dredging in 2016. Specific to the area near the inlet, the recently formed lands comprised of wind-borne dunes, dredged material placement sites, exposed bare sand between dunes, and near shore flats all with demonstrated habitat value. What is interesting is the relatively high value of recently formed habitat in this energetic and changeable environment. That is, the dynamic areas tend to have the higher values. Great Lakes Dunes and Sand Beach are in fact either critically imperiled or imperiled with less than 20 occurrences in New York State per the Natural Heritage Program. The sand dune willows that stabilizes the dunes and is abundant in this area is a state endangered plant species that occurs in less than 12 locations statewide. A rare tiger beetle is also found in the bare sand areas (NYS Parks, Recreation and Historic Preservation 2017). Each of these natural resources requires protection and management that may include habitat creation or alteration, protection from human and predator disturbances, and protective time windows to reduce disturbance. What is particularly challenging is the highest habitat values are also adjacent to the highest human recreational values on the beach and inlet. Locations of sand fencing mark the limits of the bird sanctuary in 2015. Though some may find the juxtaposition of these competing uses unacceptable, the compliance and willingness of boaters and beach users to observe and protect the bird sanctuary is both remarkable and commendable (Figure 13, Figure 14).

Figure 13: Locations of sand fencing mark the limits of the bird sanctuary in 2015.

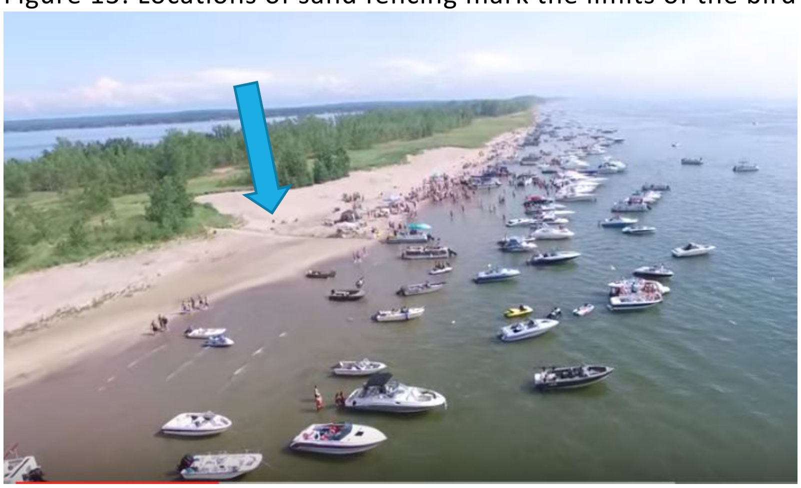


Figure 14: The southern sand fencing shown in Figure 13 illustrates the proximity of human use to the sanctuary during a busy boating event. (Youtube still image from S.Prockup; https://www.youtube.com/watch?v=h6aib0IWvLw)

Lake Levels and Lake Level Controls

A prevailing notion is that Lake Ontario water levels have been solely under control of Plan 1958D since 1960 and that prior to this time, lake levels were under only natural flow conditions. Although variation in water levels was reduced under 1958D control, lake water levels had been substantially altered before this time.

"The natural regime of the outlet from Lake Ontario has undergone changes, at least since 1825. By 1850, work in the St. Lawrence River provided a minimum channel depth of 9 feet from the Atlantic Ocean to Lake Ontario. The natural control of Lake Ontario outflows was at the Galop Rapids, located on either side of Galop Island, approximately 70 miles downstream from Kingston, Ontario. Man-made changes to the natural control began in 1876, with dredging in the Canadian Galop Rapids channel (completed in 1888). Changes continued with the realignment of the Galop channel (from 1897 to 1901), improvements to the North Channel and construction of the Gut Dam (from 1903 to 1908). The Gut Dam was removed in January 1953." (USACE ND).

The reason for removal of the Gut Dam was due to a period of high water level in 1951-1952, with associated erosion and property loss. An international tribunal was established to determine appropriate compensation for property owners. Of interest is the nature of the lawsuit wherein, in

"the Gut Dam Claims, allegations by the United States that the Canadian-built Gut Dam had caused damage to U.S. property, were arbitrated in 1967 and 1968. The Lake Ontario Claims Tribunal settled the arbitration in favor of the United States, finding: (1) that Canada, in its written correspondence, ensured compensation for any U.S. citizen whose property suffered damage due to the construction or operation of the Gut Dam and (2) that Canada's guarantee of compensation applied to the period when the disputed damage occurred" (Trigueros 2012).

The period of high water from 1929-1930, may have also been exacerbated by the Gut Dam if the high waters of 1951-1952 were attributed to the Gut Dam.

Beginning in 1954 and completed in 1959, the Saint Lawrence Seaway and Power project conducted

"extensive channel enlargements, to widen and deepen the navigation channel to 25 feet for the entire length of the river. The channel enlargements significantly increased the outflow capacity of Lake Ontario; control dams were designed to cope with the worst known (as of 1955) floods and droughts, as well as to compensate for the increased flow capacity." (USACE ND).

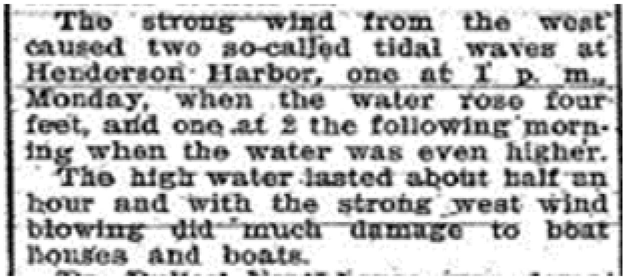
The International Joint Commission implemented Plan 2014 in January 2017. Per the IJC, "Plan 2014 is designed to provide for more natural variations of water levels of Lake Ontario and the St. Lawrence River that are needed to restore ecosystem health. It will continue to moderate extreme high and low levels, better maintain system-wide levels for navigation, frequently extend the recreational boating season and slightly increase hydropower production. More year-to-year variation in water levels improves coastal health." (International Joint Commission 2017). Beginning in spring 2017, lake levels reached record highs due to record precipitation levels in the Lake Ontario basin and unusual ice cover conditions.

The IJC offered the following explanation in a letter to Governor Andrew Cuomo (International Joint Commission 2017).

"The primary difference between last year and this is that, unlike last year's near average water supplies, from April 2017 onward, this year's supplies to Lake Ontario in April and May were record setting. Combined April and May supplies set a new record high for any two consecutive months, while last month's supplies also set a new record high for May.

The capacity to forecast such conditions currently does not exist. Additionally, weather conditions restricted winter outflows from Lake Ontario and prevented the Board from lowering lake levels prior to spring. Both Plan 2014 and Plan 1958D allow the Board to increase outflows from Lake Ontario once a solid ice cover is formed in the St. Lawrence River. However, it is critical to reduce flows when the ice cover is forming to prevent ice jams that could severely restrict Lake Ontario outflows for an extended period of time. During the winter of 2017, due to alternating periods of cold and mild temperatures, ice cover formation began an unprecedented five times. However, a solid stable ice cover that would withstand higher outflows never formed. The International Lake Ontario-St. Lawrence River Board capitalized on the greater flexibility in Plan 2014 to release more water when ice was not forming in January. That said, the difficult and fragile river ice conditions in February and March hindered the Board's ability to release additional water before the rains of April and May set in and the record setting Ottawa River freshet began. Even so, the Lake Ontario level on March 17, 2017 was within a half inch of the level recorded on the same date in 2016. The difference between the years is not because of the plan implemented, but because of the inputs received since mid-March."

Lake levels lead to either long-term flooding or low water conditions depending on the amount of precipitation and evaporation from the Great Lakes basin and to the Lake Ontario basin. In addition to long-term, multi-year periods of high or long water, seasonal changes occur with low water typically in January followed by spring runoff and high water and then a gradual reduction through fall. Water fluctuations have short-term changes too, depending on prevailing winds and whether the lake is thermally stratified leading to either external or internal seiches. External seiches lead to the reports of "tidal waves" with attendant changes in lake level of 4 or more feet (Figure 15). Strong storms can also cause temporary flooding and are often the cause significant shoreline erosion that can lead to breaching in combination with high lake levels. The frequency of storms is highest in fall and early winter, with highest storm-based erosion rates typically occurring prior to ice formation on the Lake. The topic of lake elevation levels is exhaustively covered in many publications not reviewed for this report.



The strong wind from the west caused two so-called tidal waves at Henderson Harbor, one at 1 p. m., Monday, when the water rose four feet, and one at 2 the following morning when the water was even higher.

The high water lasted about half an hour and with the strong west wind blowing did much damage to boat houses and boats.

Figure 15: Wind-driven large seiche record from 1929 (SCN, 04 April 1929)

Pond levels, Ice Formation and Inlet Ice Dams

In addition to those associated with high lake levels, flood impacts occur from ice formation and ice dams blocking the inlet. Periods of inlet change or when inlets are shallow and shoaled may have a higher frequency of ice dam formation. The process appears to be dependent on formation of ice in late December and early January prior to extensive ice pack cover, combined with a drop in lake level in winter. The formation of two new inlets in 1929 were associated with a period of flooding in January of 1930 (SCN, 09 Jan 1930) where high January thaw runoff at Little Sandy Creek was noted along with water levels higher than the marsh at the Creek's mouth. More recently, Sandy Pond water levels were elevated during an ice dam in January 2014. Sandy Pond levels rose 4 feet to near IGLD 249.0 in one week. Multiple plans to remove the ice dam were being discussed at the time of the flooding ranging from use of heavy equipment to explosives. The lake level during this flood event was near 244.9 for over a four-foot head or level difference between the pond and Lake.

In North Sandy Pond on February 15, 2016, pond levels were rising and rapidly rose 1 foot by the next day, followed by another foot on February 17, peaking on February 18 at 246.9 feet IGLD. On February 19, the water level dropped one foot, then another 8 inches the next day and 3 inches on February 22nd (Ron Fisher, pers. communication 3/12/2016). This record illustrates the rapid rise in pond level that can occur with ice dams.

Winter flooding impacts include loss of access and road closures, flooding structures and associated property damage, flooding septic systems or sewage storage containers, and potential breaching of beach barrier from backside hydraulic forces.

Navigation and Inlet Dredging

History of Dredging

Each time an inlet approached the end of its hydrologic lifespan, boating access became unreliable due to shallow depths. In two cases, dredging projects were attempted to address inlet shoaling in the past (Figure 16).

1896 Dredging.

The inlet located at the south end of North Pond at Wigwam Cove, was prone to shoaling in the mid 1890's and an initiative to dredge a new channel ensued. Dredges arrived and entered the pond by digging through the existing channel. Once within the Pond, the "work of opening up the wind gap opposite Blind Creek Cove will be entered upon in earnest" (SCN, 14 May 1896). The work was supported by a grant from the State legislature for $10,000 to create a harbor of refuge. The dredged inlet quickly filled in and the inlet remained at the outlet at Wigwam Cove until a new inlet was to form in 1929, 33 years later.

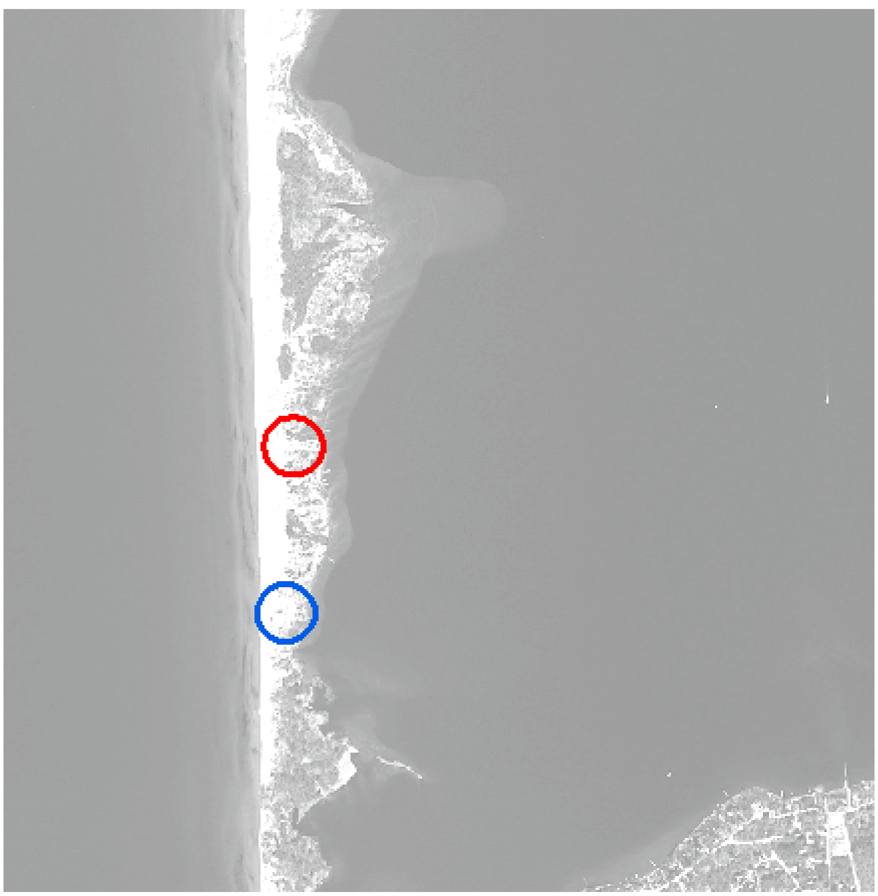


Figure 16: Locations of historic dredging projects: 1896 (bottom site, blue), 1950 (top site, red).

1950 Dredging.

Low waters in 1950 led to a plan to dredge a new inlet south of the 1938 inlet using private funds. $3500 was raised to dredge 4,460 yards of sand in the effort using two excavators. Contrary to the assertion that Dr. Groman's cruiser would be the first to pass through the new channel, a speedboat immediately raced through the channel as soon as it was open (R.Groman, pers. communication). A picture of the dredges in operation is available in the publication "Sandy Pond Memories II" (Cole ND). By October 1950, the new inlet had filled (Figure 17).

Dredge Starts Excavation of New Channel

Dredging operations have started on the proposed new channel from Lake Ontario into Sandy Pond 3,000 ft. south of the present channel, on land donated by Perry A. Bartlett, of Sandy Creek. Donald M. Page is in charge of operations for the A. S. Wikstrom Co. of Skaneateles, who are doing the job. Two shovels, one operating from a barge and the other from the sandbar, are now at work.

A total of 4,860 yards of material will have to be excavated. Donald M. Page, of the Wikstrom Company, flew over the area on Friday, July 21st, and found that there were three sand bars on the lake side extending approximately 500 feet into the lake. These were not taken into consideration on the previous estimate, as they could not be seen except from by air. Mr. Page flew over the area ten times, at an altitude of 100 feet, thoroughly examining the proposed site.

As much of the digging as can be done from dry land will be done by a clam; and the rest of the dredging, out in the water part, will be done by a self-propelled dredge that is coming from Brewerton and is expected to arrive today. The dredge will work on the lake side, unless the water is rough. In that event, Dr. Groman will pilot the dredge through the old channel into the pond, and the work will be done on the pond side.

Two Shifts Working

There will be two 10-hour shifts working. The night crews will be operated under powerful lights on a truck lighting system. The sand excavated will be bulldozed away from the channel, to prevent washings. The channel will have a 40 foot width, and be of a 10 foot depth, with a 20 foot bottom sloping to the 40 foot sides.

Speed limit through the channel will have to be limited to less than five miles per hour, to prevent the sand from washing back in. Arrangements are being made for a blinker light system to be installed through the Federal government. Movies of the dredging will be taken and televised over Station WHEN at a later date.

The work will be finished in less than ten days. Dr. Groman's cruiser "The Hayseed" will be the first boat to officially pass through the new channel, upon completion of the work.

Because of three sand bars on the lake side, the cost of the project has been increased from $2,000.00 to $3,500.00 Many of those who have contributed so generously will be contacted again for further donations to insure the completion of this dredging project.

At present, the project is undersubscribed $1,500.00. Please mail all pledges immediately to Dr. Groman at 1303 Midland Avenue, Syracuse 5, N. Y., or give them to Bob Alexander at Sandy Pond.

Figure 17: Dredging description for 1950 Channel (SCN, 27 Jul 1950)

Modern Inlet Dredging

Five dredging permits were issued to Oswego County between 1991 through 1999 with the last permit not being issued. The permit initiation in 1991 is likely in response to low water levels near 244.1 IGLD which would have restricted use of the channel. Dredging was not performed in 1991 due to the occurrence of a large storm that which opened the inlet sufficiently for navigation. The permit called for dredging to be done on barge-mounted backhoes with disposal of dredged material to be done in the nearshore area of the lake to avoid impacting bird nesting areas.

Lake levels returned to higher levels and no dredging project was completed until April of 2000 when the County used land-based equipment. Sand was placed in the near shore wave zone near the inlet or trucked offsite. Records available for this period are unclear although the options to conduct dredging with either barge-mounted or hydraulic equipment seems to be the last approved permit.

Beginning in 2003, with the return of low water and a large depositional shoal formed behind the inlet, interest in dredging the channel resumed. The Sandy Pond Channel Maintenance Association (SPCMA) was formed and was issued its first permit to dredge the channel by mechanical means. Records provided by SPCMA indicate dredging was performed by Cransville Aggregate as contractor between 06-09 Aug 2006 to remove $19,000 worth of sand (~8,000 cubic yards). Sand was permitted to be placed in the littoral zone, 1000' north and south of the inlet. In 2008, dredging was again performed by Cransville Aggregate between 01-08 Aug, removing 8,000 cubic yards of sand at a cost of $22,000. Sand was again to be placed in the littoral zone. Overall, it was observed that sand returned quickly to the inlet, although navigation was maintained for two seasons (K. Goodnough and Tom McLeod, pers. communications).

SPCMA purchased a small hydraulic dredge to reduce costs and have the flexibility to dredge as needed. Dredging was done by Town of Sandy Creek personnel and volunteers to operate hydraulic discharge pipes beginning 8 Sep 2010. Cost of the project was $6,352.50 for the Town operator and $15,000 for dredge cost. An estimated 4,000 cubic yards were placed on the north barrier lakeside shoreline. The project was repeated 15 Aug 2012 at a cost of $5,143 plus $15,000 to move 4,275 cubic yards, again to the beach on the north side of the inlet. Using the hydraulic dredge proved extremely labor intensive to move the hydraulic discharge pipe and the size of the dredge was deemed small for the task (K. Goodnough, pers. communication).
In 2013, a State grant of was obtained from Senator Patty Ritchie. Mechanical means were used to remove 1279 loads at 20 tons per load. Using a wet weight estimate for sand of 3000 lbs per cubic yard, the amount of sand removed and placed on the south barrier was likely between 16,000 and 17,000 cubic yards. Total project cost was $94,531.25.

In 2016, dredging started 08 Aug and used mechanical means to move between 6,000 and 7,000 cubic yards at a cost of $36,335.00 (Figure 18). A storm in September filled much of the inlet. The 2016 permit was the first accompanied by a comprehensive permit application for working on State Park lands and included a complete project plan with narrative descriptions, maps and operational conditions (Figure 19).

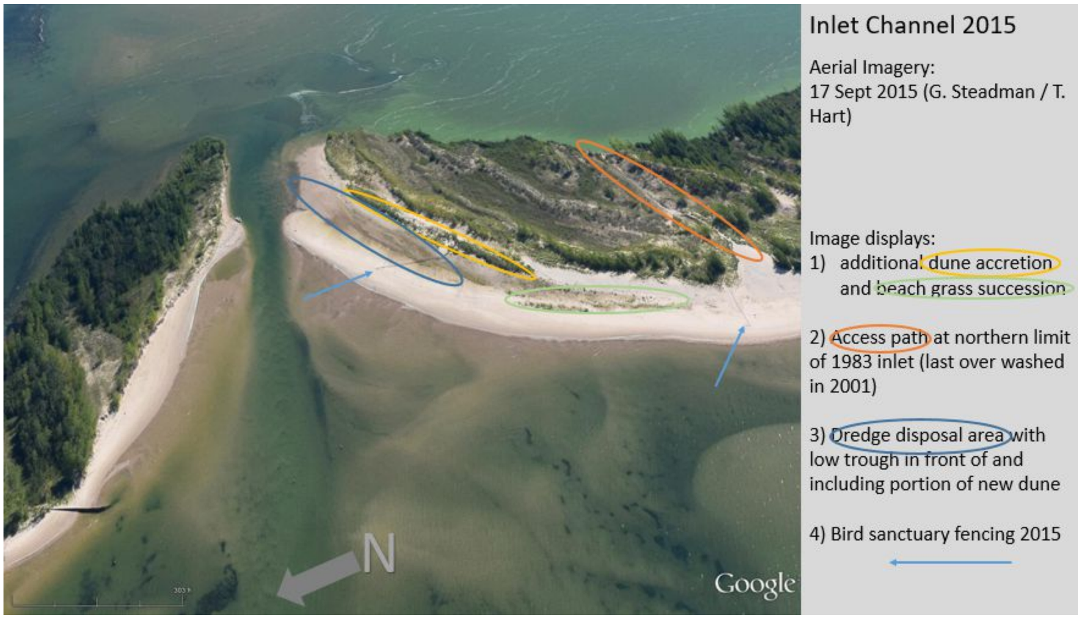


Figure 18: Inlet dredging plan map for 2016 project. Google Earth Pro used to display image only.

Figure 19: 2016 Inlet dredging operation

Analysis of Coastal Processes for the North Sandy Pond Barrier System

Background and Literature Review

A major focus of this study is an analysis of how much change there has been in the North Sandy Pond Barrier System and how can it be measured to better understand processes shaping and controlling the shore barrier landforms. The following section introduces shoreline change methods, coastal processes applied to the area, and reviews previous studies.

Shoreline change is often used as a method to better understand the dynamic nature of coastal environments and to establish quantitative measures of the extent of change due to erosion or accretion. Much of the focus of shoreline change analysis has been on open-ocean sandy shores of the United States. Indeed, a significant effort has been made by the Coastal and Marine Geology Program of the U.S. Geological Survey (USGS) in "conducting an analysis of historical shoreline changes along open-ocean sandy shores of the conterminous United States and parts of Alaska and Hawaii. A primary goal of this work is to develop standardized methods for mapping and analyzing shoreline movement so that internally consistent updates can periodically be made to record shoreline erosion and accretion" (USGS 2015). The result has been impressive in terms of the amount of coast analyzed, standardization of methods, measurement of accuracy, incorporation of LiDAR as new remote sensing data and in development of software to facilitate analysis. In additional to two dimensional measures of the location of shorelines, recent availability of LiDAR data allows for estimation of shorelines and modeling at different water levels and affords a potential opportunity for three dimensional or volumetric measurements of coastal landform change.

Shoreline change in the Great Lakes, however, has not enjoyed a comparable level of attention as open-ocean facing shorelines, nor have methods for shoreline analysis been standardized. The main difference between open-ocean facing shorelines and the Great Lakes shoreline is the lack of significant tides. Ocean facing shorelines are complex in that tidal cycles lead to different shoreline locations based on mean low water, high water, mean high water, mean high high water and vegetation lines (NOAA 2016). On the Great Lakes, water level changes in mean lake levels, post glacial changes based on isostatic rebound, and lake level control by engineered works (Zuzek, Nairn and Thieme 2003) (FEMA 2014) (Lewis, Blasco and Gareau

2005). Several authors itemize consideration of factors in Great Lakes shoreline change analysis including: “1) seasonal to decadal changes in mean lake levels, 2) yearly fluctuations in storm tracks and intensity, which ultimately determine the local wave climate that impacts the coast, 3) climatic influences on the presence or absence of shore fast ice during the winter season, and 4) the response of highly variable shoreline geology to these forcing functions” (Zuzek, Nairn and Thieme 2003).

Shoreline change analysis has been done in the Great Lakes in Michigan with an emphasis on recommended methods for conducting shoreline change analysis in a freshwater environment (Zuzek, Nairn and Thieme 2003). The study successfully used historic aerial imagery from 1938, 1955, 1968 and 1978 using traditional registration and stereoscopic measurement and 1999 imagery as a reference. Many of the recommendations were offered including consideration of mapping hazard zones, use of toe of dune and crest of dune delineations, and by including data from high and low water decades to address lake level variation. Selection of dune crests were difficult in some instances due to dense vegetation. Overall the study represents an advance in applying shoreline change methods to the Great Lakes, although none of the study area on Lake Michigan included dynamic barrier beach and embayment systems like North Pond.

In the context of Lake Ontario and North Pond specifically, the number of shoreline change studies is small in comparison to the relative uniqueness of the barrier beach complex (NYS Department of State 1989). The first study focusing on North Pond shoreline change divided the area into North, Central and Southern Reaches and calculated long term recession rates from 1874 through 1975 (Wier 1977). Weir set the groundwork for future analyses at North Pond, documenting sediment characteristics and movement, inlet locations, in addition to recession rates. Recession rates were calculated by optical measurement of shoreline locations on scaled ground survey maps and aerial photography without correction. Shorelines mapped were corrected to low water datum for Lake Ontario without documentation of methods used (elsewhere in the report, measurements of slope are presented for both above water and below water beach faces so that it can be inferred that some combination of slope and lake water elevation records were used to offset shorelines to low water datum of 74.01 m). Weir documented that the central reach, where new inlet formation was occurring at the time of his study, experienced the highest rates of recession at 1.33m/year between 1874 and 1975. Of considerable interest is that the time of Weir’s study coincided with a period of historically high lake level, providing valuable documentation of conditions at that time. Weir also summarizes broader geologic studies describing glacial and post glacial sand sources notably by Sutton in the early 1970’s.

Weir estimated area changes in north, central and southern reaches of the barrier system comparing 1874 shorelines with those in 1975, the last period of high water elevations. "Examination of the barrier shorelines indicated that there has been a large landward migration of the bay shoreline within the central reach, while the north and south reaches have exhibited negligible changes in the location of their bay shorelines. The central reach has experienced a net widening of 84 m since 1874, while the north and south reaches have undergone a net thinning of 72 m."

Weir notes that the overall change in land area of the barrier system was preserved in comparing the two periods. He further noted that the north and south relict dunes backing the active beach "present obstacles to the processes that widened the central reach" (Wier 1977). The next significant measurement of shoreline change analysis was conducted in relation to New York State Laws of 1981 and implementation of Article 34 of the Environmental Conservation Law, the Coastal Erosion Hazard Act (NYS CRR 2016). The Coastal Erosion Hazard Act (CEHA) regulates protection of Natural Protective Features (nearshore areas, beaches, dunes and bluffs) and establishes Structural Hazard Areas as a function of annual erosion rates in feet/year times 40 feet. To do so, annual erosion rates were calculated prior to passage of the law comparing shoreline positions between 1875 and 1979 (NYS DEC nd). The methods for conducting this analysis were documented by Stewart who derived erosion rate estimates from the original CEHA mapping, but noted that there were significant gaps in shoreline recession rate data for Jefferson/Oswego County Barrier Complexes data (USACE 1994).

Local colleges and universities played a role in studying the North Pond dune and beach complex. Additional mapping of the 1975 inlet was done by students engaged in courses at the State University of New York at Oswego, with subsequent mapping in 1978, 1982, 1983 and 1990. It is not clear whether that work survives, but a simple summary report is available documenting inlet change with historical local references (DelPrete 2000)

Gaining understanding of natural processes has been identified as a continuing need in management plans for the area prepared in concert with The Ontario Dunes Coalition ((NYS Department of State 1989) (Steadman 1997, Commission 1989). The need for additional research in shoreline change analysis, littoral processes and sand budgets, and inlet management led to studies by Colgate University in 1999 under contract to The Nature Conservancy (McClennen, McCay and Pearson 2000). McClennen et al. assembled a set of aerial images, attempting to compile representative data sets from 1938 forward for each decade representing the entire 17-mile stretch of the eastern Lake Ontario shore. The research team found working with the aerial imagery challenging, given the quality of photographs, derived scans, and lack of readily identifiable control points from available USGS topographic quadrangle maps leading to a limited set of control points (only four to five). Given the limitations of photography that was available at the time of their study and inaccuracies in registration, a quantifiable shoreline change analysis was not completed. The focus of the study shifted to interpreting land cover changes over each available decade with interpretations of observations of aerial imagery. The effort is notable for attempting to compile a record of imagery for potential shoreline change prior to the age of readily available digital orthoimagery and online availability of digital scans of historical photography.

A collaborative effort by Colgate University and Hobart and William Smith Colleges studying sediment transport for Eastern Lake Ontario was conducted (Woodrow, McClennen and Ahrnsbrak 2002). This work first presented evidence for a relatively stable shoreline through most of the Eastern Lake Ontario shore except for the North Pond Inlet location. The authors also noted that the inlets provide a sink for littoral sediments, removing sand from the longshore system and trapping it in the Pond. This observation was also made by Weir 25 years earlier with estimates of the increase in both area and volume of the barrier spits from 1875 to 1975, a reference not included in the Woodrow research. This study suggested that the sand source for the system is static, with no new sand being added. It was noted that the position of the beach/dune complex at North Pond has changed little over the last 150 years except for changes in inlet location, an observation not supported in current study. Finally, the authors note that the internal structure of the barrier system suggests that inlet-movements occurred much early than 150 years ago, and were normal.

While the Woodrow et al. study was concluding, a significant coastal engineering study by was initiated in support of the International Joint Commission Lake Ontario – St. Lawrence River water level regulation policy development (Baird 2006). Baird performed a series of site studies after setting the stage with comprehensive information on and modeling for water levels on Lake Ontario. Two of the specific study sites are within the current project boundary for this study: Eastern Lake Ontario Sediment Budget; and, North Pond Barrier Beach, Eastern Lake Ontario.

Eastern Lake Ontario Sediment Budget. The sediment budget work entailed comparison lakebed profiles based on a 1948 ship-based bathymetric survey and 2001 aerial topobathymetric LiDAR and bathymetric scans. This information was coupled with a high quality 2001 digital orthoimagery data set, representing a technological leap in data quality and availability that first became possible at the turn of the century. No overall measurement of the barrier system volume changes has been completed. Bathymetric analysis of the pond was, however, completed using a shore-parallel transect comparing 1878, 1948, and 2001 data (Figure 20: Bathymetry analysis for North Pond (Baird, 2006). The analysis that follows presents transect B profiles (Figure 21: Profile B comparison from 1878 to 2001 at North Pond (0 on the x-axis corresponds to south) (from Baird, 2006).

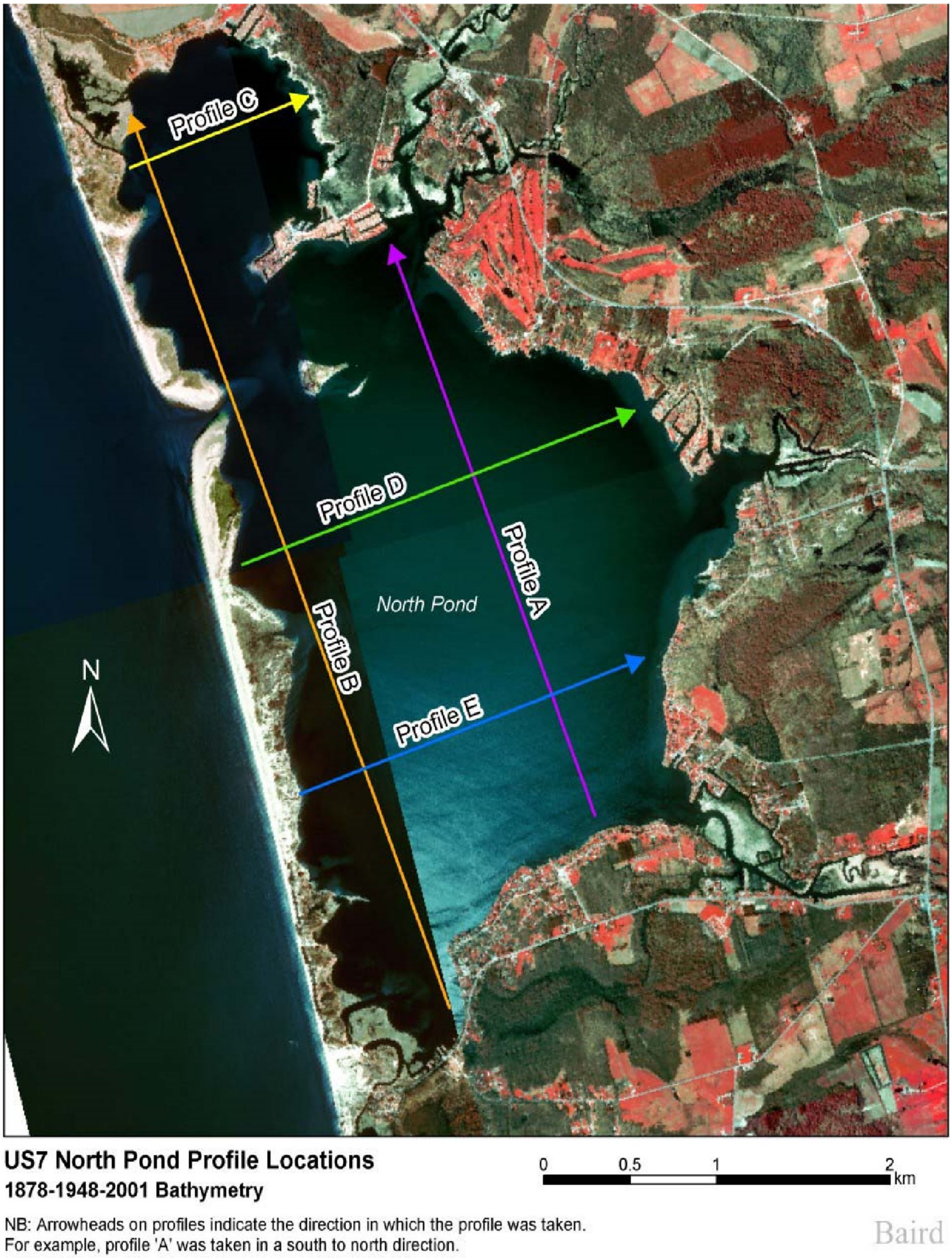


Figure 20: Bathymetry analysis for North Pond (Baird, 2006)

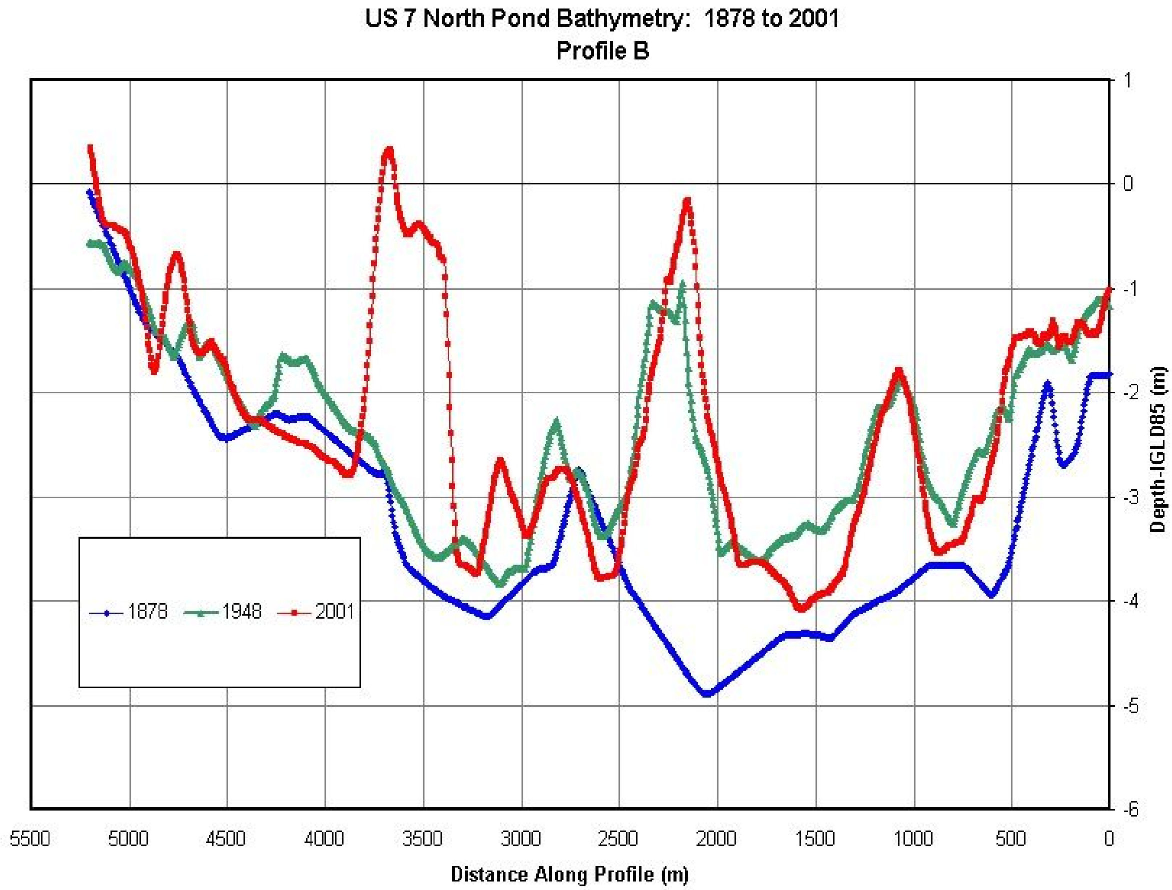


Figure 21: Profile B comparison from 1878 to 2001 at North Pond (0 on the x-axis corresponds to south) (from Baird, 2006)

"Based on the contours of the lake bottom, it appears the flood shoal for the inlet in 1878 was between 2,500 and 3,000 m on the x-axis." This statement is confusing as that location is also noted as being the inlet location in 1948. The following provides additional interpretation of the comparative bathymetric analysis from Baird:

"Sometime between 1878 and 1948, the inlet was located along the southern half of the barrier, likely just north of the large relic sand dunes along the current south barrier. This inlet location is documented by the flood shoal in Figure 21 between 800 and 1,300 m on the x-axis. In 1948, the inlet was located between 2,000 and 2,500 m on the x-axis in Figure 21. In Figure 20 this corresponds to the word "Profile" along the line for Profile B."

These statements probably should state that the data support an inlet being present north of the relict dune prior to 1878 as the inlet location was at the south end of North Pond (Figure 22). Weir also notes the location of an inlet prior to 1829 near the north end of the high dunes in an 1830 atlas of New York State at the rare books collection within the Erie County Public

Library (not obtained for this study). Regardless, the current depositional shoal suggests an inlet may have been present in this location.

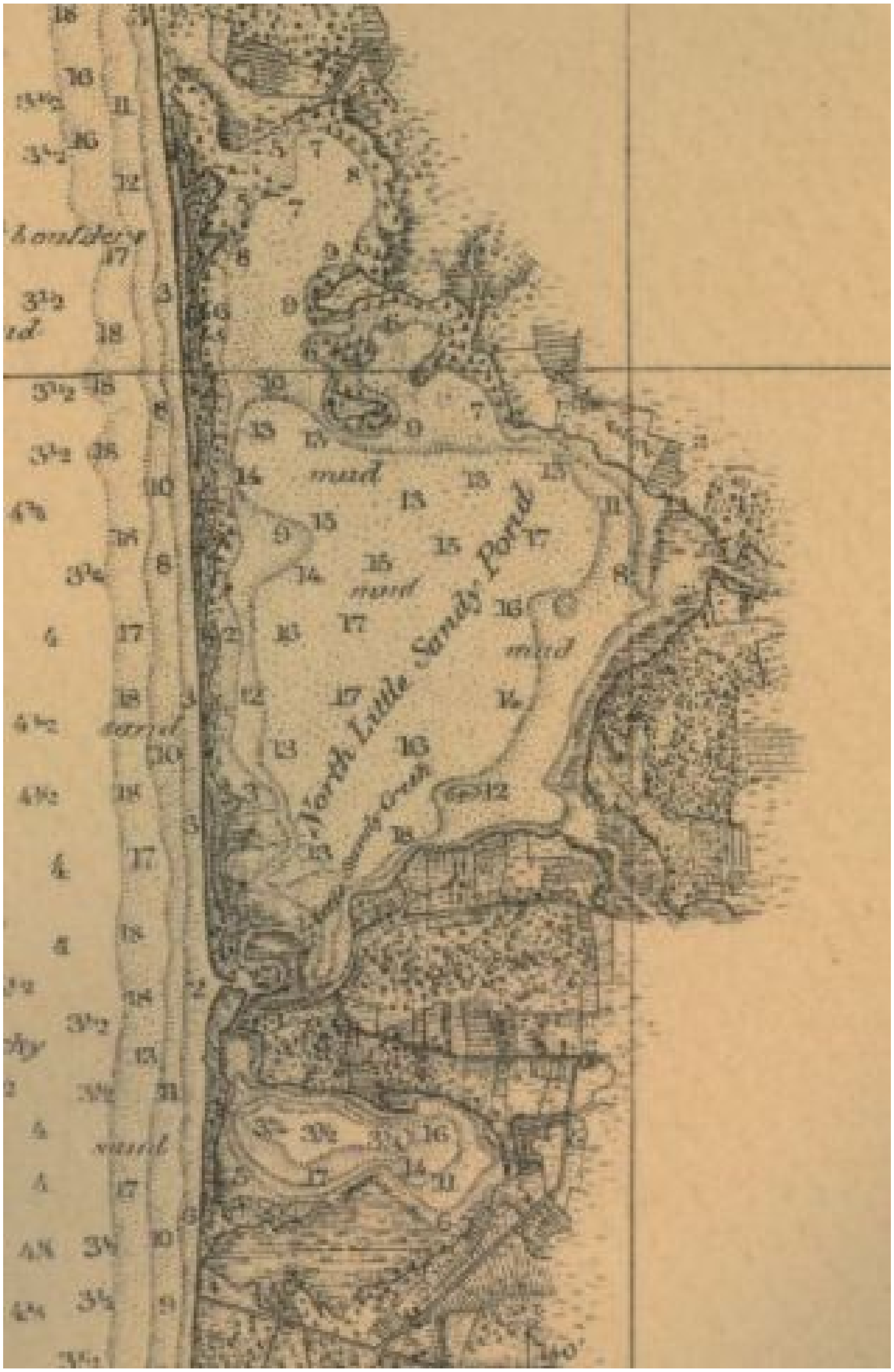


Figure 22: 1878 survey map showing depth data and inlet location

More recent inlet and overall shoal formation is further described by Baird:

"The 2001 bathymetry records the location of the modern flood shoal between 3,400 and 3,800 m in Figure 21. In 1878 to 1948, the surveys record depths in the pond ranging from 2.5 to 5.0 m below chart datum. Today much of the flood shoal is at chart datum or slightly below. A significant volume of sand has accumulated inside North Pond in this depositional feature.

A 3D volumetric comparison of the lake bottom in 1878 and 2001 was completed in GIS. It should be noted that in addition to sedimentation associated with the flood shoals, deposition of fine sediment, such as silt and clay has also occurred in the pond since the 1878 survey. This deposition is thought to be more concentrated in the eastern (back) half of the pond.

The annualized rate of sediment deposition in North Pond is approximately 58,000 m^3/yr. Since some of this deposition is associated with the riverine transport and deposition of fine silts and clays, it is estimated 40,000 to 50,000 m^3/yr of sand has been deposited in the pond, on average, since 1878. This represents a large sediment sink for the littoral cell."

Also, note the amount of sand deposited in the pond by aeolian transport at northern high dune blowout between 4500-5000 meters (Figure 20). The sediment budget work by Baird substantiates and adds quantitative measure to the statements by Woodrow et al. and Weir that the inlet represents a sediment sink.

Lakebed changes. Like the bathymetric analysis done within the Pond, 1948 and 2001 depth data was compared at a several transects by Baird. The findings suggest that areas north and south of North Pond were stable over the last 50 years showing little change, while the area fronting the current inlet to Montario Point shows lakebed erosion or undercutting of the lakebed due to raising of the lakebed from glacial isostatic rebound. This suggests the area has been subjected to scour and that the scoured lakebed sand, once mobilized, was not deposited lakeward, but is more than likely resident in the barrier beach and shoals. The amount of sand lost from the lakebed was not calculated; however, the data would support a three-dimension volumetric analysis to perform this calculation.

Regional Sediment Transport Patterns. Baird also modeled the littoral flow of sand on the Eastern Lake Ontario shore. Factors included in the models included assumed sand grain size, wind direction and force, and shoreline orientation. The models indicate that the predominant drift is to the south for the northern half of the eastern lakeshore, and to the north from the southern half, reaching a net shoreline transport of zero near North Pond (Figure 23). Baird also concludes that the net southward shoreline transport is also likely close to zero rather than the modelled 200,000 m3/yr volume as there is not a continuous sand source to the north at Stony Point; why the potential net loss due to erosion and loss of high dunes is not considered in the southerly transport is not discussed. This is an important consideration as the modelled sand movement to the south may represent a deficit that is not being met.

Regardless, the notion that the North Pond inlet and barrier spits provide a sink for sand captured within overall littoral transport is supported in Baird's analysis.

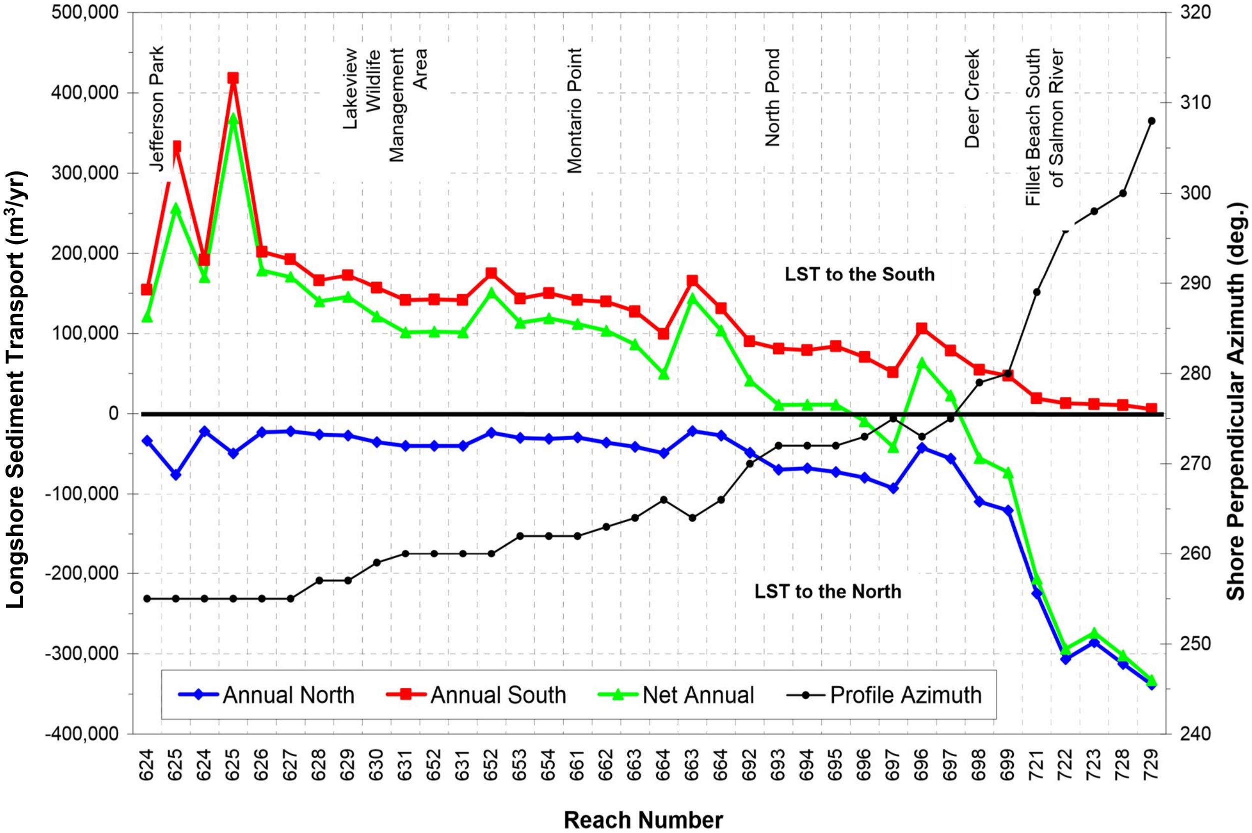


Figure 23: Regional longshore sediment transport estimates for Eastern Lake Ontario (average annual RATES) (inlet location is 664) (from (Baird 2006))

Isostatic Rebound. Baird provides an interesting analysis of the role of lakebed elevation due to isostatic rebound where bedrock is still rising after being depressed by the weight of ice sheets. Per Baird, "The rate of rebound in the area is 0.75 feet per 100 years During the last glacial period, the weight of the ice sheets that covered the Lake Ontario Basin depressed the underlying bedrock. When the continental glaciers melted, and migrated in a northerly direction, the underlying bedrock slowly began to bounce back. This process is known as isostatic rebound. The measured rate of rebound for the eastern end of Lake Ontario is 2.3 mm/yr. Over a century, this translates into a rebound rate of 0.23 m."

Without the erosive action of waves and currents in Lake Ontario, in theory. isostatic rebound would raise the Lake bottom along ELO by 0.23 m per century. However, as the profile comparisons have shown, the Lake bottom at ELO is in a state of dynamic equilibrium with the wave climate. In other words, over time the shape of the sand sheet has evolved in response to Lake levels and waves. This observation is at odds with isostatic rebound, since the nearshore environment should be slowly getting shallower.

"If the rebounding lake bottom is eroded by waves and currents, this process may represent a sediment sink for the littoral cell. For example, consider the following volumetric calculation. The ELO sand sheet is approximately 28 km in length from the Salmon River Jetties to the outlet at Black Pond. Waves and currents are generally focused on a zone of the lake bottom between the 6 m depth contour the and the waterline. This region is approximately 1 km in width. Collectively, this zone of active sediment dynamics is 28,000,000 m^2. When the annual rebound rates is applied (2.3 mm/yr), approximately 64,000 m^3/yr of new sediment is added to the littoral zone. In other words, for the profile morphology to maintain its equilibrium form, waves and currents must erode this sediment and this process generates sediment for the littoral cell.

Over periods of multiple decades, sand is eroded from the lake bottom to maintain the equilibrium profile shape and this new sediment is transported alongshore and onshore to build beaches and dunes. Therefore, in a regional context, the rebounding lake bottom represents a source of sediment for the littoral cell."

Estimating rates of isostatic rebound is an evolving science. Since the Baird report in 2006, new models have been produced suggesting rebound rates of 6 cm per 100 years and water-gauge derived rates of closer to 20 cm per hundred years (Mainville and Craymer 2005). Even these estimates are being supplanted by newer methods and measures using GPS station rise in combination with new gravity-sensitive satellite systems (NASA JPL ND) used in combination to measure glacial isostatic adjustment. Regardless, the rate of isostatic rebound appears to be greater than the values used by Baird in 2006, suggesting that something more like two to three times the amount of new sediment may be available due to erosion of the Lake bottom as it is elevated, provided localized scour does not deplete the sand sheet. The transect analysis presented in Baird for a 50-year period only found lake bed erosion in the Montario Point and North Pond transects, leaving the evidence for lake bed erosion throughout the eastern Lake Ontario basin unresolved.

Shoreline Change. Baird includes a section on "Beach and Dune Erosion" based on comparison of shoreline locations of 1960's aerial imagery against the 2001 orthoimagery. Baird reported that some of the 1960's photography could not be registered using methods described to a level of accuracy less than the anticipated magnitude of shoreline change that is being measured. No registration accuracy report is included in the analysis. The toe of the dune was digitized as the reference feature with no correction for lake elevation. An illustration of shore offset using calculated slopes for the 0.13 m difference in lake level elevation is provided indicating little difference in feature offset would be needed. Normally, offsets are done for shorelines based on water level such as wet sand line, or high-water lines and not for toe of dune delineations. The concept is that the dune is more stable than the wet shore and naturally accounts for differences in water elevation.

Twenty-five transects were used in the Baird report to calculate erosion rates in the 17-mile stretch of the Eastern Lake Ontario shore. Shoreline change rates varied from 3 meters per year of erosion (at the new inlet) to accretion of greater than 1 meter per year where the former inlet filled in (Figure 24). No overall shoreline change measure is offered.

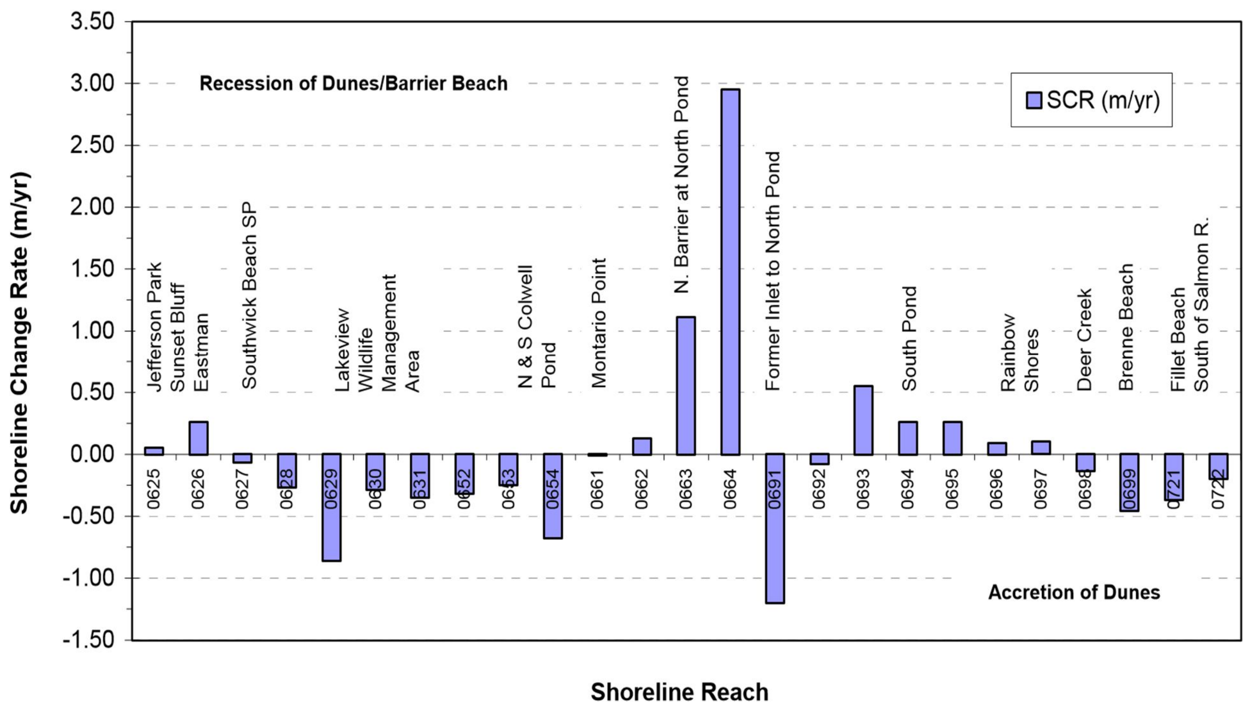


Figure 24: Shoreline change rates from 1960 to 2002 (based on toe of dune measurements) (Baird 2006)

Since the conclusion of the Baird study, three new studies were conducted, two by universities, and one by Baird.

Youngstown State University conducted research in 2014 (Mattheus, et al. 2016). Mattheus et al., represents a significant new body of work focusing on a small section of the central barrier from the 1938 inlet to the current inlet. The stated study objectives are to: “(1) better characterize surficial and subsurface landforms across the North Pond barrier and how they relate; (2) evaluate geomorphic changes in context of hydrologic forcing (i.e. lakelevel changes, storminess, and winter-ice covers); (3) provide an inclusive geomorphic model.”

Two sets of data were used. One set focused on extracting bathymetry, shoreline and inlet locations using historic aerial photography, digital orthoimagery, topographic maps and nautical charts (Figure 25). A second set of data was derived from field samples and measurements including sediment cores, ground penetrating radar and tree-dating cores.

Several historic aerial photos were registered for use in the study, with all reported as using:

"fixed structures (i.e. building corners and road intersections) and available latitude/longitude lines … as fixed control points. The resulting root mean square (RMS) sum of all residuals for each georeferenced map was utilized to compute the error, which was less than 4m in all instances, providing suitable spatial resolution for assessing coastal changes on the order of tens to hundreds of meters along the barrier over the timeframe of study."

No additional information is provided as to the method of georeferencing (e.g., what conversion was used to fit the image to reference points) or whether there were issues in identifying features on the barrier beach that lacked buildings or road intersections. RMSE is a useful measure, and often used as the final indicator of accuracy, but validation against a known base map should be the final step in using imagery along with adding pass points in overlapping areas of adjacent images to provide seamless features. This is especially true for historic imagery that is subject to many sources of distortion including those associated with an aged paper product. As noted by ESRI:

"Although the RMS error is a good assessment of the transformation's accuracy, don't confuse a low RMS error with an accurate registration. For example, the transformation may still contain significant errors due to a poorly entered control point. The more control points of equal quality used, the more accurately the polynomial can convert the input data to output coordinates" (ESRI 2016).

Table I. Information for obtained nautical charts, topographic maps, and aerial imagery, including data source, vintage, and use in this study

Vintage	Image source	Image type	Utility
1878	NOAA	nautical chart	bathymetry, shoreline position
1943	USGS	topo map	shoreline position
May 1957	USGS	aerial	shoreline position
1958	USGS	topo map	shoreline position
May 1960	USAF/USGS	aerial	shoreline position
June 1970	USGS	aerial	shoreline position
May 1974	USGS	aerial	shoreline position
October 1978	USGS	aerial	shoreline position
1978	NOAA	nautical chart	bathymetry, shoreline position
May 1981	USGS	aerial	shoreline position
July 1983	USGS	aerial	shoreline position
June 1994	USGS	aerial	shoreline position
April 2006	USGS	aerial	shoreline position
August 2008	USGS	aerial	shoreline position
April 2011	USGS	aerial	shoreline position
May 2013	GoogleEarth	aerial	shoreline position

Figure 25: Maps and Image Data Sources used in Mattheus, 2016

Mattheus created bathymetric maps using data from the 1878 Nautical chart supplemented with shoreline elevation points as well as 1978 nautical chart data to estimate volumes of lakeside shoreline loss and pond side accretion (Mattheus, et al. 2016).

Their analysis documents that the area immediately south of the current inlet to the 1938 inlet showed a general retreat of this section of the barrier system by ~150 m. The volume of sediment forming the features associated with the 1938 and 1957 was estimated at 759,000 cu yards and 327,000 cu yards respectively. Sources for near shore water depth and shorelines to establish a lake elevation line are documented, however, the upland surface elevation source used in calculations is not provided.

Matheus also notes that the new depositional areas (shoal and recurved inlet shores) could not be measured as no data were available to them to help quantify sediment volume.
Although the research conducted presents new advances, it overly relies on incomplete information. For example, “shoreline dispersion” (i.e., littoral transport) references general observation based models pointing towards northward flow from Sutton rather than recent models (Baird 2006) that use significantly more robust quantitative methods to identify a bi-directional transport. Available aerial imagery was not included in the study that would have added more information to some of the early inlet formation discussion. For example, readily available imagery from 1938, 1942, and 1955 would have helped addressed the noted lack of information in the 1930 through 1950’s range. “As little information on the geomorphic evolution of the barrier exists prior to the 1950s, we cannot infer linkages between increasing numbers of strong cyclones over time with the dynamics of the system.”

Similarly, the bathymetric analysis could have added available survey data from 1948 already in digital format and with a much higher resolution than points shown on nautical charts. Regardless of the lack of a thorough information base, the study provides new information on descriptive locations of inlets over time, an excellent presentation of the results of inlet formation and resulting deposition of sand in the pond and estimating inlet structure (recurved spit and shoal) volumes using bathymetric information from 1878 and 1978 nautical charts. Nautical charts do not present a rich data source for nearshore bathymetry and the authors combined a zero-elevation shoreline and likely interpreted points from chart shading or contours to provide a complete surface model for analysis in GIS.

Major findings in the study include the observation that the shoreline retreated by up to ~150 m in the southern extent of the study. Mattheus et al., report:

“Areas of net-accretion occur as three distinct lobes, each affiliated with back barrier marshes and relict tidal channels situated between relict recurved spits (Figure 26). Fan A, the largest in aerial extent and volume of these depositional lobes (at ~0.00058km3 and ~0.33km2, respectively), extends ~0.72km landward (to the east) from the terminus of Inlet A, which became inactive between 1957 and 1970 (Figure 26c; Table III). Fan B1, situated on the back barrier of an inlet position open from at least 1957 to 1970 (Figure 26), is not as extensive, reaching only ~0.36km eastward into North Pond. Its associated aerial extent and volume (at ~0.00025 km3 and ~0.15km2, respectively) are also approximately half that of Fan A. As Fan B2 was quite young in 1978 and had not yet grown to its current extent (~0.16km2 in area and 0.68 km in length from inlet to distal portion), no metrics currently exist to help quantify its sediment volume."

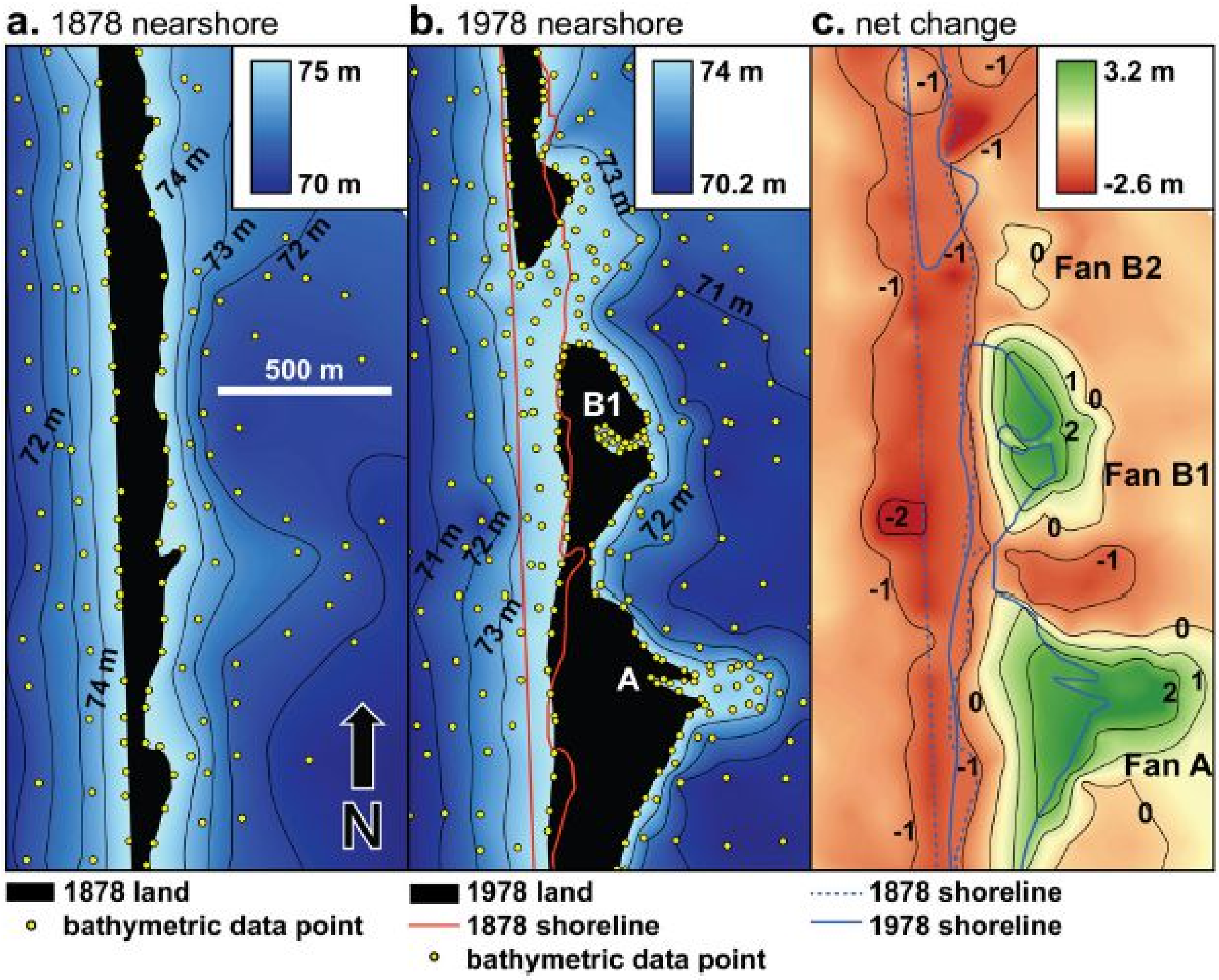


Figure 26: "Structure maps generated for studied nearshore regions from nautical chart-derived bathymetry data (yellow data points) showing: (a) 1878 nearshore elevations based on bathymetry data (yellow data points) and the shape of the barrier (black); (b) 1978 nearshore elevations and the shape of the barrier (black) along with its position in 1878 (red outline); (c) a net change map for the 100-year interval between 1878 and 1978 highlighting areas of net accretion (green) and net erosion (red). Sediment fans A, B1, and B2 are labeled" (used with permission from Mattheus, 2016).

Although Mattheus et al., prepared several shorelines, a quantitative method of estimating shoreline change rates was not presented, but is likely done by a series of transects in areas of interest. Barrier dynamics are presented in a separate section with interesting interpretations. One presents the former inlet structures and deposition shoals as being analogous to overwash fans on oceanic barrier islands. Although citing several authors, overwash fans operate very differently from inlet formation and shoaling in sand deposition. Overwash fans are formed by very high storm-driven waves and at very high lake levels. Overwash fans are often formed by over topping barrier islands by hurricanes and nor'easter storms on open ocean-facing shorelines. In the study area, overwashes do occur, but are not the principal means of forming deposition fans.

A second observation notes: "Foreshore sediment losses and backshore sediment gains modeled from bathymetric data strongly suggest a central barrier that has been in continuous landward retreat over the timeframe of study, a process already described by Sutton et al. (1972), who attribute the longer-term transgressional nature of the barrier to a rise in lake levels…". This observation is supported by the research and consistent with the much earlier observations of analogous barrier island roll over in relation to rising water levels (Leatherman 1988). What is not considered is the episodic nature of lake level high water periods and how that relates to new inlet formation, rather than long term lake level rise.

A third observation attempts to link lake levels with lake control structures of the St. Lawrence Seaway built in 1959.

"The subsequent evolution of Inlet B, mainly defined by a northward migration with associated changes in width occurred when seasonal and inter-annual lake-level variations were less pronounced than before management. Exact linkages between process and form cannot be from the data at this temporal resolution and we can only speculate on the specific influences of high and low lake levels on the geomorphic evolution of the system, which likely require a coupling with the occurrence of high-energy storms and/or the influence of lake ice to perform the amount of work necessary to significantly modify the barrier (i.e. open and close inlets)."

Although management of lake levels has led to less variation than before management, one of the periods of highest sustained lake level occurred in the 1970's under current level management controls. Further, lake control structures have been in place since the 1880's.
A final observation relates to the potential roll of lake ice cover in erosion and inlet width. "Inlet width increased from ~300m in the mid-1960's to ~550m by the mid-1970's, coinciding with a period of increasing winter-ice coverages. Our data place maximum inlet width between 1974 and 1983, which is coincidental with the peak in winter ice cover at >80% in 1979. This period of high winter-ice covers could have facilitated winter erosion of the low-elevation central portion of the barrier, allowing inlet migration to speed up." Ice formation is often viewed as being protective of barrier beaches by reducing wave effects of January through

March storms. Others have suggested that lake rim ice may drive sand from the lakebed towards the beach with prevailing winds (ice flow phenomenon). A statistical analysis evaluating National Park shore coastal vulnerability evaluated 22 National Parks, with three sites in the Great Lakes included (Pendleton, Thieler and Williams 2010). These are: Apostle Island National Lakeshore, Sleeping Bear Dunes National Lakeshore, and Indiana Dunes National Seashore. The analysis included variables "to describe the physical characteristics of the coast and the physical processes that affect the coast over human time scales. The geological variables of geomorphology, historical shoreline change rate, and coastal slope account for a shoreline's relative resistance to erosion, its long-term erosion and accretion trend, and its susceptibility to flooding, respectively. The physical process variables (sea- or lake-level change, significant wave height, and tidal range, or mean annual ice cover for the Great Lakes) contribute to the inundation hazards along a coastline." Of these variables, shoreline change and ice cover did not have significant contribution to an index of vulnerability. This is not conclusive either, but the role of ice is more likely protective of winter storm effects than a contributor to erosion.

Currently, SUNY Oswego is conducting research in the North Pond barrier beach and inlet system including Ground Penetrating Radar (GPR) imaging revealing former inlet locations (Bradley 2016). Initial work appears to be able to identify subsurface features with less ambiguity than GPR studies presented in Mattheus et al. Results of the current resiliency study will be provided to aid in interpretation.

Baird prepared a draft report, "Lake Ontario Sediment Budget", from the mouth of the Niagara River to Stony Point, just north of the Eastern Lake Ontario Dunes Complex (Baird 2011). This report includes detailed information on methods used to construct sediment budgets and focused sediment and ecological linkage study areas for Western Lake Ontario, Braddock Bay, and Eastern Lake Ontario. Sediment modeling for the Eastern Lake Ontario area shows longshore sediment transport from both the north and south, converging around North Pond and suggesting the area is a sediment deposition area (Figure 27). This contrasts with the conclusion reached by Sutton, where the predominant littoral shore transport was deemed northward, and that the long-term result would be loss of sand to the north and exposure of gravels over many hundreds of years (Sutton 1970). The Baird analysis takes advantage of analytical techniques previously unavailable and represents a more likely scenario. In addition, a revised recession rate analysis was performed, showing net shoreline retreat throughout the Sandy Pond area (Figure 28) (Baird 2011).

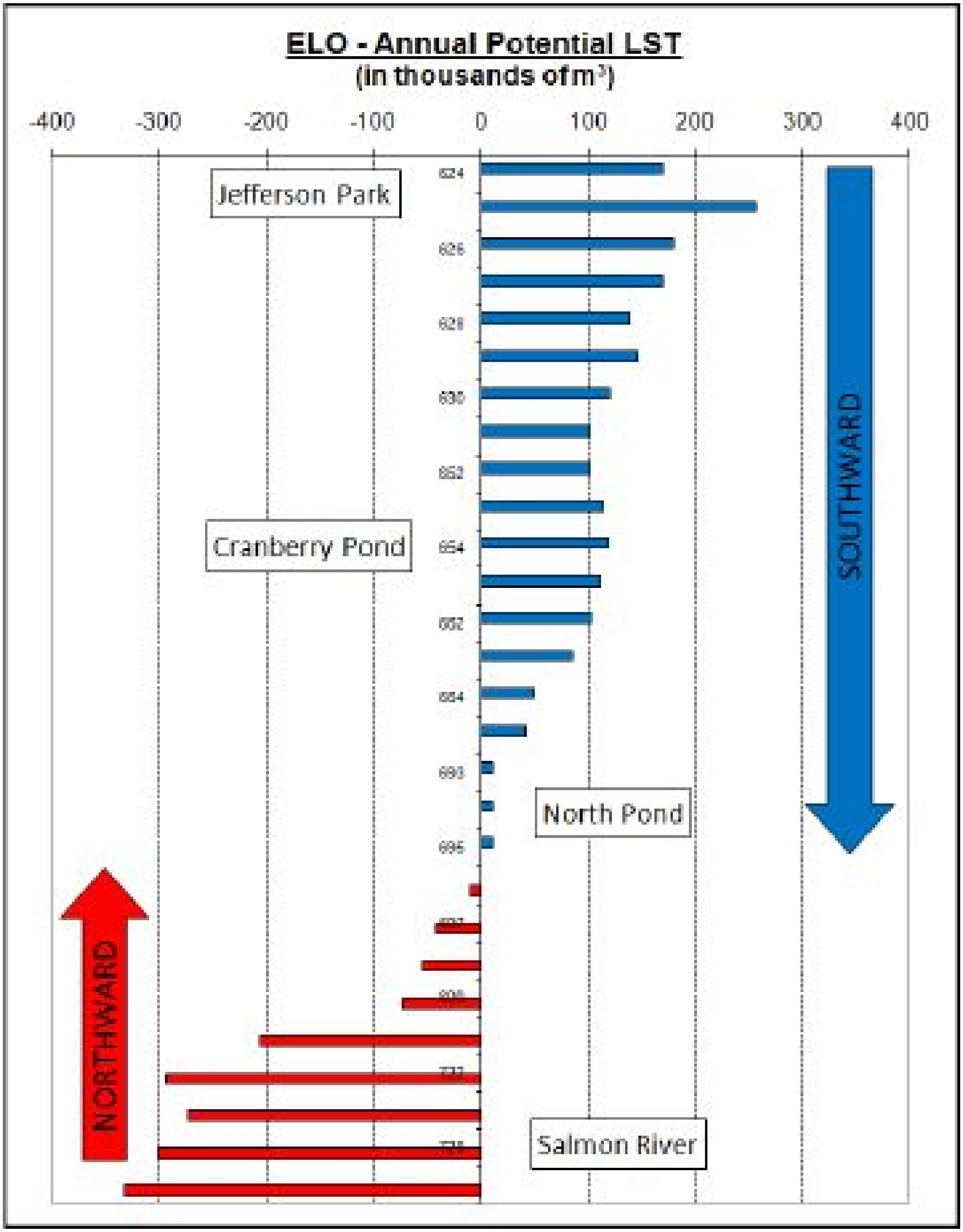


Figure 27: Annual Eastern Lake Ontario potential longshore sediment transport (Baird, 2011)

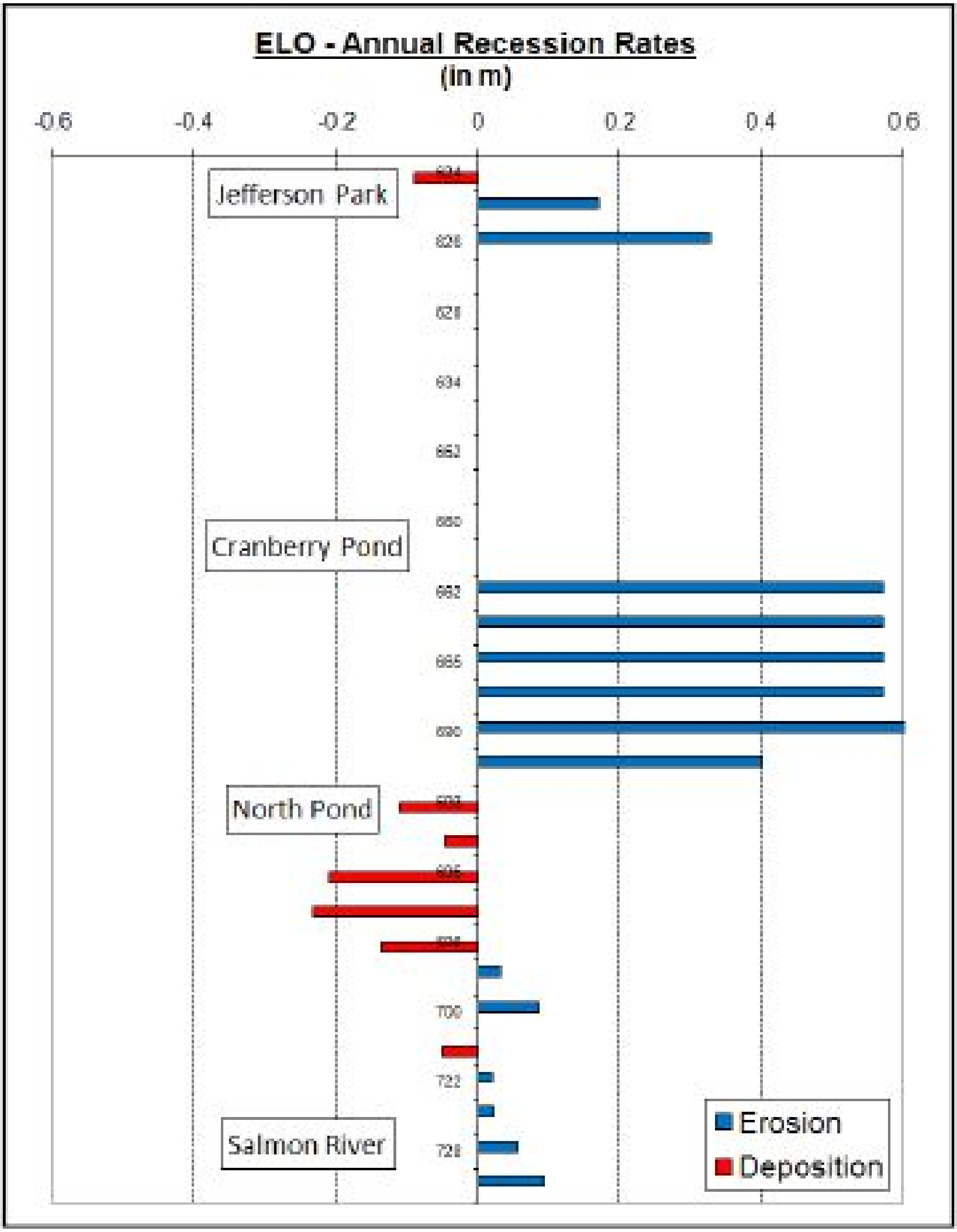


Figure 28: Annual Eastern Lake Ontario erosion rates at selected locations (Baird, 2011)

The sources of sediment are stated as nearshore erosion and exposure of the nearshore sand sheet to isostatic rebound. Baird notes that the area around North Pond may be accumulating sand at a rate of approximately 40,000 m^3/yr. Sand accumulation is noted for the current along with prior inlet locations (Figure 29).

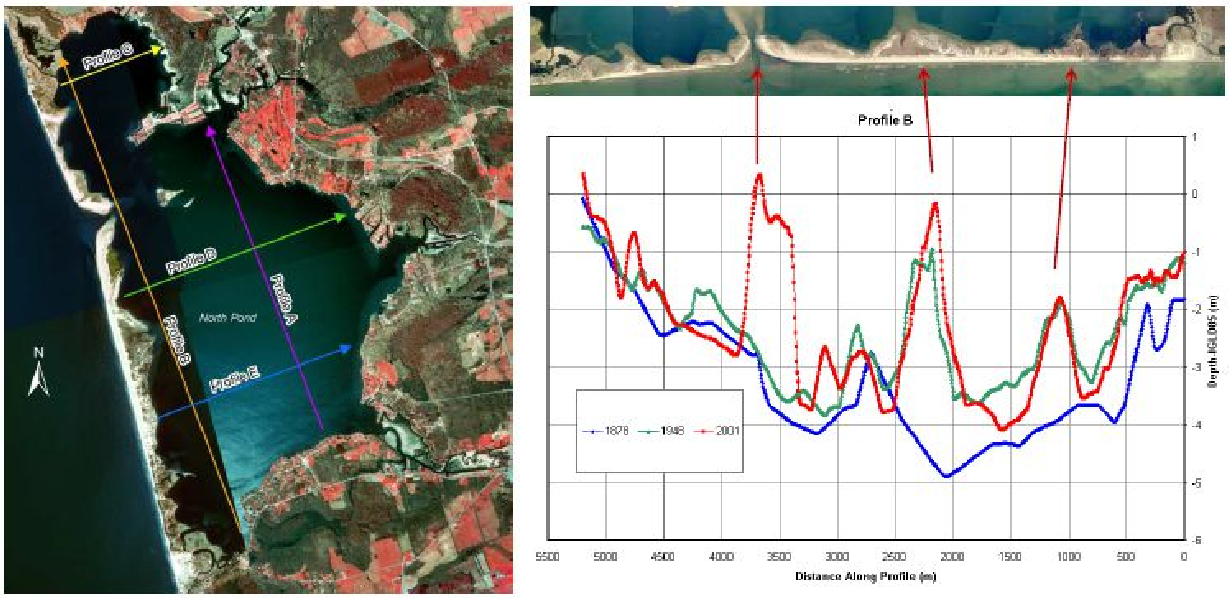


Figure 29: Profile analysis of sediment accumulation at North Pond (Baird, 2011)

The source of sediment from the near-shore sand sheet was updated, suggesting greater availability of sand than presented in the Baird 2006 report:

"The northern retreat of the glaciers that covered the Lake Ontario basin (and suppressed the underlying bedrock) is the cause of isostatic rebound in the region. The measured rate of rebound for Eastern Lake Ontario is 2.3 mm/year. Though this rate appears low, the size of the sand sheet in ELO suggests this is the primary source of sediment input to the ELO system. If the lake bottom is assumed to be at an equilibrium elevation, the gradual rebound of the lake bed is compensated by erosion of the sand sheet, so that the bed level remains constant. This creates a source of sand from the sheet on the lake bed, and this sand is supplied to the nearshore zone. Initial calculations as part of the sediment budget analysis show that approximately 46,000 m3/year of sand is added to the nearshore system (assuming 80% of the lakebed is sand sized sediment)."

Current Study Process and Product Overview

The prior section reviewed works done to date. The structure of the following sections presents the general outline of the supporting grant. Overarching study objectives are clearly presented in the project plan. Items stated here are related conducting technical aspects supporting these larger objectives.

1) Assemble a comprehensive set of
    a. Historic aerial photography
    b. Modern digital orthoimagery
    c. Relevant nautical charts
    d. Elevation data sets
2) Relate these data sets to lake level information
3) Prepare digital georeferenced imagery from photography
    a. With documented accuracy
    b. With matching edge features
    c. In distributable format
4) Derive shorelines
    a. For the entire study area
    b. Including beach face, inlet and pond shorelines
    c. Assess accuracy of each shoreline
5) Conduct two-dimensional shoreline change analysis
    a. Including various rates of change
    b. Net shoreline movement
    c. Long term and short term
    d. Include inlet change or migration
6) Explore three-dimensional change
    a. Using historic bathymetric and elevation data
    b. And recent LiDAR data-derived surfaces
7) Add information regarding
    a. Ice formation and storm incidence
    b. Inlet blockage and ice roles
8) Hydrologic forcing
    a. Add information regarding input flow to the Pond
    b. Flows from the lake
    c. Comparison and seasonality

Photographic and Map Record

What is in this section? All the various sources of aerial imagery, maps and elevation data using in this study are reviewed here. Aerial photography is available from 1938 to 2016 at the time this document was prepared. Photographic records can be divided into two periods: historic photography taken by traditional film, and modern orthoimagery which is processed digitally to have map-like characteristics including accurate scale. Prior studies used have only used a fraction of the imagery that is now readily available. A full annotated bibliography of available photography accompanies this report as a separate appendix.

Modern Digital Orthoimagery

Technology has made significant advances since 2001 in several important ways to facilitate this study since the robust work completed for the USACE and IJC in 2006 (Baird 2006). Nothing short of a technical revolution in remote sensing has occurred starting at the turn of the century. Beginning with standard aerial cameras and fine scanning processes of true color or color-infrared photography, acquisition of digital imagery from scanning systems has resulted in widespread availability of highly accurate and more frequent 4 band color imagery based on improved cost and program efficiencies.

For shoreline change analysis, a wealth of available recent images was identified, more than was anticipated at the beginning of the study, including the addition of USACE imagery from 2001 and 2007 and U.S. Department of Agriculture National Agriculture Imagery Program (USDA NAIP) imagery from 2015. Few data gaps exist in recent years. Only 2014, 2012, 2010, 2005, 2002 and 2000 are not represented since 2000. In total, 20 sets of digital orthoimagery were obtained. Of these, 15 shorelines were digitized. Several imagery sets were not used to create additional shorelines based on redundancies (same dates, differing projections of the same imagery and differing formats).

The first digital orthoimage data set for NYS dates to 1994. In this study area, high quality digital orthoimagery starts in 2001 with the IJC overflight. The State's Digital Orthoimagery Program provides early spring leaf-off imagery in the study area starting in 2003, and the USDA National Agriculture Imagery Program provides summer full vegetation imagery starting in 2004. From 2001 through 2016, 17 sets of digital orthoimagery was obtained for this study. Information about available orthoimagery was compiled along with corresponding lake level from the Oswego water level station (Figure 30). Several internet sites and applications were essential in searching for and obtaining this data including: the New York State GIS Clearinghouse, USDA Geospatial Gateway, USGS Earth Explorer and USGS National Map.

Historic Aerial Photography

Collections of hardcopy photography remain important repositories. For this study, photographic sets were obtained and scanned from: the New York State Museum, Oswego Soil and Water Conservation District and the National Archives. A partial listing of available imagery was compiled and imagery was selected for scanning if required from paper sources. Technologic advances in internet access to already scanned photography has also radically affected the availability of historical photography. Most scanned photographic images were downloaded from internet sources including Earth Explorer, USDA's Geospatial Gateway and the National Map. Wherever possible, historic imagery collections were georeferenced and used to develop digital shorelines (Figure 31).

Each of the sets of imagery used in this study are described in terms of quality of imagery, georeferenced accuracy achieved, and characterization of inlet and shore conditions at the time (Appendix B). In addition to photographic imagery, both as digital orthophotography and georeferenced scanned photography, USGS topographic maps and point-based elevation information was obtained representing historic bathymetric data and more recent topobathymetric LiDAR data (Figure 32).

Nautical Charts

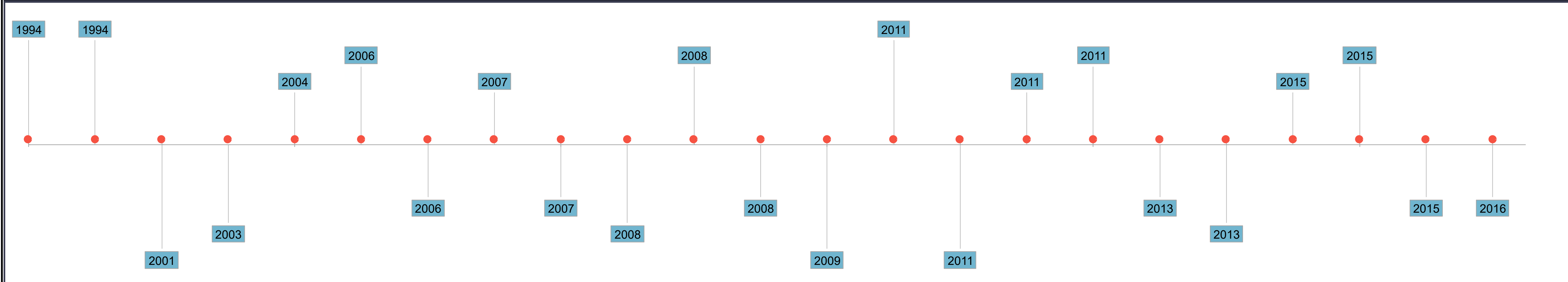
Finally, nautical charts provide a rich history of maps for the eastern shore of Lake Ontario. The earliest of these include bathymetric data within North Pond (1878) which had a minor update in 1912 (correcting the erroneous label for Little Sandy Creek) and then again with updated bathymetric cartography in 1917. For years after this update, no bathymetric data was included for North Sandy Pond. It was not until the 1959 nautical chart that the new location of the inlet was shown, missing the years of the 1938 inlet and indicating that the shoreline for North Sandy Pond was not reliably represented in this map series. The 1963 chart was the first to include a detailed inset map for North Pond with new bathymetric data and cartographic representation. Shorelines were not necessarily updated in the 1960's and 1970's series. Only the most recent nautical charts appear to have accurate shorelines and these too are generalized for changing features such as the inlet shoal.

Topographic Maps

Five sets of topographic maps were referenced in the study (Figure 32). The earliest used was from 1895 and provides the earliest base shoreline reference. Other maps were available near this year and were all comparable (scale 1:62,500). Accuracy of these maps were suspect in showing misaligned upland features such as road and bridge locations. The map was re-registered to improve alignment while preserving shore locations which show three benchmarks along the shore study area. More recent topographic maps from 1942 forward were used to validate accuracy of rectified imagery created in this study.

North Pond Resiliency Project: Modern Era Imagery

Digital Orthoimagery Timeline



Digital Orthoimagery Map Inventory

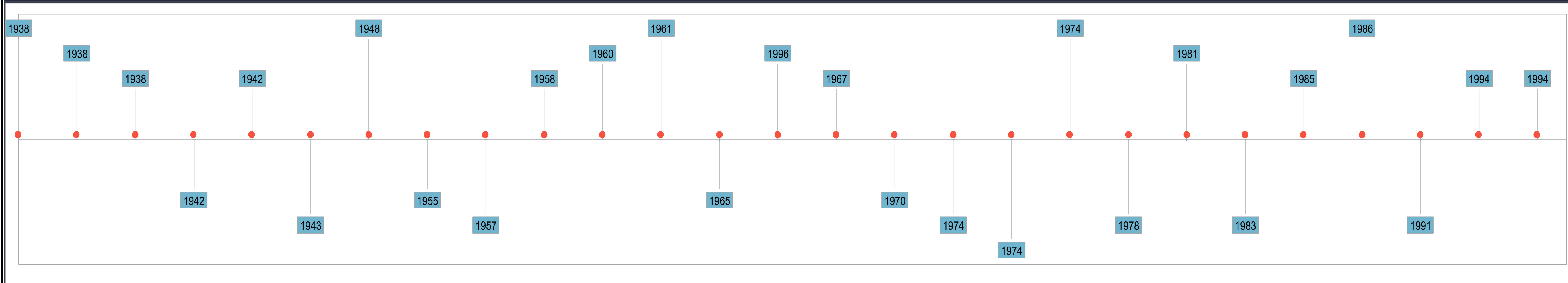
Date	Source	Project	Pixel Size	Image Type	Comment	Accuracy	Digitized	Lake Level	MILESTONE	245+-0.15	245.5+-0.15	246+-0.15	246.5+-0.15
5/3/1994	USGS EE	DOQQ	1 .0m	Color Infrared		20 ft	yes	246.2	1994			C	
5/3/1994	Date+B21:B43	DOQQ	1.0 m	Color Infrared	modified color balance set from DOS	20 ft	yes	246.2	1994			x	
6/23/2001	USACOE	IJC	0.5 m	True Color	not online - delivery by CDROM 6/03/16; custom projection	4 ft	yes	246.0	2001			C	
4/1/2003	NYS GIS	DOP	2.0 ft	Color Infrared		8 ft	yes	244.6	2003	Low			
7/1/2004	NRCS	NAIP	1 m	True Color	county mosaic	19.7 ft	yes	246.4	2004				D
4/1/2006	NYS GIS	DOP	2 ft	True Color		8 ft	no	245.4	2006		x		
6/6/2006	NRCS	NAIP	1 m	True Color	pond image from 7Jul06	19.7 ft	yes	245.7	2006		B		
6/14/2007	USACE	JALB	0.4 m	True Color	5 km along shoreline/ June-August	2.5 ft	yes	246.0	2007			C	
6/14/2007	USACE	JALB	5 m	Reflectance	June up to 04Aug07	2.5 ft	no	246.0	2007	x			
7/2/2008	NRCS	NAIP	1 m	True Color	shore image from 24Sep08 (see 9/24/08 NAIP)	19.7 ft	yes	246.6	2008	x			
8/26/2008	USGS	unknown	0.3 m	True Color	tif and jpg products	19.7 ft	yes	246.0	2008			C	
9/24/2008	NRCS	NAIP	1 m	True Color	pond image fr 2Jul08	19.7 ft	yes	245.1	2008	A			
7/10/2009	NRCS	NAIP	1 m	True Color	county mosaic	19.7 ft	yes	246.5	2009				D
5/92011	NYS GIS	DOP	2 ft	4 band		8 ft	yes	246.6	2011				D
5/9/2011	USGS EE	HiRes Ortho	2 ft	4 band	same as NYSDOP, UTM projection	8 ft	no	246.6	2011				x
5/11/2011	USGS EE	NAIP	1 m	4 band	date verified w metadata	19.7 ft	no	246.6	2011				x
5/11/2011	NRCS	NAIP	1 m	True Color	county mosaic	19.7 ft	no	246.6	2011				x
5/26/2013	Google	Google	1 ft	True Color	Resolution net specified	UNK	no	245.8	2013	x			
6/19/2013	NRCS	NAIP	1 m	True Color	county and DOQQ	19.7 ft	yes	246.5	2013				D
4/15/2015	NYS GIS	DOP	1 ft	4 band	flight dates extended to May 9; lake el - 244.8-245.3	4 ft	no	244.8	2015	A			
6/6/2015	NRCS	NAIP	0.5m	True Color	county mosaic	19.7 ft	yes	245.7	2015		B		
6/6/2015	NRCS/SWCD	NAIP	0.5m	4 band	DOQQ - use for vegetation analysis	19.7 ft	yes	245.7	2015		x		
9/5/2016	Google	Google	1 ft	True Color	Resolution net specified	UNK	no	245.2	2016	x			

Figure 30: Digital orthoimagery acquisitions – image characteristics, accuracy, shoreline digitization status lake elevation and classification.

Twenty sets of digital orthoimagery were assembled and of these, digital shorelines were extracted for fifteen. Those not classified are so indicated and also not classified as indicated by an "x". Those data set not used for shoreline determinations are either duplicate forms of the same imagery (2 cases), a different format (reflectance, one case), within a few months of another data set (one case) or more recently collected (one case).

North Pond Resiliency Project: Historic Photography

Photography Timeline



Aerial Photography Inventory

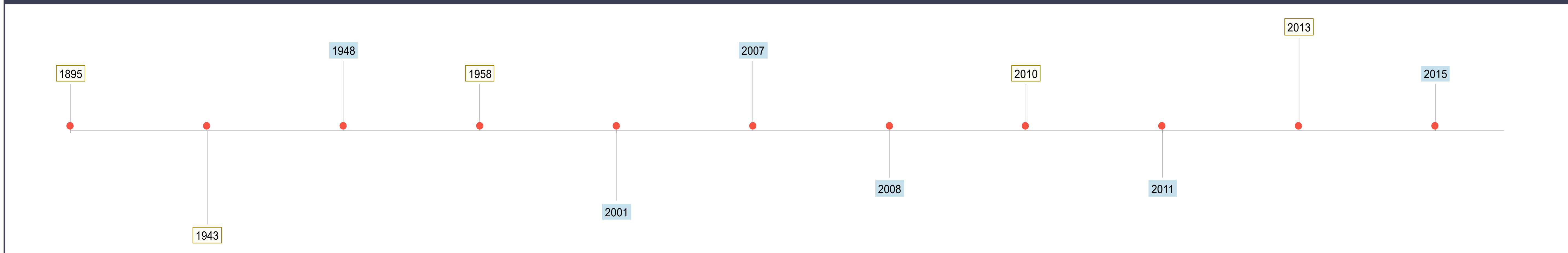
DATE	Source	Project	Scale or Pixel	Image Type	Comment	Accuracy	RMSE	Digitized	Lake Level	MILESTONE	POSITION	BASELINE	245+-0.15	245.5+-0.15	246+-0.15	246.5+-0.15
4/21/1938	National Archiv	Unknown	Unknown	Black and White	not obtained -	na		no		1938	20	1				
6/?/1938	SWCD	Unknown	Unknown	Black and White	obtained later date image	na		no	245.0	1938	15	1				
6/29/1938	SWCD	Unknown	Unknown	Black and White	chose only higher level date	na	21.00	yes	245.0	1938	10	1	A			
4/1/1942	SWCD	Unknown	Unknown	Black and White	YMCA only / TVA			no		1942	-10	1				
5/9/1942	National Archiv	TVA - McClennen	Unknown	Black and White	poor scan at 50 dpi		S_71; N_19.3	yes	245.1	1942	10	1	A			
9/6/1955	SWCD	Unknown	660' (1:7920)	Black and White		27.00	27.00	yes	247.5	1955	-15	1				D
5/6/1957	USGS	Mosaic	Unknown	Black and White	spline then readjust 2nd order	70.00	76.00	yes	245.6	1957	20	1		B		
5/19/1960	USGS EE	single frame	1:60,000	Black and White	over washes, water level higher than gauge? See renshaw wetlar	10.00	9.70	yes	246.5	1960	-10	1				D
5/5/1961	NYS Museum	DOT	1:40,000	Black and White	northern smaller scale			no		1961	-15	1	x			
7/2/1965	SWCD	Unknown	Unknown	Black and White	good imagery	20.00	7.2-16.2	yes	245.0	1965	10	1	A			
7/2/1966	SWCD	Unknown	Unknown	Black and White	renshaw and carl only			no		1996	15	1	x			
4/28/1967	NYS Museum	OPC	1::24,000	Black and White	north/center	20.00	19.70	yes	245.6	1967	20	1		B		
6/24/1970	USGS EE	single frame	1:11,087	Color Infrared	similar to 1983 data set for Color Infrared, Vegetation change? H	10.00	9.20	yes	245.9	1970	-10	1			C	
4/26/1974	NYS Museum	Oswego co	1:24,000	Black and White	northern, inlets, southern? (two not in file) _poor exposure			no		1974	15	1	x			
?/?/1974	SWCD	Unknown	Unknown	Black and White	lake level at 248 all June, date set to 7/1 based on crops in field	15.00	12.00	yes	248.0	1974	10	1				D
5/1/1974	USGS EE	single frame	1:10,390	Color	single frames - many needed to cover the study area			no		1974	-10	1				
9/23/1978	NYS Museum	SCS USDA	1:24,000	Black and White	center - priority for registration, west (not used)		7.00	yes	245.0	1978	-15	1	A			
5/1/1981	USGS EE	single frame	1:80,000	Black and White	small scale			no		1981	-20	1				
7/13/1983	USGS EE	single frame	1:13,167	Color Infrared	used this imagery	15.00	12.00	yes	246.2	1983	20	1			C	
4/29/1985	USGS EE	single frame	1:65,000	Color Infrared	small scale			no		1985	-15	1	x			
4/28/1986	USGS EE	NHAP	1:58,000	Black and White and Color Infrare	small scale			no		1986	15	1	x			
10/29/1991	NYS Museum	DOT	1:24,000	Black and White	centered	10.00	5.30	yes	244.1	1991	-15	1	Low			
5/3/1994	USGS EE	single frame	1:34,000	Color Infrared	many frames scale 34K-68K			no	246.2	1994	10	1	x			
5/3/1994	NYS Museum	NAPP	1:40,000	Black and White	not needed	20.00		no	246.2	1994	20	1	x			
6/8/1994	USGS EE	single frame	1:68,000	Color Infrared		10.00	8.70	yes	246.4	1994	-15	1				D
4/17/1995	NYS Museum	NAPP	1:40,000	Black and White	top 2/3 of pond, not registered			no	245.0	1995	10	1	x			
4/17/1995	USGS EE	NAPP	1:40,000	Color Infrared	registered 5/23/16	10.00	8.50	yes	245.0	1995	10	1	A			

Figure 31: Historic photographic data sets including image descriptions, registration accuracy, lake elevation and classifications

Twenty-seven sets of historic photography were acquired ranging from 1938 to 1995. Of these, fourteen were used to determine digital shorelines. Selection criteria for those not digitized were the same as those applied to more recent orthoimagery plus: incomplete coverage of the study area, many photo frames for the study area, or poor image quality. All photography selected was successfully rectified, with only one having poor RMSE results (1942).

North Pond Resiliency Project: Elevation and Bathymetry Data

Topographic Map and Elevation Data Set Timeline



Topographic Maps and Elevation Data Sets

Date	Source	Project	Scale or Pixel	Data Type	Comment	Accuracy	RMSE	Digitized	Lake Level	MILESTONE	POSITION	245+-0.15	245.5+-0.15	246+-0.15	246.5+-0.15
01/01/1895	USGS	historical topo	1:62500	NA	accuracy of shoreline is unknown	80 Ft		yes	244.0	1895	10	Low			
01/01/1943	USGS	historical topo	1:24000	NA	used for accuracy assessment 1942 images	40 ft				1943	-20				
7/1/1948	NOAA	bathymetry - 244 lwd	NA	point file	xyz point file collection - shows inlet change, elevation est.	unknown		NA	245.6	1948	15		B		
01/01/1958	USGS	historical topo	1:24000	NA	use for accuracy assessment 1957 images	40 ft				1958	10				
5/28/2001	USACOE	JALB	0.4 pt /m2	LiDAR TB	not as good as following lidar in 2007/2011	30 cm	30 cm	yes	245.8	2001	-15			C	
6/8/2007	USACE	JALB	0.4 pt /m2	LiDAR TB	pt dens not meaningful with bathy incl	20 cm	20 cm	yes	246.2	2007	15			C	
6/30/1905	Oswego Count	FEMA DCS Terrain	not determined	LiDAR topo	0.66 vertical accuracy/ 1.4 m spacing. Data access not provi	not reported	not reportec	no		2008	-10				
01/01/2010	USGS	historical topo	1:24000	NA		40 ft				2010	10				
7/2/2011	USACE	JALB	1.3 pt / m2	LiDAR TB	date range: 06/06 - 09/23 (date est Lake Level)	20 cm	20 cm	yes	246.9	2011	-10				High
01/01/2013	USGS	topo	1:24000	NA		40 ft				2013	20				
7/1/2015	FEMA	flood plain mapping	0.2 pt/m2?	LiDAR Topo	available on 'The National Map"	20 cm	20 cm	no		2015	10				

Figure 32: Topographic maps and elevation data sets with descriptions, accuracy, digital shoreline status and lake elevation with classification. Topographic maps indicated with dates in brown outline. All others are point elevation files. Elevation data included contour lines from topographic maps, a bathymetric point file from 1948, and four sets of LiDAR data. Of the four LiDAR data sets, the earliest was topobathymetric data (upland and lake or pond bottom), while the other three are topographic (upland only, with no water penetration). Access to the Oswego County data was not provided, but not needed. The most recent FEMA LiDAR data set was released after the analysis of other data sets were completed.

Title	Location	Type	Year Published	Edition	Chart Number
LAKE ONTARIO SOUTH OF STONY POINT TO LITTLE SODUS BAY	NY	Nautical Chart	1943	0	22
LAKE ONTARIO COAST SIX MILES SOUTH OF STONY POINT TO PORT BAY	NY	Nautical Chart	1953	0	22
LAKE ONTARIO COAST SIX MILES SOUTH OF STONY POINT TO PORT BAY	NY	Nautical Chart	1956	0	22
LAKE ONTARIO COAST SIX MILES SOUTH OF STONY POINT TO PORT BAY	NY	Nautical Chart	1959	0	22
LAKE ONTARIO COAST SIX MILES SOUTH OF STONY POINT TO PORT BAY	NY	Nautical Chart	1963	0	22
LAKE ONTARIO COAST SIX MILES SOUTH OF STONY POINT TO PORT BAY	NY	Nautical Chart	1965	0	22
LAKE ONTARIO COAST SIX MILES SOUTH OF STONY POINT TO PORT BAY	NY	Nautical Chart	1968	0	22
LAKE ONTARIO COAST SIX MILES SOUTH OF STONY POINT TO PORT BAY	NY	Nautical Chart	1971	0	22

Title	Location	Type	Year Published	Edition	Chart Number
LAKE ONTARIO STONY POINT TO LITTLE SODUS BAY	NY	Nautical Chart	1902	0	LS22
LAKE ONTARIO. STONY POINT TO LITTLE SODUS BAY.	NY	Nautical Chart	1908	0	LS22
LAKE ONTARIO. STONY POINT TO LITTLE SODUS BAY.	NY	Nautical Chart	1912	0	LS22
LAKE ONTARIO. STONY POINT TO LITTLE SODUS BAY.	NY	Nautical Chart	1917	0	LS22
LAKE ONTARIO. STONY POINT TO LITTLE SODUS BAY.	NY	Nautical Chart	1922	0	LS22
LAKE ONTARIO. STONY POINT TO LITTLE SODUS BAY.	NY	Nautical Chart	1926	0	LS22
LAKE ONTARIO. STONY POINT TO LITTLE SODUS BAY.	NY	Nautical Chart	1932	0	LS22
LAKE ONTARIO	NY	Nautical Chart	1935	0	LS22
LAKE ONTARIO	NY	Nautical Chart	1937	0	LS22
LAKE ONTARIO. SOUTH OF STONY POINT TO LITTLE SODUS BAY, N.Y.	NY	Nautical Chart	1940	0	LS22
LAKE ONTARIO. SIX MILES SOUTH OF STONY POINT TO PORT BAY N.Y.	NY	Nautical Chart	1946	0	LS22
LAKE ONTARIO. SIX MILES SOUTH OF STONY POINT TO PORT BAY N.Y.	NY	Nautical Chart	1949	0	LS22
LAKE ONTARIO. SIX MILES SOUTH OF STONY POINT TO PORT BAY N.Y.	NY	Nautical Chart	1953	0	LS22
LAKE ONTARIO, SIX MILES SOUTH OF STONY POINT TO PORT BAY N.Y.	NY	Nautical Chart	1956	0	LS22
LAKE ONTARIO, SIX MILES SOUTH OF STONY POINT TO PORT BAY N.Y.	NY	Nautical Chart	1959	0	LS22
LAKE ONTARIO, SIX MILES SOUTH OF STONY POINT TO PORT BAY N.Y.	NY	Nautical Chart	1963	0	LS22
LAKE ONTARIO, SIX MILES SOUTH OF STONY POINT TO PORT BAY N.Y.	NY	Nautical Chart	1966	0	LS22
LAKE ONTARIO, SIX MILES SOUTH OF STONY POINT TO PORT BAY N.Y.	NY	Nautical Chart	1968	0	LS22

Title	Location	Type	Year Published	Edition	Chart Number
LAKE ONTARIO STONY POINT TO LITTLE SODUS BAY	NY	Nautical Chart	1878	0	LS64
LAKE ONTARIO STONY POINT TO LITTLE SODUS BAY	NY	Nautical Chart	1880	0	LS64
LAKE ONTARIO STONY POINT TO LITTLE SODUS BAY	NY	Nautical Chart	1894	0	LS64
LAKE ONTARIO STONY POINT TO LITTLE SODUS BAY	NY	Nautical Chart	1896	0	LS64
LAKE ONTARIO STONY POINT TO LITTLE SODUS BAY	NY	Nautical Chart	1897	0	LS64

Figure 33: Nautical charts referenced. None were used after review of shorelines indicated other sources were more accurate.

Rectification of Historic Photography

Except for a 1994 orthoimagery date set, prior to 2000, the imagery is source is photographic paper copy, requiring manual registration. Twenty-seven sets of scanned photography were obtained, with several sets of paper imagery scanned at either the NYS Museum or at the SWCD offices.

Manual registration was completed for 15 sets of imagery with acceptable accuracy using ArcMap 10.3 (ESRI 2014). Baird previously noted difficulty in registering photographs:

"A historical 1960s aerial photograph was geo-referenced against the 2002 detailed orthophotograph collected for this study. This region of the lake was a difficult area for photographic registrations, since the vast tracks of open natural areas do not provide suitable low level ground control points, such as road intersections. In some locations, it was not possible to register the 1960s photographs with acceptable error limits (horizontal registration error less than predicted change in the shoreline change reference feature, such as the toe of dune)" (Baird, 2001).

Accordingly, a different approach was taken in registering photographs in this study. Photographs registered have acceptable accuracy, with many having relatively low RMSE values, although this statistic is only a general measure of precision. The registration strategy used here was to apply known or trusted base sources for control whenever possible (USGS imagery from 2008 was the most useful base due to accuracy and clarity of imagery). Then, if no recognizable control features were available, control points from other registered imagery falling closer in time to the imagery being registered were used. In many cases, it was possible to identify specific structures, vegetation, or patterns of pixels in imagery from other registered imagery.

As many as 30 initial control points were used for each image, with those points adding larger error being sequentially discarded until residual errors were sufficiently reduced under a second order polynomial rectification. All registration was initially performed using the following projection: NAD 83, State Plane New York Central FIPS 3102, US feet. Pixel size and band numbers varied per the original image characteristics.

In a barrier island environment, there is no choice but to use temporally sequenced control points representing pixel patterns as there are no readily recognizable features. The 1938 imagery was registered early in the study process without reference to other registered images (as opposed to orthoimagery). The 1942 imagery from McClennen was determined to be of poor quality, followed by the 1955 imagery revealing radical changes in barrier features due to inlet formation and landward migration of the barrier. Single frame imagery was also used to create consistent reference images used to assist with registration of multiframe imagery which, because each set of photos required separate registration, carried higher overall error.

Finally, tie points were used between multiframe images of the same year to achieve consistent registration along the overlapping edges of each frame. Overall, accuracy was checked against known features and found to be consistently good.

The focus of registration efforts was on inlet and shore locations. Areas at the far inland edges of photographs may not be as accurate and users should make independent assessment of accuracy for those areas. In some cases, warping was not corrected along these far edges.
As noted previously, several methods are used to assess accuracy of the final registrations including: 1) comparison against data sets of known high accuracy (single frame registered photography and the 2008 USGS orthoimagery data); 2) inspection of overlay with 1:24 000 USGS topographic quadrangles for photography used to generate those topographic quadrangles; 3) co-registration of derived shorelines along areas of the backside of the barrier spit in areas that showed little movement over time; and 4) identification of common features among different years of imagery. Overall, registration accuracy results were well below that necessary to measure shoreline changes.

Shoreline Change Analysis

Shoreline change analysis is a common tool used to measure linear change in the location of the barrier spit and its inlets in two dimensions. The goal in the analysis is to compare two or more shorelines and express the change in either rates of accretion or erosion.

Shoreline change analysis by aerial imagery interpreted shorelines was completed using the Digital Shoreline Analysis System (DSAS, USGS and Woods Hole Oceanographic Institute) (Himmelstoss 2009) in concert with ArcMap 10.3. This method has been the mainstay of conducting shoreline change analysis along the open ocean coasts of the United States as part of the National Assessment of Coastal Change Hazards (USGS 2017). The stated objectives of the National assessment are to:

- Develop methodology to produce and update nationally-consistent long-term coastal-change analyses that integrate historical data from sources such as maps and photographs with modern data sources such as LiDAR and satellites;
- Produce a publicly-available database of historical shoreline positions that is regularly updated as new data become available; and,
- Identify and understand the processes that affect long-term coastal change including geomorphology, human impacts, the cumulative impact of storms, and sea level rise.

Many studies have been completed for open ocean shoreline regions including Alaska and Atlantic, Gulf, and Pacific coasts. The Atlantic Coast analysis includes “methods of analysis, interprets the results, provides explanations regarding long-term and short-term trends and rates of change, and describes how different coastal communities are responding to coastal erosion along shorelines of Virginia, Maryland, Delaware, New Jersey, New York, Rhode Island, Massachusetts, New Hampshire, and Maine.”(Figure 34) (Hapke 2011)

Figure 34: Long-term shoreline change rates for several of the Virginia Barrier Islands (left) and the historic shoreline position data used to calculate the rates (right) as viewed in the Coastal Change Hazards portal (from USGS, 2017)

Shoreline Digitization

Once accurately registered historic imagery and more recent orthoimagery were created or assembled, a representation of the shoreline needs to be made from the imagery. Shoreline delineation depends on identification of a feature, such as the wet beach line or toe of dune line, which can be used to generate repeatable measurements. Research has been devoted to identifying variance and repeatability among these features, with most studies focused on the open ocean facing environment. Recent advances in topographic imaging using LiDAR have aided in determining how to measure shoreline at different features and their influence on shoreline erosion rate calculations (Laura J. Moore 2006). On the Great Lakes, several studies digitize the foot or crest of the dune or bluff (Baird 2006) (Calkin 1981) (Zuzek, Nairn and Thieme 2003). Zuzek et al., provide a comprehensive assessment of error sources and rates associated with assessing shoreline change and include analysis of the effect of transect spacing.

Digital shorelines were sketched for 13 sets of historic imagery following the wet edge of the shore plus the 1895 USGS topographic map. An additional 12 sets of more recent digital orthoimagery were sketched using the wet edge of the shore as determined by visual inspection and alteration of imagery appearance when possible. Because of the varying location of inlets and the changes in upland dune features, plus the inability to determine dune locations accurately in historic imagery, the wet edge of the shore is used as the identifiable feature. Overexposure of photography is the main reason dunes could not be identified, where the entire beach area is often uniformly bright. It was concluded that the wet shoreline would provide the most reproducible feature.

Wave run-up and lake elevation changes where the wet edge feature is located when looking at imagery from different years and seasons. Methods to control for this source of ambiguity are presented. Imagery enhancement methods to identify the wet shore included classified symbology based on image band values, adjustment of contrast and brightness, and use of colorized bands. Shorelines were digitized along the backside of the barrier island as an independent check of accuracy achieved by comparison of shorelines on features that are relatively stable, even in this shifting environment. Lake level was recorded for each data set using the NOAA Oswego station gauge for reference.

Digital Shorelines: Inventory and Display

Digital shorelines created for this study are listed, along with lake elevation and error metrics (Table 1).

Table 1: Digital Shorelines created for analysis. See appendix for source information. Elevation is lake elevation at time of imagery acquisition. RMSE – root mean square error, a general measure of image rectification accuracy. Error – a value used in shoreline analytical processes based on either stated map accuracy per map scale, rounded values based on RMSE for rectified images, or stated accuracy for digital orthoimagery.

Number	Year	Date	Source	Elevation	RMSE (ft)	Error (ft)
1	1895	7/1/1895	USGS Topo	244.0	na	80.0
2	1938	6/29/1938	SWCD	245.0	21.0	30.0
3	1942	5/9/1942	TVA NatArch	245.1	5.9	9.0
4	1955	9/6/1955	SWCD	247.5	26.9	27.0
5	1957	5/6/1957	USGS Mosaic	245.6	71.0	70.0
6	1960	5/19/1960	USGS	246.5	9.7	10.0
7	1965	7/2/1965	SWCD	245.0	16.2	20.0
8	1967	4/28/1967	OPC	245.6	9.6	10.0
9	1970	6/24/1970	USGS	245.9	9.2	10.0
10	1974	7/1/1974	USDA	248.0	12.0	15.0
11	1978	9/23/1978	SCS	245.0	7.2	10.0
12	1983	7/13/1983	NAPP	246.2	12.0	15.0
13	1991	10/29/1991	DOT	244.1	8.7	10.0
14	1994	5/3/1994	DOQQ	246.2	na	20.0
15	1995	4/17/1995	NAPP	245.0	8.5	10.0
16	2001	6/23/2001	IJC/USACE	246.0	na	15.0
17	2003	4/1/2003	NYS DOP	244.6	na	8.0
18	2004	7/1/2004	USDA	246.4	na	19.7
19	2006	6/6/2006	NAIP	245.7	na	19.7
20	2007	6/14/2007	USACE/JALB	246.0	na	2.5
21	2008	9/24/2008	NAIP	245.1	na	19.7
22	2008	8/26/2008	USGS	246.0	na	19.7
23	2009	7/10/2009	NAIP	246.5	na	19.7
24	2011	5/9/2011	NYS	246.6	na	8.0
25	2013	6/19/2013	USDA NAIP	246.5	na	19.7
26	2015	6/6/2015	NAIP	245.7	na	19.7

Mapping all shorelines at once for the study area creates a complex presentation of shorelines that generally shows the landward progress of the central area of the barrier system (Figure 35). The dynamic nature of shoreline change near the three major inlet areas is evident on closer inspection (Figure 36).

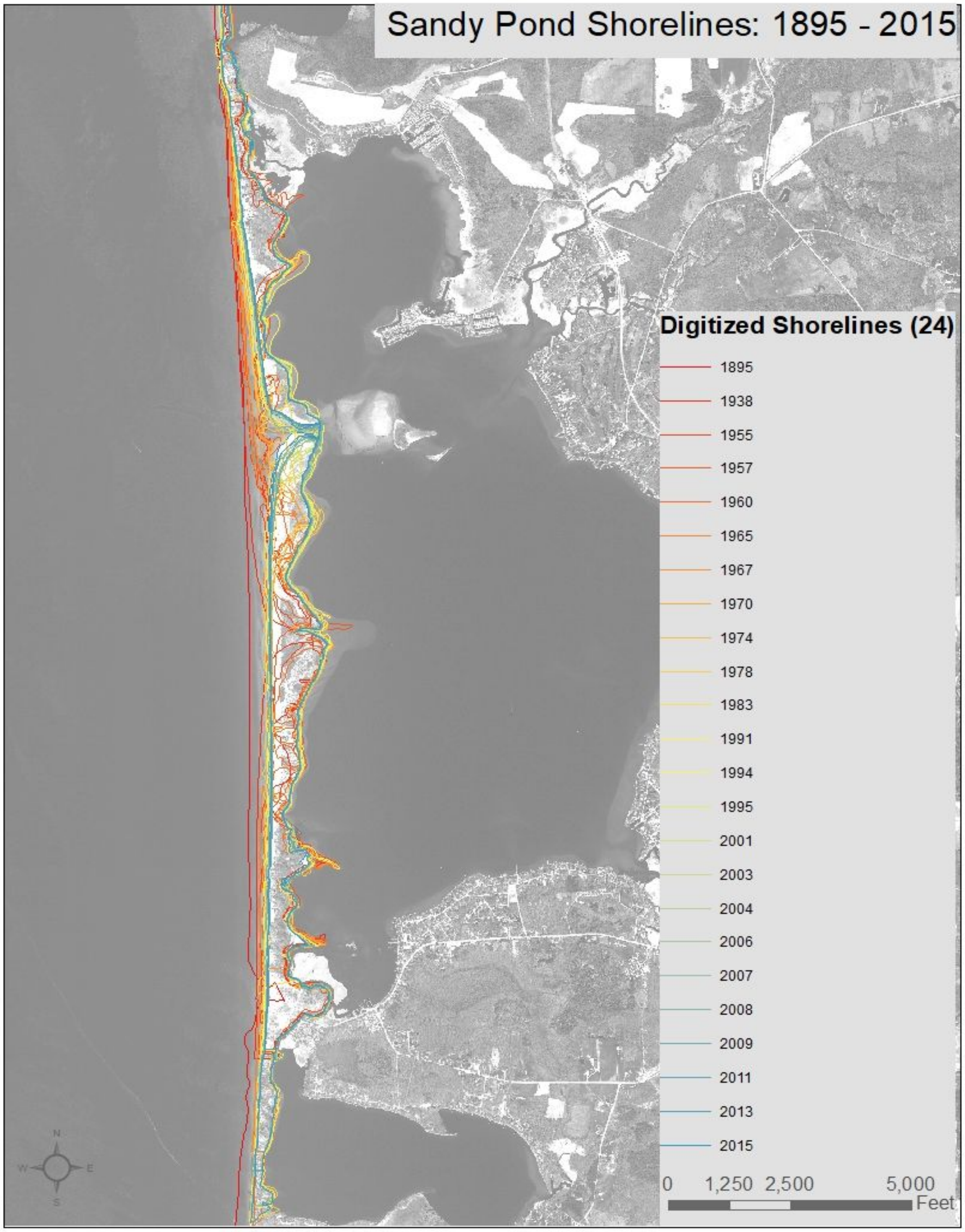


Figure 35: Digitized shorelines within the study area on 2015 base map

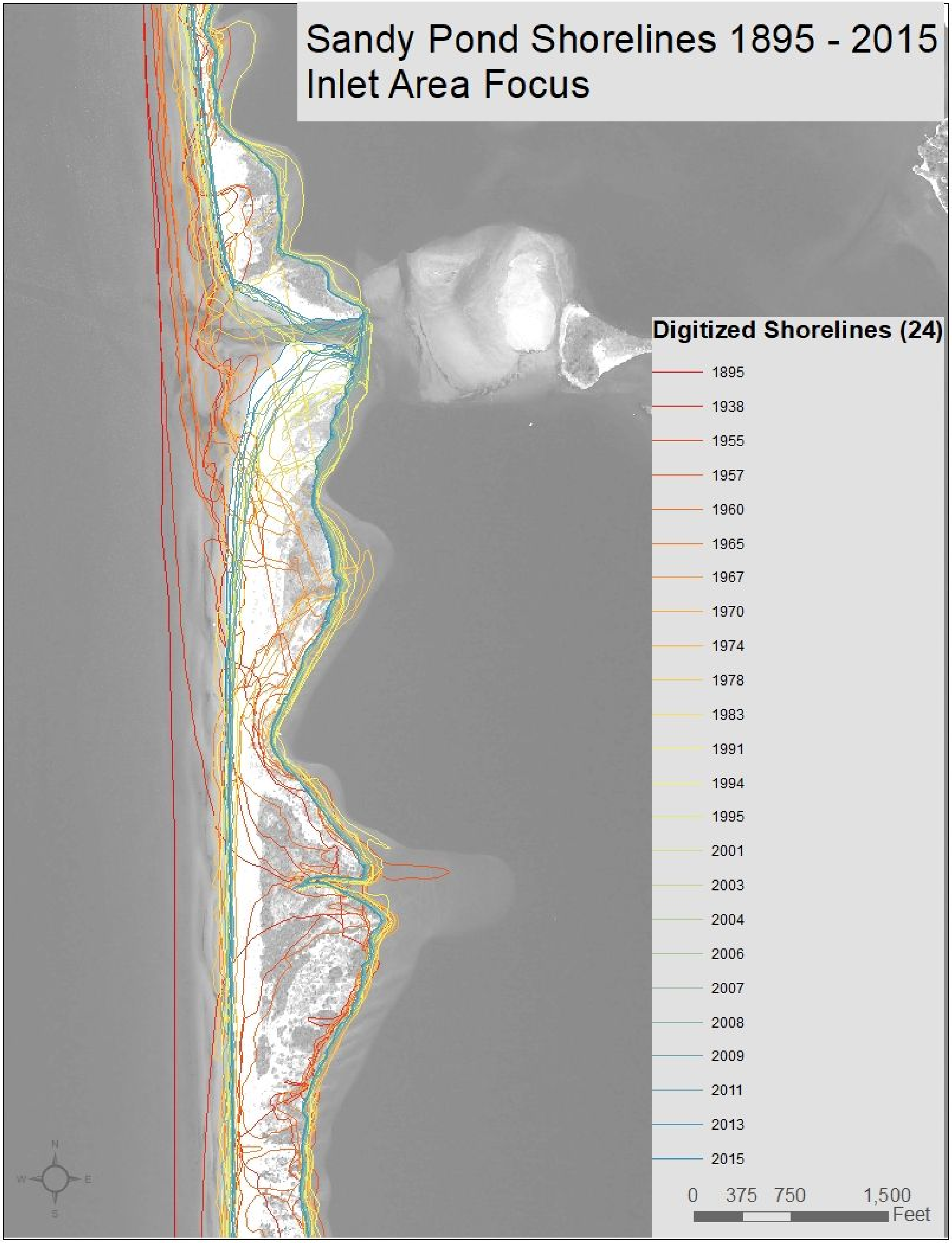


Figure 36: Digitized shorelines focused near inlet areas

Shoreline Representations and Lake Elevation

Within the Sandy Pond study area, prior efforts to conduct shoreline change in the study area were based on selection of several representative transects and tabulating the change in a limited number of shorelines as previously reviewed from Wier, Baird and Mattheus. For this study, the availability of 26 digital shorelines along with 160 transects allows for a comprehensive assessment of shoreline change and development of new methods to address issues with shoreline representation and changing lake level.

Variation in lake levels is significant over the 1938-2015 study period. Other researchers indicate the need to control for lake level and suggest altering the shoreline location based on a low water datum with the amount of correction based on observed nearshore slope. Weir noted corrections were made in his analysis using a 1 on 100 slope based on nearshore transects. How his corrections were made was not documented. Baird noted that the two shorelines selected in that study (1960 and 2001) had similar lake levels and calculated the small offset that would be needed for correction as being negligible. That study used the base of dunes as the shoreline measure to further control for lake level.

"Once registered, the toe of the dune in 1960 was digitized. This feature is commonly the edge of active vegetation for stable or accreting beaches or the base of the eroding dune scarp. Since the lake level difference between the two photographic series was only 0.13 m, the lines were not corrected for water level differences. For example, if we assume a 1:10 (V:H) beach slope the 0.13 m difference in lake levels only corresponds to a horizontal positional shift of 1.3 m or 0.03 m per year." (Baird 2011).

The possibility of applying offsets using nearshore slopes was evaluated in combination with LiDAR data observations from 2001, 2007 and 2011. Results were consistent with Wier's observations, but only in relatively static areas of shore fronted with relatively stable beach areas (Wier 1977). Wier measured beach profiles and reported correcting for lake elevation using a shoreline offset of 100 feet to compensate for a 0.8-foot difference in lake level. In this study, near inlets, nearshore slopes were measured and found to be highly variable due to shoaling and complex beach structure. At times shores near inlets showed steep features and, at other times, broad flat features. An analysis using 2001 LiDAR topobathymetric elevation data compared two sets of photography with different lake elevation ranges to quantify offsets. The beach face analysis shows that a difference of 0.8 feet (as measured in Wier) would require a lakeward offset of 150 feet corresponding to a 0.5% slope (Figure 37) while near the inlet, only a 22 foot offset is needed corresponding to the steeper 3.7% slope (Figure 38). Near-inlet changes are harder to compensate for lake level based on flats and shoals and steeper slopes, all occurring near each other.

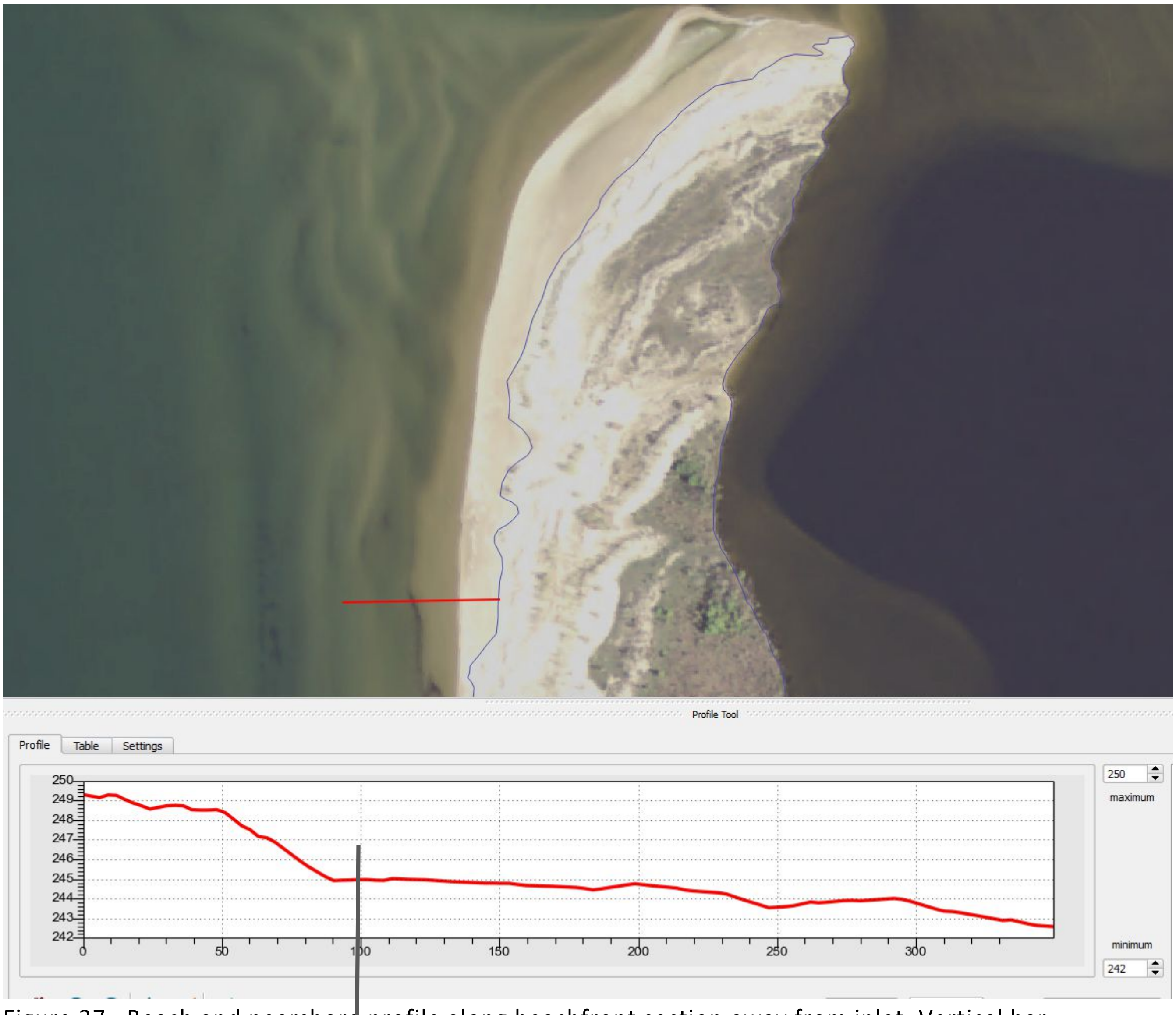


Figure 37: Beach and nearshore profile along beachfront section away from inlet. Vertical bar depicts shoreline location.

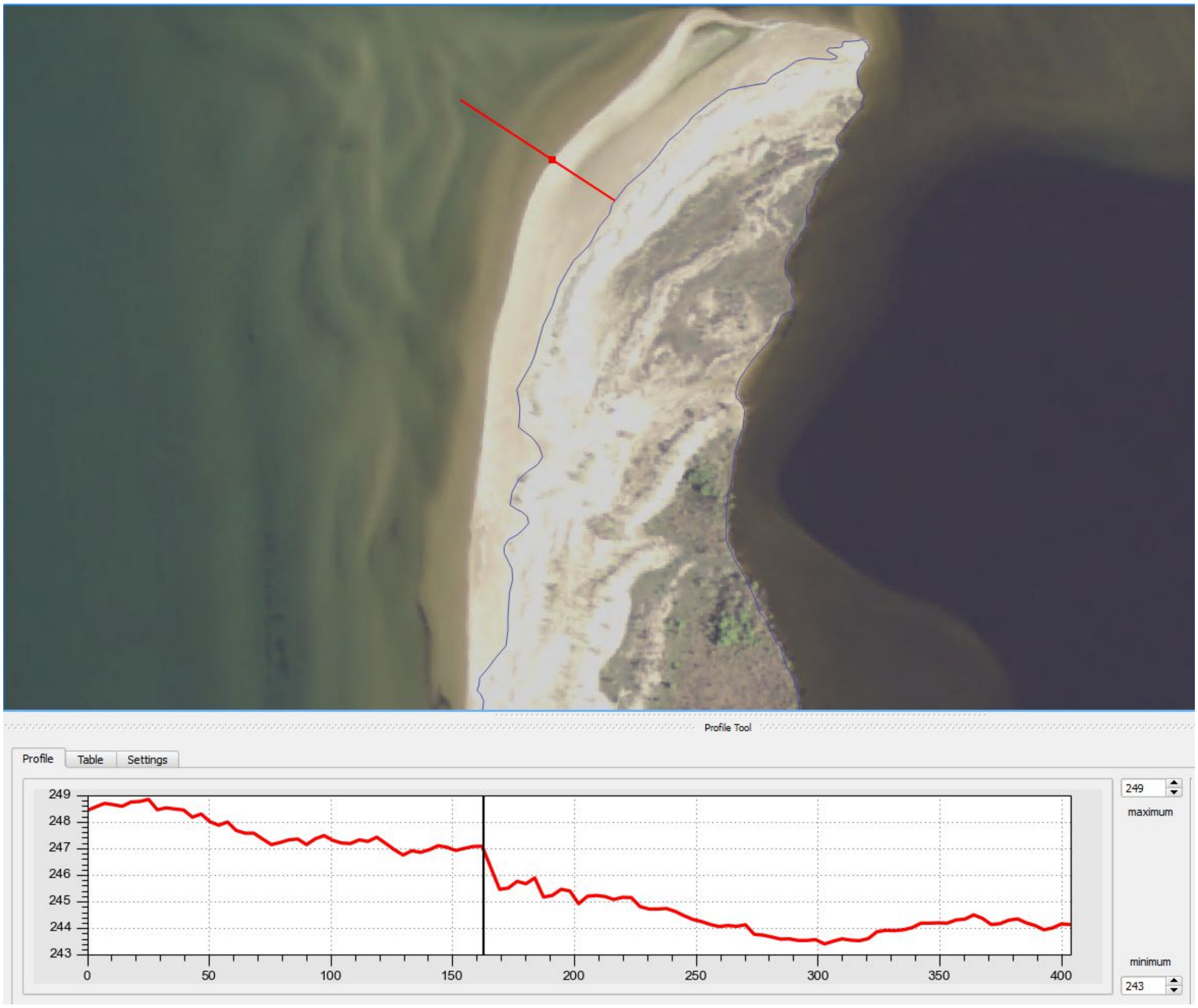


Figure 38: Beach and nearshore profile near inlet. Vertical bar depicts shoreline location.

Attempts to correct for lake level may introduce potential error well beyond anticipated shoreline change in inlet areas and were not adopted for this study. Rather, the wealth of recent imagery and a comprehensive collection of historic imagery allowed for development of a new approach. Lake levels for all imagery and derived shoreline data sets were analyzed and then selected and grouped by lake level. Shorelines from imagery at lake level 245.0 +/- 0.15 feet (A) provided a grouping of 6 data from 1938 to 2008. Four shorelines from 1957 to 2015 at 245.5 +/- 0.15 feet (B) formed the second group while 7 and 8 sets of shorelines were available at higher lake levels of 246.0 +/- 0.15 (C) and 246.5 +/- 0.15 (D) feet respectively. Outliers at low (2) (L) and high (1) (H) lake levels were not included in initial shoreline analysis until it could be determined what the effect of differing lake levels are on calculations of shoreline change.

Shoreline Representations and Inlet Locations

The study area includes a highly dynamic inlet environment, not comparable to many other locations on the Great Lakes or many marine environments. In other areas, shoreline change analyses often exclude inlet transects based on the open front or back side of the inlet depending on configuration and year. For example, in illustration (A) of Figure 39, transects reach into open water areas behind the inlet and cannot be used to calculate change.

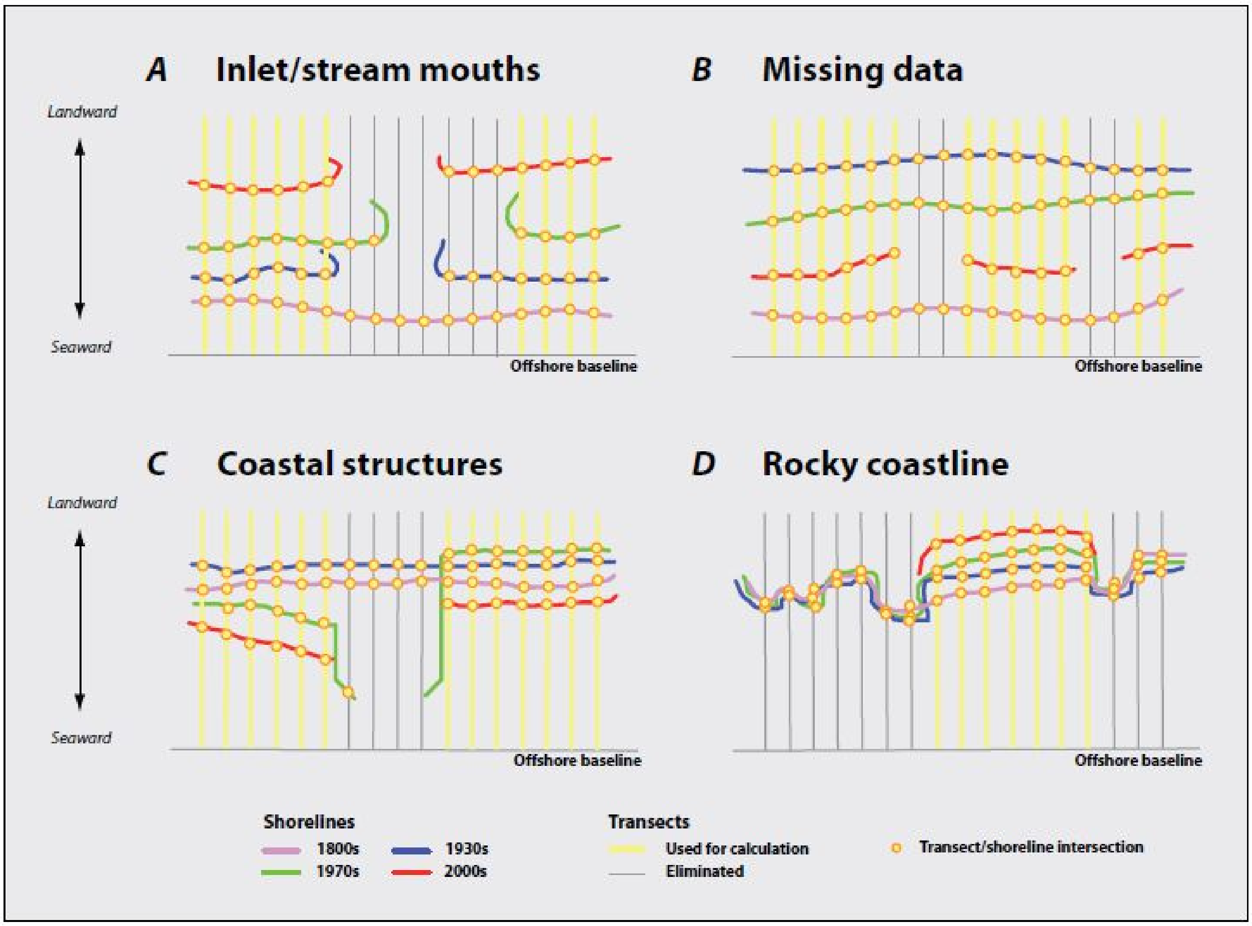


Figure 39: Schematic diagrams showing examples of common conditions where transects are eliminated in the absence of four shoreline intersections: (A) inlet/stream mouths, (B) missing data, (C) coastal structures, and (D) rocky coastline. (from (Hapke 2011)).

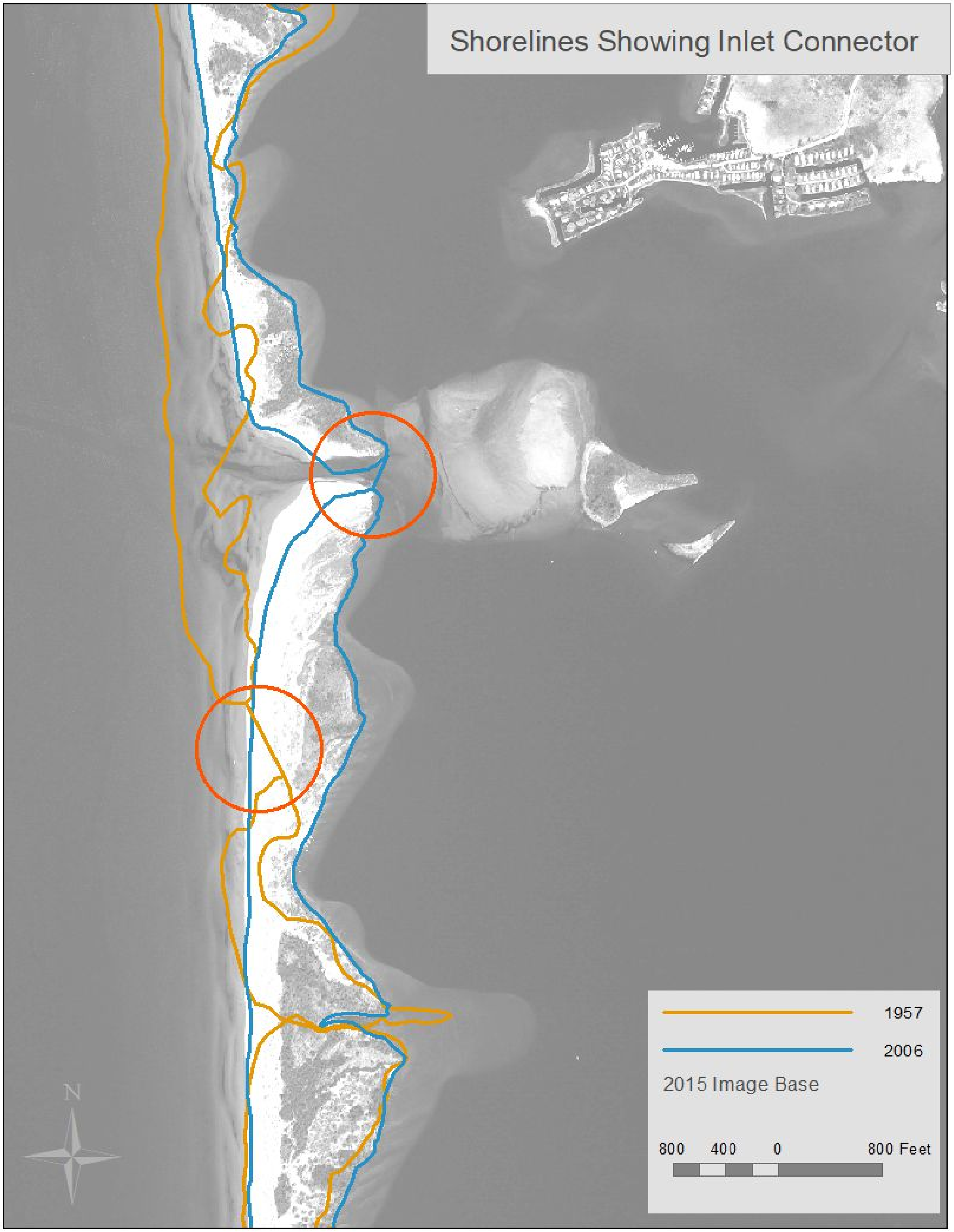


Figure 40: Method used to include inlet measurements in shoreline change using a line tangent to the landward limit of the inlet to connect pond shorelines

In the case of Sandy Pond, all areas of the shoreline at one point in time during the study was a cohesive or continuous barrier beach, with inlets forming in many locations between 1895 and 2015. A modified method was used in conducting shoreline change analysis to be able to include inlet area measures throughout. For each shoreline, an additional line was used to define landward extent of the inlet. This line was drawn tangent to the end of each recurved spit, that is, where the curve of the inlet shore turned away from the inlet and towards the Pond, a connecting line is included (Figure 40).

Shoreline Change Results

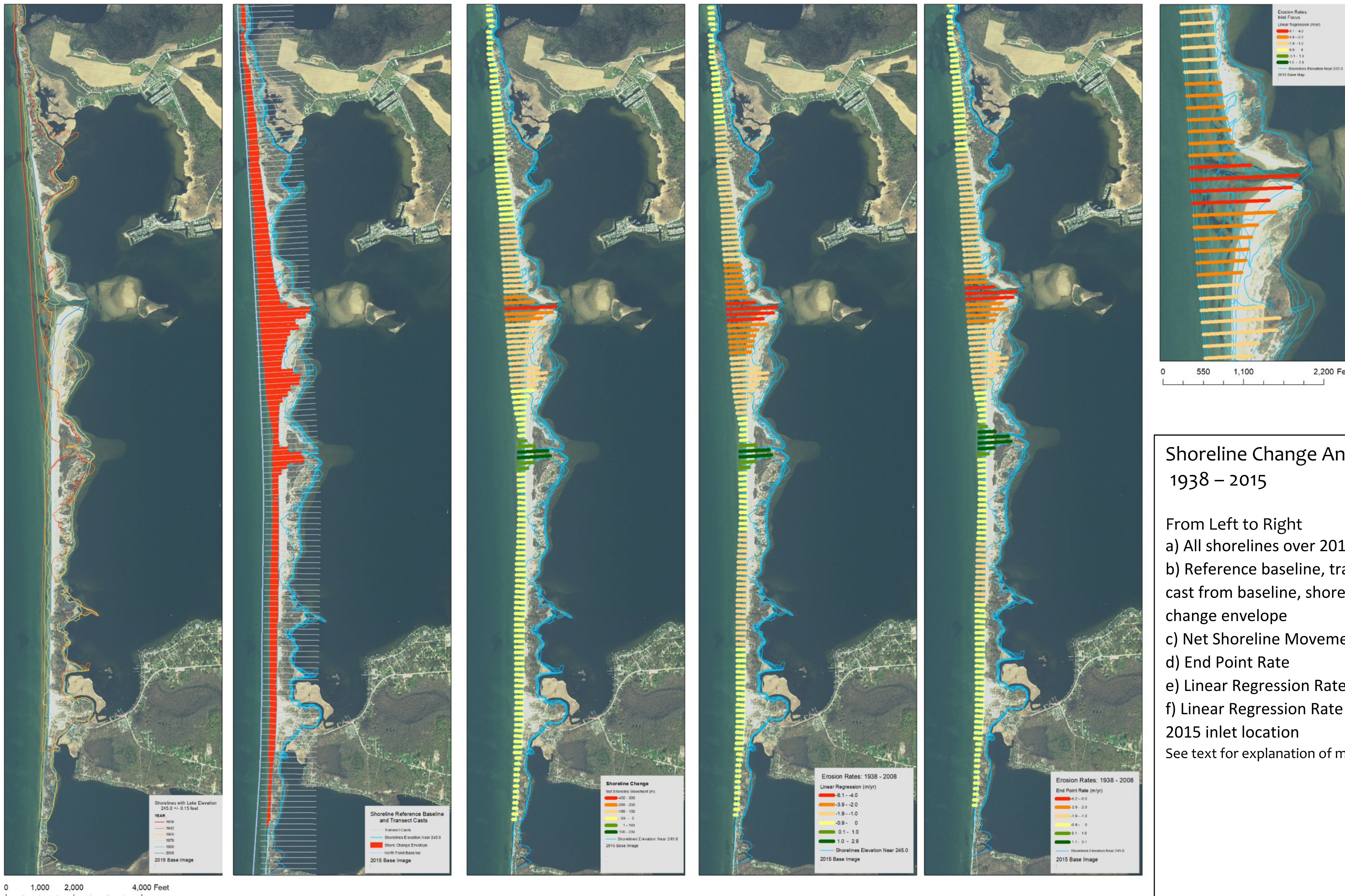
This section explains how shoreline change is measured in the study area, and displays the results of that analysis for two data sets illustrating the effect of lake level. The USGS Digital Shoreline Analysis System allows for analysis using transects across a study area, each generated at a specified interval. Once transects are cast from a reference line, each transect is analyzed per several available methods. First the greatest distance is calculated between all shorelines without respect to date of the shoreline to determine the shoreline change envelope (SCE). Net shoreline movement (NSM) is calculated as the distance between the earliest and latest shorelines. Adding date information for these two shorelines, an end point annual erosion rate is calculated (EPR). A linear regression rate-of-change (LRR) is calculated considering all shorelines intercepted by the transect with the slope of the regression solution representing the rate of change. A final method available is least median of squares solution which “minimizes the influence of anomalous outliers on the overall regression” solution. (Himmelstoss 2009). In addition, measures of statistical fit are available including R-squared and standard error (All shoreline transect metrics are included in the Appendix. Individual statistics are included for each transect: end point rate (m/yr), net shoreline movement (m), linear regression rate (m/yr), regression r-squared, regression standard error, and regression confidence intervals at 95%).

Using a narrow range of lake levels for shorelines (+/- 0.15 foot) allowed for comparison of shoreline change where no offset correction was needed for shoreline location based on water elevation. Results from six shorelines at 245 feet were compared to other groups of shorelines with common lake elevations (Figure 41). Comparison among these shoreline elevation groups indicated that the error associated with lake elevations over a range of two feet in lake elevations, produced comparable erosion rate results. Analysis of the first two groups of data shows little difference in range of calculated shoreline change absolute or rate values, though the locations of these values change based on the features included (i.e., inlet location) in the imagery set.

All shorelines, except for outlier low and high lake elevations (Figure 42**Error! Reference source not found.**) were then included in a complete analysis from 1895 to 2015. The 1895 shoreline from the corresponding USGS topographic map, accounted for most of the observed change in shoreline erosion rates, showing higher rates of erosion as this shoreline was located more lakeward than the earliest 1938 shoreline derived from photography.

From the 1938-2015 lake elevation 245 data set the range of change rates determined by linear regression was from 2.9 m/yr to -6.1 m/yr, while the all-shoreline analysis range of change rates ranged from 2.7 m/yr to -7.2 m/yr. Comparing the narrow lake level analysis for elevation 245 with the entire shoreline data with broader lake level conditions illustrates that the amount of shoreline change is large compared to errors that might be associated by not using lake level offset. In addition to producing results with comparable ranges of change rates, the distribution of those rates along the shore is similar (Figure 41, Figure 42).

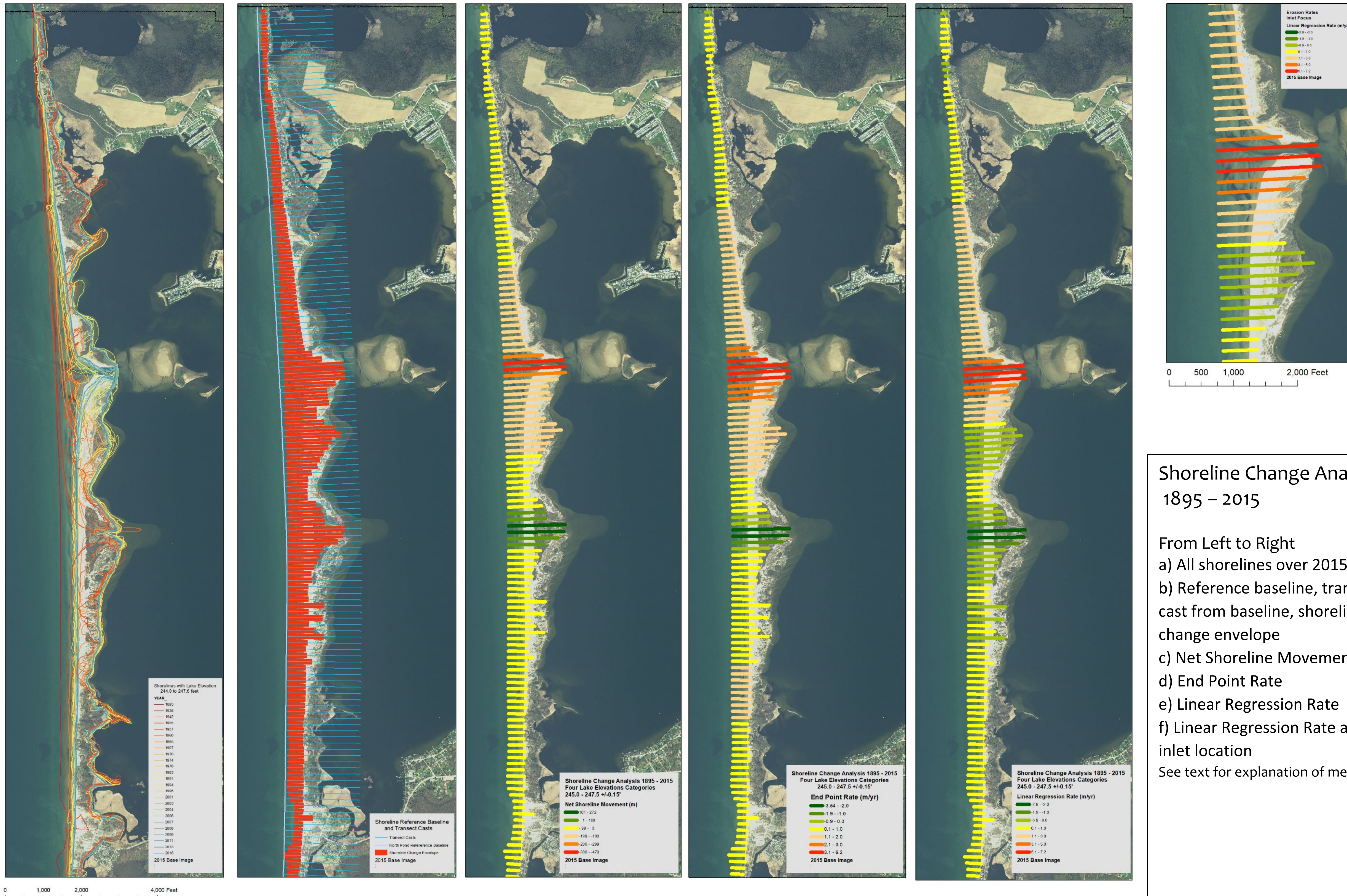
What does the shoreline change analysis show? The entire project study area has experienced substantial shoreline movement. Areas without inlet formation have retreated less with the lowest amounts fronting existing high dune features such as the blow-out area at Sandy Island Beach State Park, ostensibly due to the scavenging of sediment from the feature (Figure 43).



Shoreline Change Analysis 1938 – 2015

From Left to Right
a) All shorelines over 2015 base
b) Reference baseline, transects cast from baseline, shoreline change envelope
c) Net Shoreline Movement
d) End Point Rate
e) Linear Regression Rate
f) Linear Regression Rate at 2015 inlet location
See text for explanation of methods.

Figure 41: Shoreline change analysis 1938-2015 limited to shorelines with lake elevations near 245 feet IGLD



Shoreline Change Analysis
1895 – 2015

From Left to Right
a) All shorelines over 2015 base
b) Reference baseline, transects cast from baseline, shoreline change envelope
c) Net Shoreline Movement
d) End Point Rate
e) Linear Regression Rate
f) Linear Regression Rate at 2015 inlet location
See text for explanation of methods.

Figure 42: Shoreline change analysis 1985-2015. All shorelines included save for extreme low and high lake elevations


Figure 43: Dune blow-out showing lower shoreline retreat of ranging from 60 - 70 meters (left). Northern extent of study area with lower shoreline retreat ranging from 10 to 50 meters (right).

Areas with former inlets show gain in sediment due to the closure process (Figure 44). These analyses document the extent of sand that filled the former inlet from its landward extent forward. The shoreline itself has retreated 118 m from 1895 to 2015 in front of the 1938 inlet.

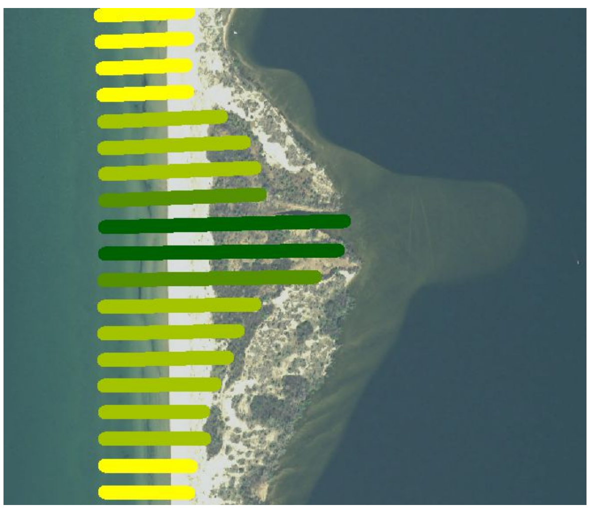
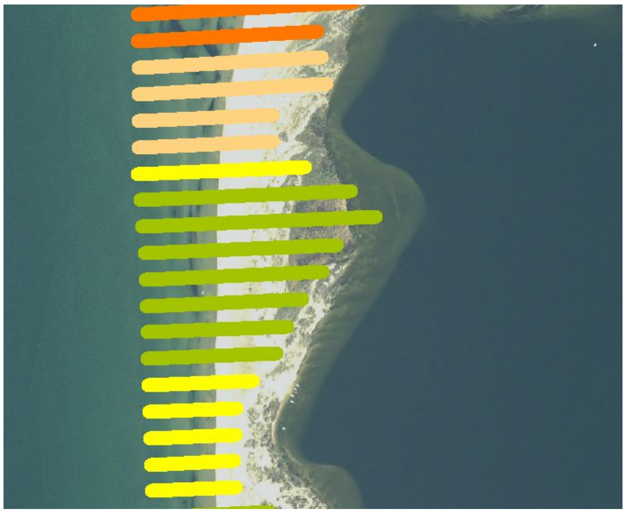



Figure 44: Former inlet locations show as shoreline gain areas. The shoreline has retreated in these areas, however the change analysis accounts for the gain in sediment on the pond side, showing a gain in barrier width. The process of the barrier system rolling towards the pond is documented by this analysis. The 1938 inlet closure shows significant growth (left), while the 1957 inlet shows less growth (right).

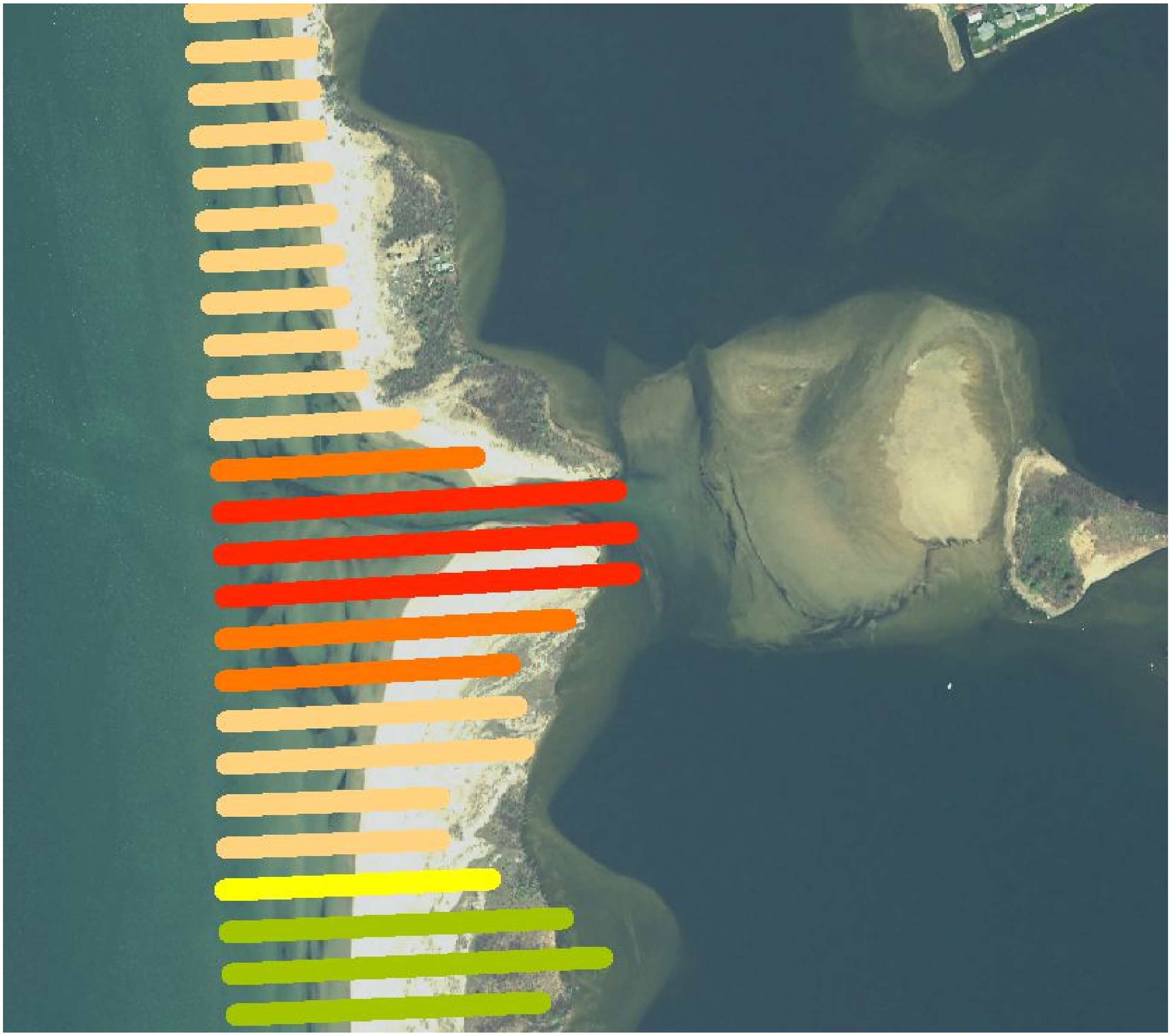


Figure 45: Shoreline recession at the 2015 inlet location. Barrier accretion is shown as fill in the 1957 inlet location, while landward recession at the 2015 inlet shows the highest losses.

The amount of shoreline recession documented in the shoreline analysis around the 2015 inlet is remarkable. Excluding the inlet transects, net shoreline movement in the immediate area of the inlet is between 200 and 280 m (Figure 45). There are two inlet morphological differences from prior inlets. One is the accumulation of sediment in the shoal fronting Carl Island, a feature not found in prior inlets. The second feature difference is the angular offset of the shore at the inlet location. With each new formed inlet, the shore and barrier system has rolled landward, effectively changing the angle of the shore leading to the inlet.

Figure 46: Comparison of shoreline locations - 1895 and 2015

Shoreline angle is an important aspect governing stability of shorelines. For example, groin fields (a series of shore-perpendicular jetties designed to capture and hold sand) are recommended to taper to the natural shoreline at not more than an angle of 4 degrees ((U.S. Army Corps of Engineers 1981). This design standard was used to reconstruct a groin field on Westhampton Beach, Long Island per recommendations of the New York State Coastal Management Program in the 1980's (Hart 1988). The reconstructed groin field has performed well since that time once the abrupt end of the field was tapered by reconfiguring two groins that were 480 feet in length to 417 and 280 feet followed by insertion of a groin of 337 feet in length between the two terminal groins. The main point here is that abrupt changes in shoreline angle (accompanied by sediment trapping in this example) can result in significant erosive forces.

Baird (2006) notes that the east end of Lake Ontario acts as a basin to trap sands based on both north and south littoral drifts occurring centered at the Sandy Pond inlet area (Figure 23). The changes in shoreline configuration since the late 1880's have significantly altered the function of the eastern shore acting as a basin for sand. In 1895 Sandy Pond barrier system showed a slightly concave shoreline, with a maximum offset from an artificial straight-line off-shore baseline of 60 m or a shore angle of 1.7° in both directions when measured from the maximum shoreline concavity centered near where the 1938 inlet would form. The entire shoreline from the 1895 inlet north indicates that the barrier system is slightly offset, creating a shallow basin.

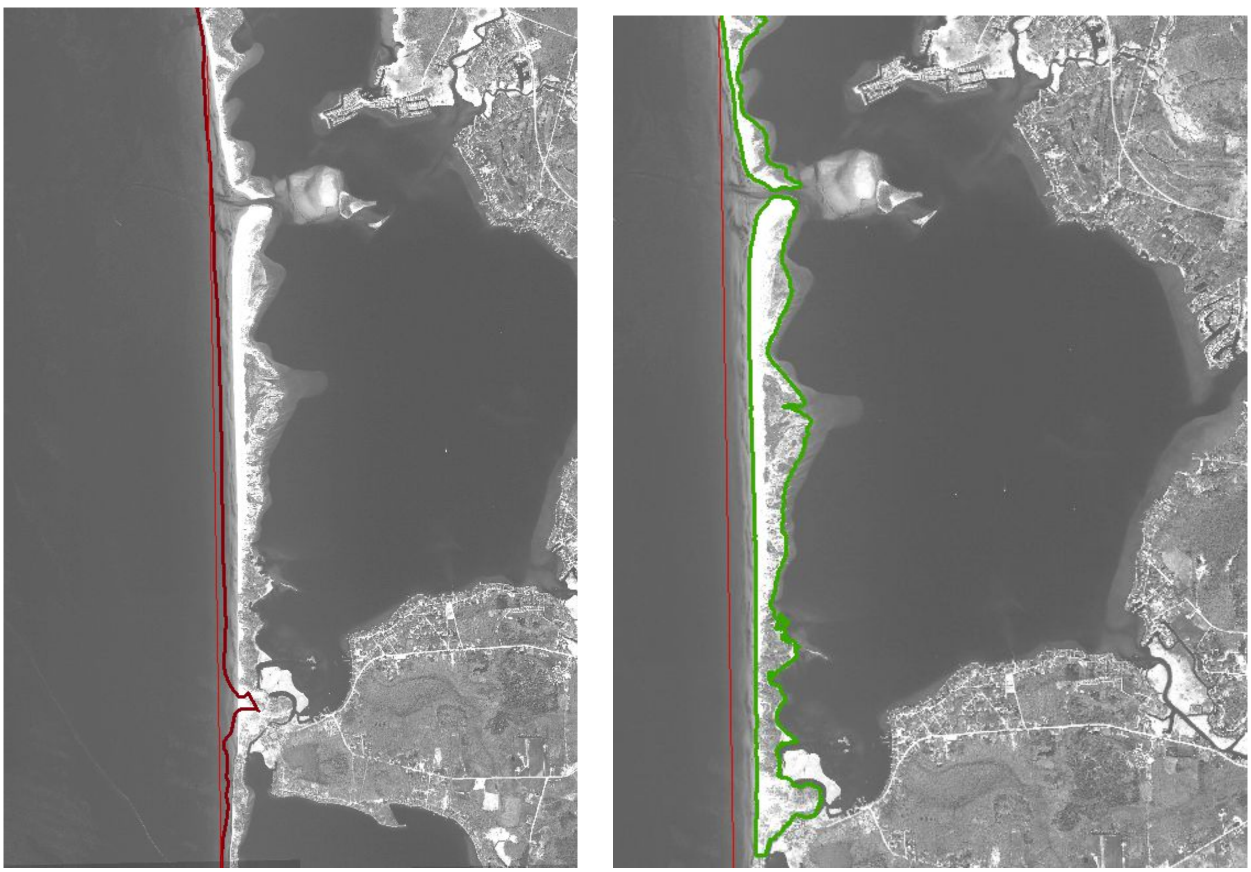


Figure 47: Shoreline offset from an artificial straight baseline compared to the shoreline in 1895 (left) and 2015 (right). 2015 background image.

The barrier system in 2015 illustrates a significant landward movement that is anchored at the north by high dune features and at south by shoreline south of South Sandy Pond. When the straight-line offset used to measure shore angle for 1985 is applied to the 2015 shoreline, the configuration shows a significant enhancement of the basin form. The southern barrier section straight line now is anchored further south at the south end of South Pond and shows a shore angle from this point to the 2015 inlet of 2.2°. The northern barrier section offset is more severe from the high dunes area to the 2015 inlet having a shore angle of 6.9°.

Why is this important? Shoreline angles will enhance the tendency for sand to be retained in the Sandy Pond area with the inlet acting as the apex for the shifts in north and south littoral flows. Carl Island may be involved by altering hydraulics near in the 2015 inlet compared to prior inlets in 1938 and 1957. The land formation in Wigwam Cove at the south end of Sandy Pond may provide an analogous comparison, where the structure at the back of the inlet became an anchor for sediment deposition. In this case, the 1895 inlet may have enjoyed a longer lifespan, with less influence of lake level changes based on hydrological restriction more dominated by stream outflows at the time. Even the terminology at the time suggests this with the barrier breach called the “outlet”. Historic collections suggest “with only the original outlet as a drain into the Lake, it must have been a very muddy, weedy body of water truly named a pond”. (Cole ND)

More importantly, the inlets act as conduits for sand into the Pond, with wave-suspended sand carried through the inlet with rising lake level and depositing in the calmer pond waters. With an increase in shore angle, the tendency for sand to accumulate or be retained in the basin formed by the shoreline curvature, will likely be greater, remaining near the inlet to be captured in the inlet recurved spits and the depositional shoal. This may provide a plausible explanation for why the shoal has formed at the 2015 inlet location and Carl Island and not at previous inlet locations.

In addition to acting as a sink for sand removal from the lake side, the higher shore angle for the northern barrier also offers a possible explanation for continued northward migration of the inlet. Further, the northern barrier appears to be losing mass under continued erosive processes. When compared with the formation of the 1938, 1957 and 1970 inlets, all cases reinforce the notion that the northern barrier continues to receive disproportionate erosive force and has led to a thinning of the barrier, then overwash during high lake level periods, which has historically been followed by new dominant inlet formation.

Inlet Dynamics

Historic Location of Inlets and Overwashes

Predominant movement of the barrier system has been due to inlet formation and lake-driven current passing through the inlet based on water elevation changes. Lake elevation changes drives the hydrodynamics of the system, save for periods of snow melt runoff from the watershed. Only in the spring runoff period do flows from tributary streams rival the flux of water forces in inlets due to lake elevation changes. During periods of rising lake level, sand in suspension due to littoral drift is carried into the pond, forming recurved spits and deposition shoals. When lake levels drop, the amount of wave energy in the pond is much lower leaving deposited sands in place and returning finer materials. Repeated pulsing of lake level layers sand deposits along the recurved spits and deposition shoals, removing sand from the lakeside environment. The occurrence of overwash processes is rare in comparison to active open ocean environments and contributes much smaller amounts of sand to the pond environment. Only photography from 1960 shows formation of over wash areas and that only for a brief period. Mattheus reported overwash processes as the major factor in barrier migration here which is not supported by the photographic record. Certainly, breaching the barrier starts with overwashes, but it is not the major operational mechanism for movement sand.

Another source of deposition in the pond is aeolian transport: winds carry fine beach face sands and that not captured in dune formation or by back-side vegetation, may be added to the pond. The area immediately south of the high dunes of the north barrier demonstrates this process of deposition and accretion. More importantly, once an inlet has closed, the beach face provides sand to rebuild the elevation of the barrier, all of which is carried by wind and deposited in dunes. The elevations of the recurved spits while an inlet is open is also based on wind-deposited sands. This is a significant source of sand for reconstruction of the barrier system and accounts for the significant elevation of sand in treed areas at former inlets. It is unclear what the limit is in dune height that can be built from exposed beach in recent years. The lack of cobble deposits and fine nature of sands in the high dunes indicates they too were formed by wind-driven sands as noted by Sutton (Sutton 1970).

How many inlets have formed over time? Most prior studies focus on the two main former inlet features associated with the 1938 and 1957 inlets. Although there are four main groupings of inlets (1885, 1938, 1955, and 1978), the variability of inlet formation accounts for 23 separate and distinct features, four of which are classified as over wash zones in 1960 (Figure 48). The system demonstrates remarkable dynamics with each epoch or period of new inlet formation, invariably accompanied by elevated lake level events. All inlets have formed by jumping from the prior location to the new location, with the prior inlet gradually closing over several years. The 1938 inlet closed over the course of 8 years, while the inlet from 1955 closed over 4 years from 1974-1978 over very different circumstances.

Figure 48: History of inlet and overwash locations - 1895 - 2015

Pre-1829 Inlet.

Sutton report an early inlet immediately north of the southern barrier's high dune that had closed prior to 1893 and Weir noted an earlier survey map in 1829 where that inlet is not shown. This location is also the location of the 1898 dredged inlet. The shadow of the depositional shoal is evident in 1978 imagery (Figure 49).

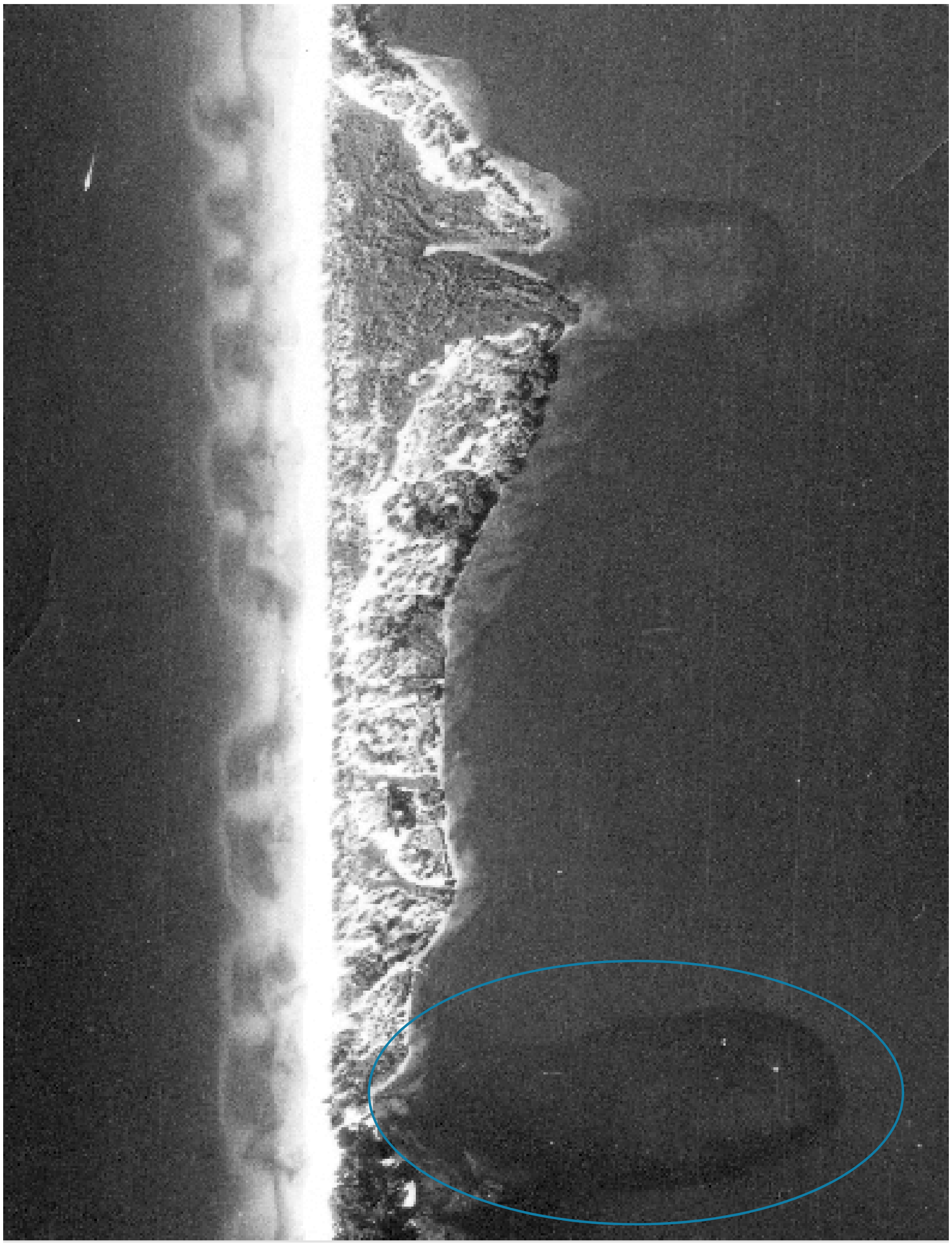


Figure 49: 1978 aerial image showing depositional shoal, potentially as an artifact from the reported pre-1829 inlet.

1893 Channel.

The channel located at the south end of Sandy Pond was already well-developed by 1893, with shoaling during low waters making navigation difficult (Figure 50). The area was simply known as the Outlet at Wigwam Cove. By 1896, funds were obtained to dredge a new inlet to establish a port of refuge. A barge-mounted bucket dredge first gained access to the pond by excavating through the outlet and then moved north to the wind scoured section north of the high dunes to create a new channel in the same area as the pre-1829 inlet. The marsh now located in the cup shaped pocket of shore is likely a combination of inlet shoal deposit overlain by wind-borne sands. Note how much this area gained significant elevation due to wind transported sands.

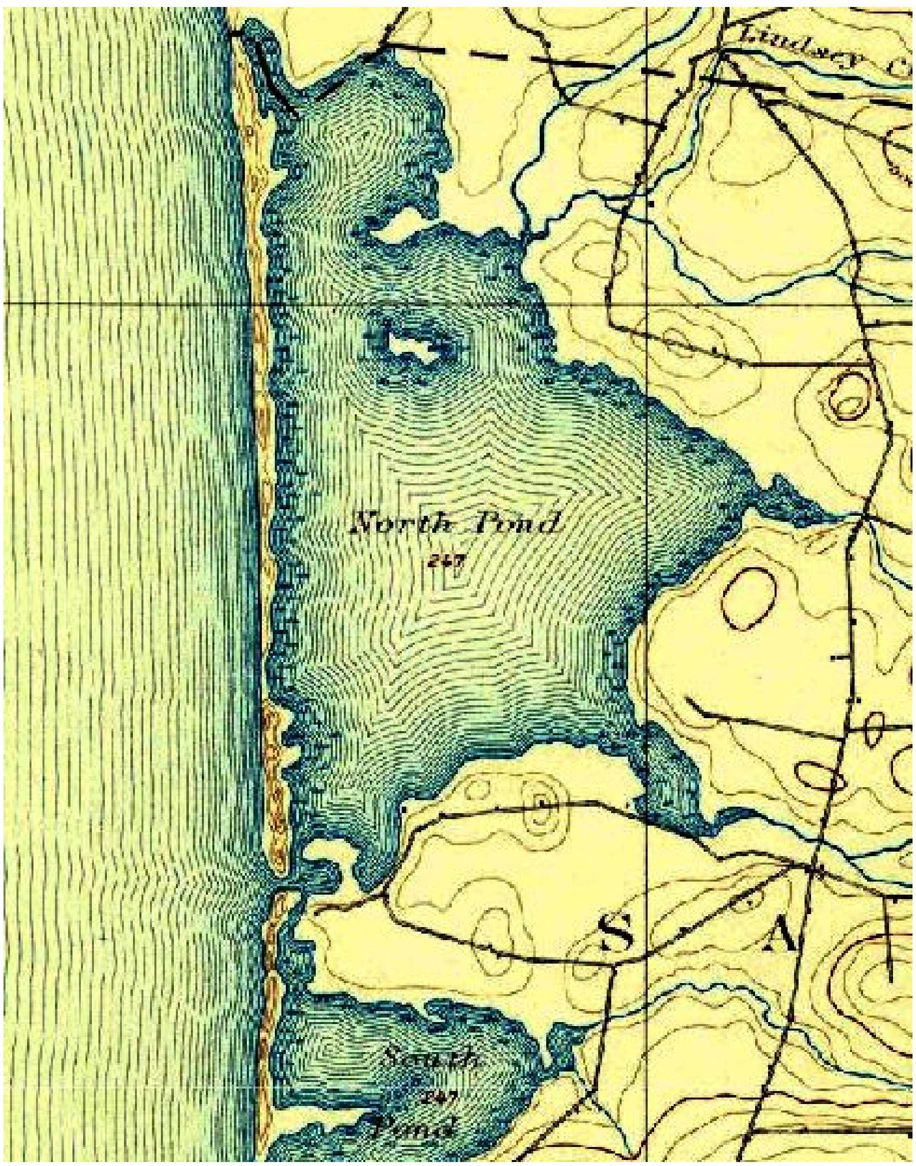


Figure 50: 1895 USGS topographic map showing outlet location at Wigwam Cove

1938 Inlet. This report refers to the main southern inlet on the south barrier beach as the 1938 inlet, in part because the date of the new inlet was not known at the start of this project. Weir reported that a new inlet formed in 1911, citing an 11 August 1911 SCN article at that time. The paper did not publish on that date and reports from that period matched of low lake levels reported by NOAA's Oswego lake level gauge. An inlet forming in 1911 seemed unlikely, given low water conditions. Writers were eloquent in documenting the broad sandy beach in 1911 (Figure 51).

> Would you like to see the nicest, smoothest beach that you ever saw or could imagine? If so, come to the lake. Would you like to see a great marvelously smooth cement block tnat varies in width from one to two hundred feet and that extends in either direction both noith and south just as far as the eye can reach? If you wish to behold the marvel of a life time, if you would see the wonderful work of the tempest in smoothing out wrinkles and in evening up irregularities, come and behold this great stretch of smoothed sand. Bring a pencil and paper to compute the number of grains of sand that are employed in this great work. Ask yourself how long it took to grind all of this sand from the fragments of rock which lie upon the shore in the form of smooth stones along the beach in the southwest corner of our town. The low water is largely instrumental in forming this great natural wonder The great west winds cause monster waves to rush up with irresistible force against the foot of the high ridge. These smooth out every wrinkl .

Figure 51: The beach in 1911 is described as a "marvel of a lifetime" (SCN, 23 November 1911)

To determine when the inlet in 1938 may have formed, imagery for the inlet formed in 1957 was reviewed from 1957 through 1965 and then compared to the earliest record for the 1938 inlet. An aerial oblique image from 1936 was compared to the 1957 series and determined that the inlet, if formed under similar circumstances, would have formed between 5 and 8 years prior to the time of the photograph (Figure 52).

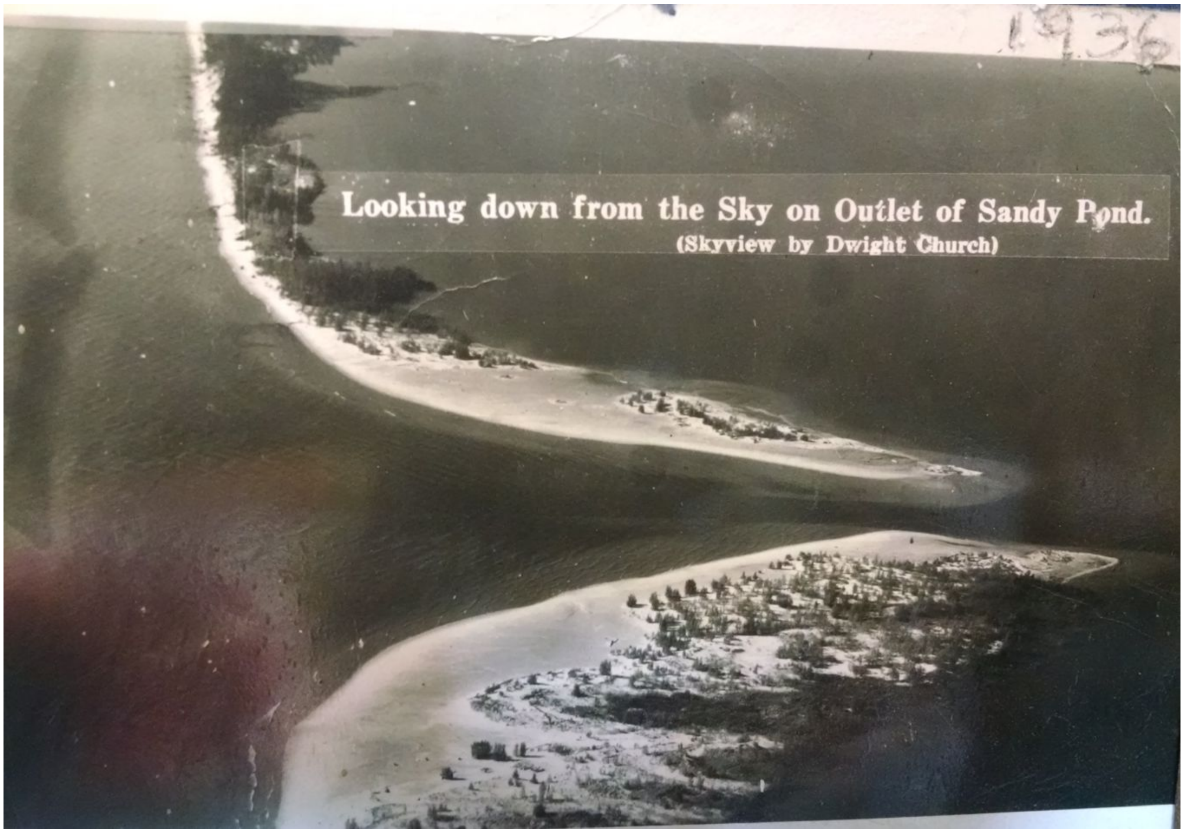


Figure 52: 1936 aerial image documenting early formation stage (courtesy of K. Goodnough)

Using a likely 5-8 year prior formation period as a guide, lake elevation records were reviewed from 1928-1931 and high water in 1929 and 1930 was identified as the likely period for inlet formation and further investigated (Figure 53, Figure 54).

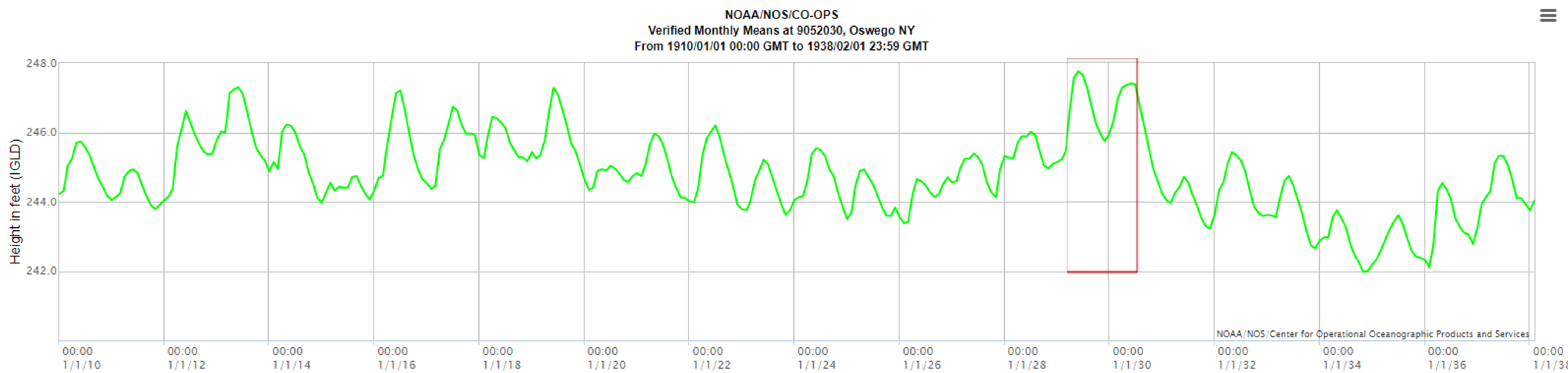


Figure 53: Lake levels 1910-1938 from NOAA Oswego Station historical data. High water period in 1929-1930 highlighted. Note low water in 1911.

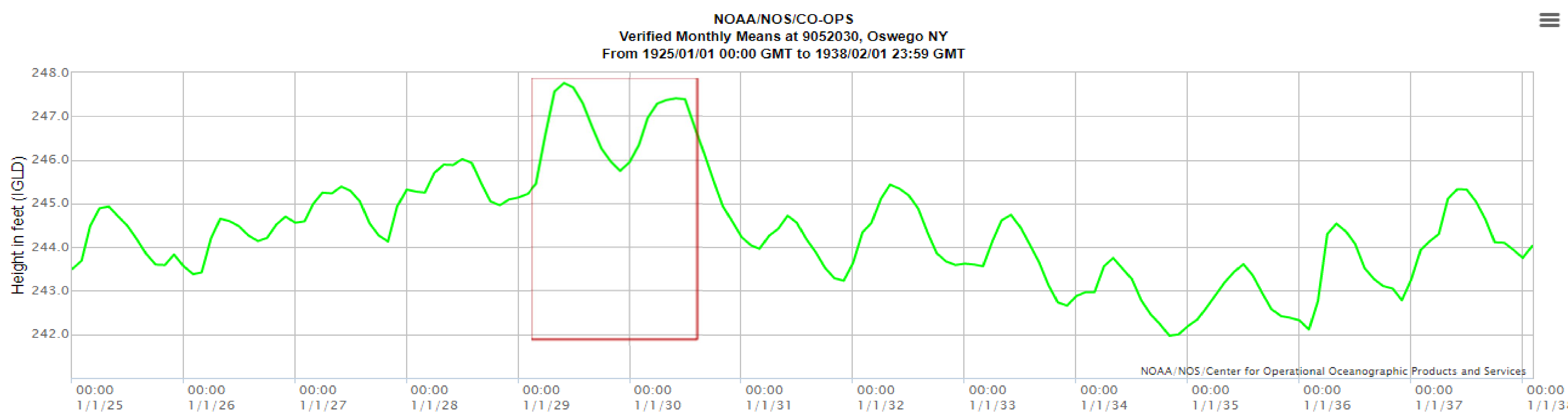


Figure 54: Lake Ontario Water Levels from 1925 – 1938 with high periods in both 1929 and 1930

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Twin Villages Escape Damage From Wind Storm Monday Night

Vicinities of Adams, Henderson, Selkirk and Oswego Retain Heavy Losses to Property

Slight actual damage has been reported locally as resulting from the wind storm of Monday. Trees and telephone poles were down across roads in places, making driving difficult. The electricity was off that night between the hours of 10 p. m. and 4 a. m.

The first that Adams realized the serious consequence of the storm was when a telephone call came from J. A. Bradbury on the Harold Gates farm at Thomas Settlement asking for help in the rescuing of his cattle which were caught in a barn which had collapsed. The roof of the barn was first taken off and then the barn was blown several feet from its foundation, the whole structure collapsing. Some of the 20 cows in the barn were uninjured and free, others caught beneath timbers were later pulled out to safety while seven were killed. Of the three horses in the barn one was killed.

Mr. Bradbury's 14-year-old son was in the barn when it collapsed. Realizing the danger, he got in the auto, seeking the protection of the seats. Luckily the auto was unharmed and the boy made his way out of the fallen structure in safety. Mr. Gates carried no insurance to cover the loss of barn or cows.

At the same time roofs were blown from two buildings on the Collins & Bates farm and one from a barn on the Pitkin farm on the Adams Center road.

A silo is reported blown down on John Johnson's farm at Allendale, and a man who was driving his car from Lorraine to Adams had his windshield broken and the whole top of his car torn off. Several large trees were blown down and many branches broken off.

The strong wind from the west caused two so-called tidal waves at Henderson Harbor, one at 1 p. m., Monday, when the water rose four feet, and one at 2 the following morning when the water was even higher.

The high water lasted about half an hour and with the strong west wind blowing did much damage to boat houses and boats.

Dr. Dulles' boat house was demolished and the boat damaged, also boats belonging to Dr. H. E. Ralph, E. B. McCumber and Dr. Fawdrey, G. T. Jewell and Robert Brodie. Little damage was done on the west shore of the harbor. The total damage along the lake and river is estimated at $1,000,000.

Selkirk was visited by what old residents say was the hardest blow ever experienced in this part of the country. As the storm approached the lake and clouds were both of inky blackness and big waves were lashing the shores of lake and river. Huge waves as high as those in the lake were lashing at the buttments of the docks and cottages along the shores of the Salmon river up as far as the new long bridge at Port Ontario.

The water at the mouth of the river raised until it overflowed the road and crept up to and surrounded the Lighthouse hotel and also the Fitch cottage. Continued beating of the fierce waves soon completely washed away the breakwater and the surrounding property is covered with the logs, ties and other wreckage washed up by the storm. The road is washed out and big holes worn in it which make travel impossible. All walks to cottages, roofs and porches from some, and docks washed away, are among the numerous damages done.

The water at the mouth of the river raised from four to six feet high and all docks across the channel were also washed away with the exception of the concrete one owned by Dr. French, and the cement wall was all that saved his cottage from being washed out into the lake.

The diving tower was blown down and washed away. So great was the damage done that it will take the greater part of the summer to repair it.

Sam Abbott, fisherman and trapper, who lives in his cottage the year around was surprised to see the water creeping in over the floor of his cottage and it soon extinguished his fire and he was obliged to wade waist deep in water to the Goodwin barn where he sought shelter for the remainder of the night.

Abbott had another experience with the wind this winter. He had gone on the rounds of his trap line, leaving his boat tied at the shore. The wind came up and the boat was washed from its moorings and drifted away. It was a case of either get another boat or swim and not being able to find another boat it was up to Abbott to swim the river across to his home side. This he did.

The marsh lands are flooded and the road washed out nearly up to George Bohannan's place. Wreckage strews the lawns and even up to the buildings, some distance from the lake and river. Lillie's boathouse is turned over into the river.

Estimates made placed the damage in Oswego as the result of the storm at many thousands of dollars. A survey of conditions made by officials of the department of public works disclosed that the damage was more extensive than it was first believed. The storm worked havoc along the water front and it is evident that it will be necessary to construct a new pier around Grampas bay on the east side of the Oswego harbor.

This property is owned by the New York, Ontario & Western railway. Under government regulations it will be necessary for the owner of the property to renew the structure. Heavy gales of the past year or more have been gradually weakening the pier and the storm added greatly to the damage.

According to Capt. George A. Jackson of the U. S. Coast Guard station, it was the most severe storm experienced in many years. The action of the water did considerable damage to the coast guard boathouse. A surf boat which was out of the water over the slip in the boat house was carried trough the doors and driven up the river a considerable distance and then tossed upon the shore.

The wind also did much damage to the buildings at the Oswego Yacht club. Several boats were damaged. A gasoline pump at the end of the yacht club dock was wrecked. Other property along the water front suffered considerably.

Throughout the city the damage was extensive. More than 20 trees were either uprooted or broken off at the base and huge limbs were torn from trees. Employes of the department of public works were busy during the following day removing trees and limbs. Linemen of the lighting and telephone companies were also busy making repairs to broken lines.

Houses suffered damage by falling trees. Among the residences damaged was that of Allan W. Davis in East Fifth street Oswego where a huge elm was uprooted. Several other homes were damaged. A smokestack on the Hotel Pontiac was blown down while the flag pole at the Oswego state normal school was damaged.

Reports from the surrounding country indicate that much damage was done to buldings and trees. Summer homes at Beach Oswego and vicinity which received the full force of the wind sweeping across Lake Ontario suffered considerably.

Figure 55: Storm documenting significant external seiche effect of two lake "tidal waves" each of over 4 feet at roughly 13 hours apart (SCN, 04 April 1929)

HUMAN SKELETON IS UNCOVERED BY WAVES AT RAINBOW SHORES

Discovery of a human skull while picking up a load of stone on the Rainbow Shores farm six miles southwest of Sandy Creek, on the shore of Lake Ontario, was the gruesome experience of Arthur Burdick last Thursday morning. The skull, that of a man, was found when he moved a log beside a sand bank and bent to his assigned task. The rest of the skeleton was later found covered by sand.

He was so startled he immediately returned to the home of Miles Obleman, manager of Rainbow Shores farm, and reported the find, refusing to return with Mr. Obleman.

Mr. Obleman verified the report and telephoned the state troopers' barracks at Pulaski.

Sergeant William McNichol, accompanied by Troopers Sockman and Dudden, made an investigation assisted by Coroner's Physician Dr. A. G. Dunbar.

The skeleton was unearthed about two feet under ground, with the head entirely uncovered. The washing of the waves against the shore for years has swept the shore line all of 300 yards, in about 25 years, old residents say, and the body was located just under the edge of the sand bank at the edge of the road leading to the lake. The head and some of the back bones were dug out and taken to the Pulaski barracks.

Figure 56: Recovery of sand-buried human remains in May, 1929 (SCN, 09 May 1929)

Significant storms and related damage were documented starting in April of 1929 and in May 1929 (Figure 55). An external seiche is a basin-wide wave that is formed from a prevailing wind, much as would happen in tilting a cup of water (an internal seiche happens when a lake in thermally stratified in summer and the wave oscillation occurs between the lower and upper lake layers , explaining why offshore temperatures at Rochester can swing dramatically in summer).

Human skeletal human remains were recovered from Rainbow Shores after they were exposed, documenting increased erosion and excavation of the beach and dunes that had built up over time (Figure 56). Of interest is that local residents indicated a loss of 300 yards of sand over 25 years, consistent with reports of broad beaches in prior years, if somewhat exaggerated (Figure 57).

In May and June of 1929, heavy winds combined with high waters were noted several times and the formation of two new inlets was document the week prior to 20 June 1929 (Figure 58). Loss of sand banks, probably including some higher dune areas, are also noted.

Robert Graves, lighthouse keeper on the Galloup Islands for twenty-six years, stated that the storm that swept the lake Thursday was the worst he had ever seen. The lake is thirty-two inches higher than it was a year ago, and this in connection with the terrific wind, caused a great deal of damage to property along the shore. It is reported that practically all lighthouses along the lake will have to be repaired this season because of the high water. At Selkirk, the oldest citizens of the locality, said they could not remember the lake in such a turmoil. Over a thousand people motored to the shore at that point to see the unusual sight. At the height of the storm the waves dashed over the cottage belonging to Dr. French. At Pine Grove, the beach was covered with water and several of the smaller cottages were badly damaged.

Figure 57: May Storm recorded as the worst in memory (SCN, 23 May 1929)

July 1.

High water and heavy winds have changed the lake beach in the western part of the town to the extent that at places there is scarcely room to walk. Several of the high sand banks have disappeared and two new outlets from the bay have opened deep enough that a row boat may pass through into the lake. It is conjectured that it will be only a few years before old Lake Ontario will swallow up the remaining sand banks and rush into the bay. Some of the cottagers at the bay are obliged to get into their boat from the front porch,

Figure 58: New inlet documented (SCN, 20 June 1929)

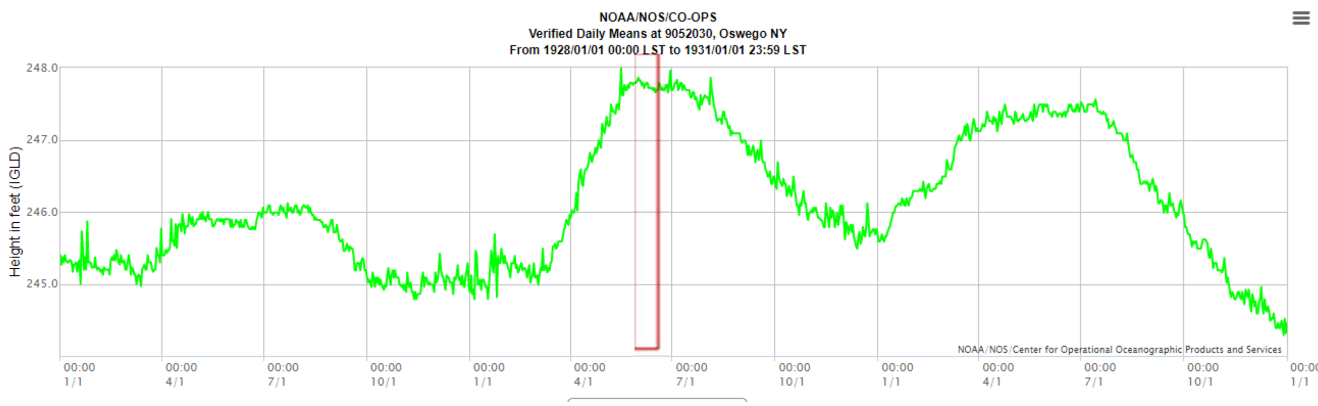

Figure 59: Daily lake level 1928 - 1930. Inlet opening date highlighted with water level near 247.8.

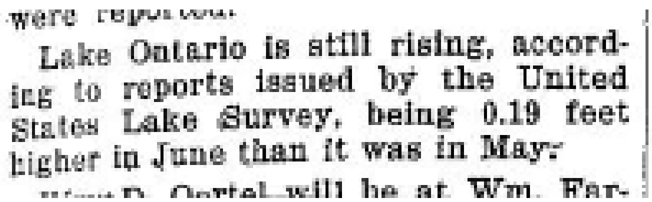
Lake Ontario is still rising, according to reports issued by the United States Lake Survey, being 0.19 feet higher in June than it was in May.

Figure 60: High water remained into June 1929. High water does not usually increase in June (SCN 11 July 1929)

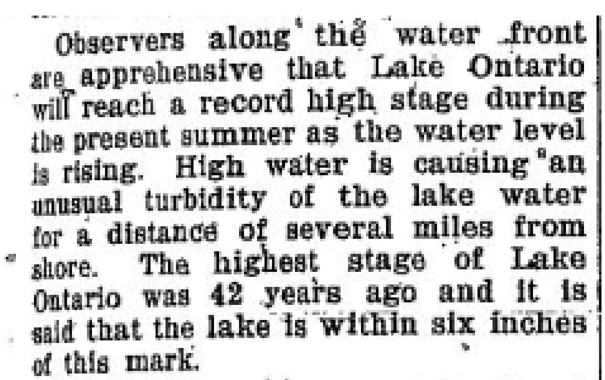
Observers along the water front are apprehensive that Lake Ontario will reach a record high stage during the present summer as the water level is rising. High water is causing an unusual turbidity of the lake water for a distance of several miles from shore. The highest stage of Lake Ontario was 42 years ago and it is said that the lake is within six inches of this mark.

Figure 61: 1930 High water (SCN, 17 April 1930)

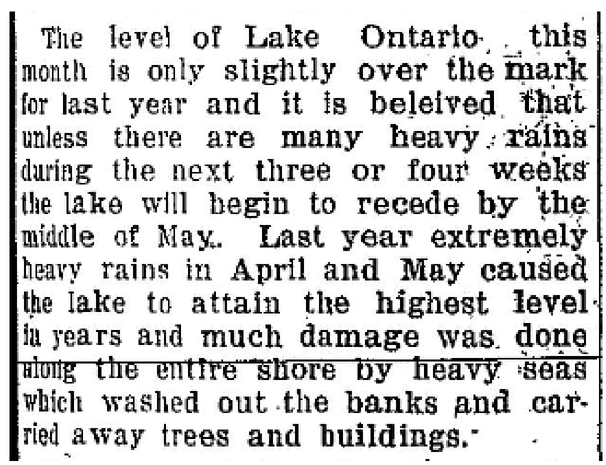
The level of Lake Ontario this month is only slightly over the mark for last year and it is beleived that unless there are many heavy rains during the next three or four weeks the lake will begin to recede by the middle of May. Last year extremely heavy rains in April and May caused the lake to attain the highest level in years and much damage was done along the entire shore by heavy seas which washed out the banks and carried away trees and buildings.

Figure 62: Retrospective view from 1930 (SCN 24 Apr 1930)

The answer to when the 1938 inlet formed is in the first week of June, 1929. Why does this matter? The observed size and deposition shoals of the 1938 inlet are very large, but did not match the expected size of material that should have been deposited over a 44-year period, nor does it match the observed life-span of the smaller 1955 inlet. The idea that an inlet would form during very low lake levels did not match the expected coastal processes for inlet formation. Solving this mystery in the absence of aerial photography, and documenting a 26-year lifespan for this feature that was formed at high lake levels reconciles expectations with observations. This all helps gain an understanding of how the barrier system is responding to lake forces during high water.

Modern Inlet Dynamics

Prior inlet formations have been driven by saltatory processes, that is, each new inlet has jumped to a new section of the barrier from the former inlet. The coastal processes controlling inlet form and function prior to 1978 resulted in inlets that remained in the same location on the barrier, only progressing towards the pond and not migrating along the barrier beach. The 2015 inlet underwent complex evolution, with first overwashes documented in 1979 imagery where formation of a new inlet started 1000' to the north of the main 1957 channel. The northern spit is undergoing dissolution between these inlets with a small island and shoal complex remaining. An additional overwash area is 950 feet further to the north, fronting the large channel feature on the pond side, visible since 1938 photography. This is the starting location of the current 2015 inlet. The small overwash seen in 1970 is the major inlet by 1974, leaving a 1275' island under assault between the two inlets (Figure 63). The lobe of the south spit remains visible in the current 2015 inlet complex preserved in location when the southern inlet filled. Historical inlet formation also follows a similar pattern where in 1929 and again in 1957, when two inlets competed for dominance.

The current 2015 inlet location has been governed by different processes since 1978. Once formed, the 1978 inlet did not remain in the same location, but has progressed or migrated to the north along the barrier beach.

Figure 63: 1970 inlet configuration and beginning formation of central inlet island.

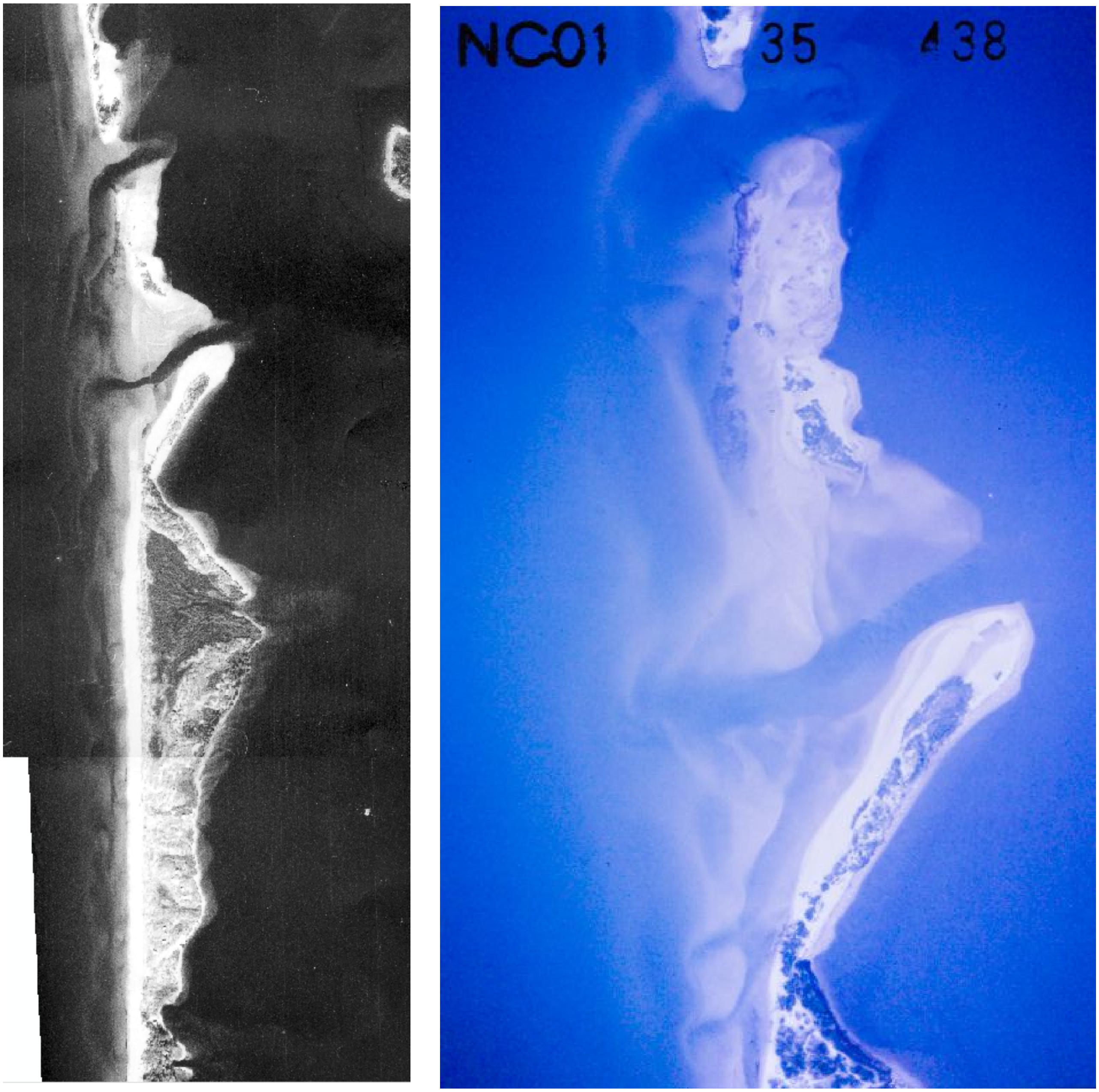

Figure 64: Inlet configuration, early 1974 (left) and later in 1974 (right) The island between the inlets is rapidly consumed under continued high lake levels, and is largely dissolved by 1976. By 1978, low lake elevation was accompanied by closure of the 1957 inlet, and resorting of sand to form the modern inlet structure.

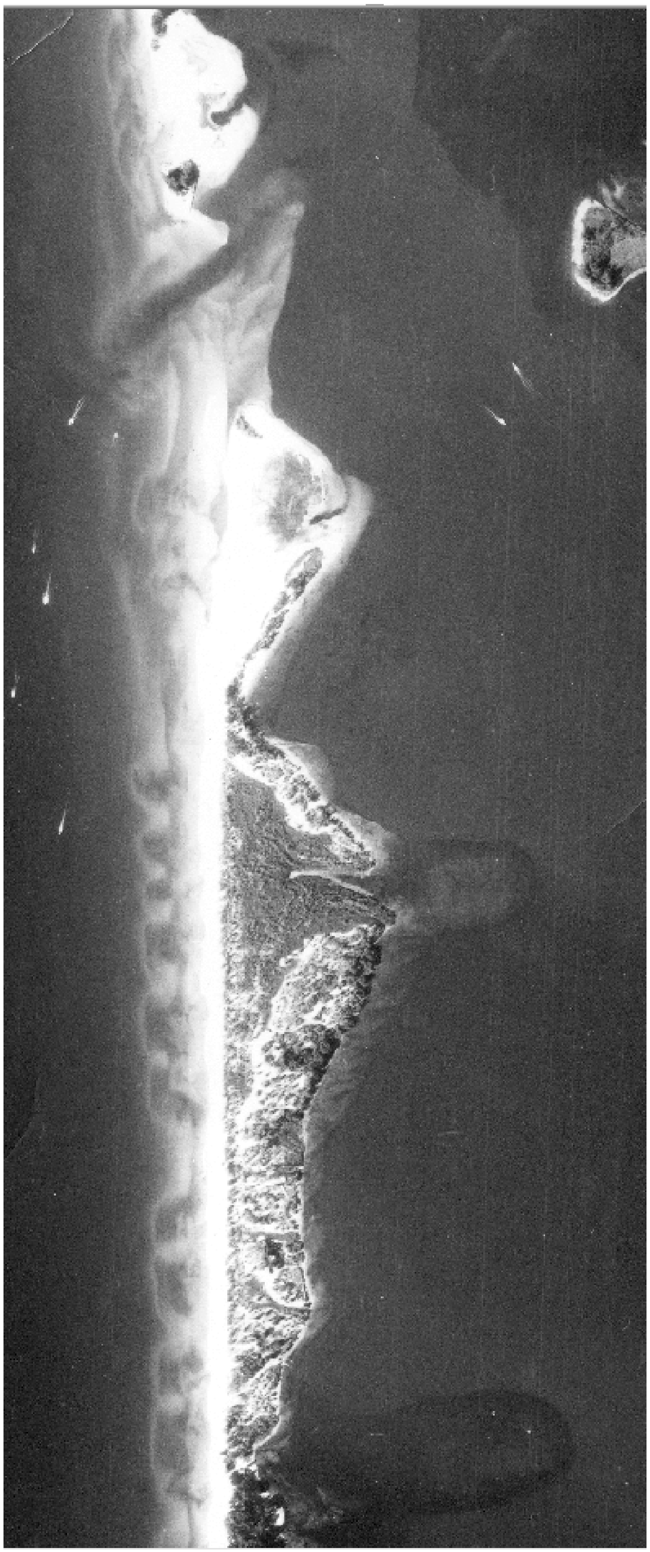

Figure 65: By 1978, the new inlet area has evolved to a single northern inlet and the remnant island forms the shoal complex at the north end of the southern barrier.

Figure 66: A return of higher lake levels in 1983 flooded low areas of new sand bars adjacent to the inlet which now was 1500 feet wide, with a small deeper channel at its center.

Inlet Migration since 1978

Shoreline change analysis methods were applied to measure inlet migration. Since the 2015 inlet's inception in 1978, southern spit has undergone progressive northward movement, unlike any prior inlet. The southern barrier has moved between 270 and 427 m, while the norther barrier has retreated northward between 60 and 140 meters (Figure 67). The inlet has narrowed accordingly. The northern barrier is under significant erosive pressure as seen with sharp bank cuts along the shoreline.

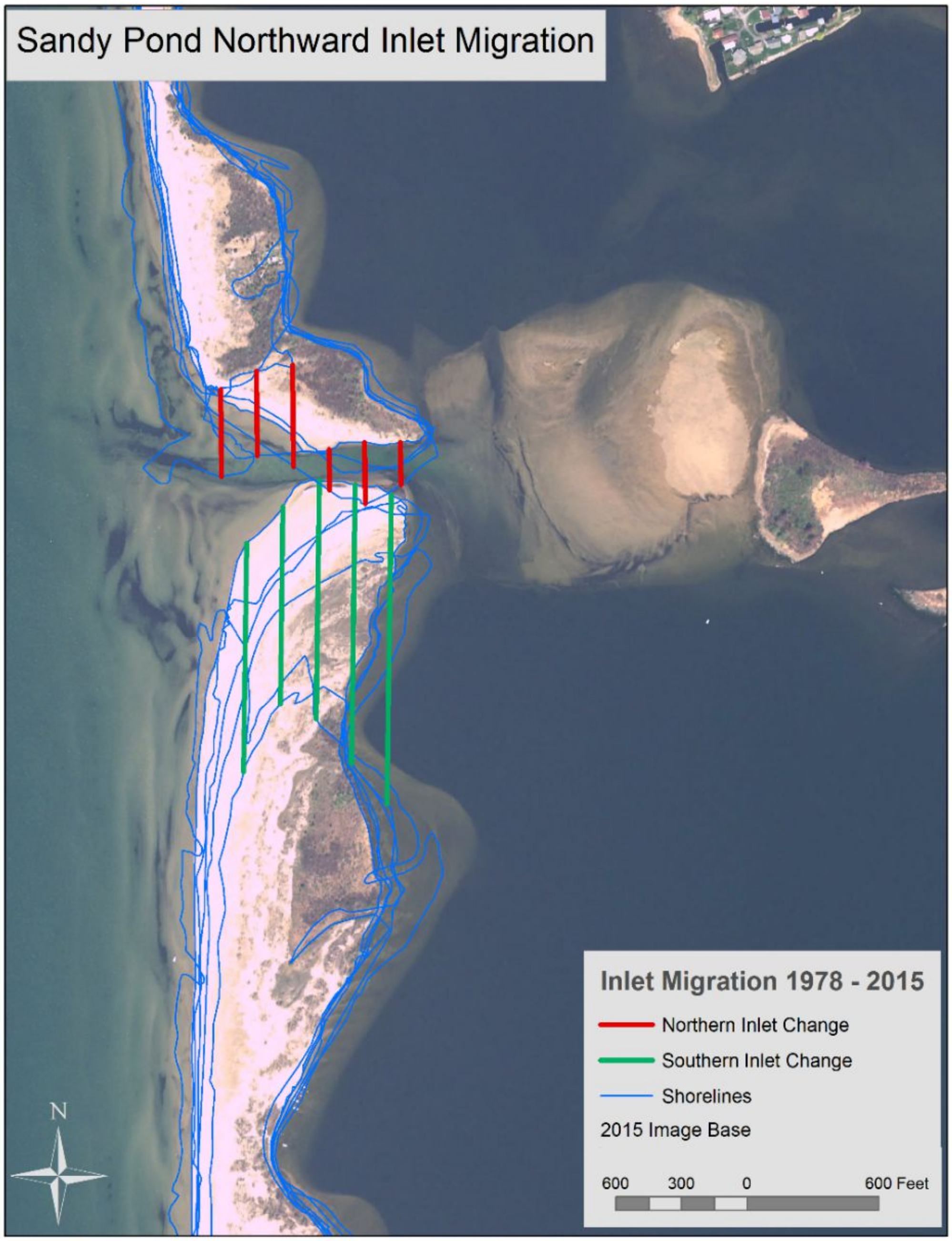

Figure 67: Northern inlet migration illustrated using Digital Shoreline Analysis System

Physical Geography Change Analysis of the Barrier Complex

This section presents methods and results for three dimensional, volumetric barrier system change including the barrier beaches and the 2016 shoal.

Three types of data are used in the following section. Elevations determined from bathymetric surveys for measurements of water depth done by boat soundings, or stadia rods measurements in shallow waters, or airborne laser systems that penetrate water column. Elevations determined from laser-based technology (LiDAR) which can determine terrain elevation and in special cases, water depth. GPS (global positioning system) which is used to determine the location of field measurements and aircraft position when measuring depth or elevation. Finally, shorelines with known elevations from the Oswego NOAA Lake level station provide valuable elevation data.

LiDAR Introduction

What is LiDAR? "LIDAR, which stands for Light Detection and Ranging, is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth. These light pulses—combined with other data recorded by the airborne system—generate precise, three-dimensional information about the shape of the Earth and its surface characteristics.

A LIDAR instrument principally consists of a laser, a scanner, and a specialized GPS receiver. Airplanes and helicopters are the most commonly used platforms for acquiring LIDAR data over broad areas. Two types of LIDAR are topographic and bathymetric. Topographic LIDAR typically uses a near-infrared laser to map the land, while bathymetric lidar uses water-penetrating green light to also measure seafloor and riverbed elevations.

LIDAR systems allow scientists and mapping professionals to examine both natural and manmade environments with accuracy, precision, and flexibility. NOAA scientists are using LIDAR to produce more accurate shoreline maps, make digital elevation models for use in geographic information systems, to assist in emergency response operations, and in many other applications." (National Ocean Service 2017)

Elevation and Bathymetry Data Inventory

The latest NOAA chart from 2015 includes updated bathymetry measurements taken in 2014 which were obtained and evaluated. A complete bathymetric pond model was created by combining 2014 nautical chart data with 2015 shoreline information. The number of observations in the inlet and shoal area from the 2014 and 2015 data was determined to not have inadequate point density to support a robust volumetric estimate of the shoal size and was not used in this study.

The 1948 data referenced in Baird was obtained from NOAA. The shoreline best matching the 1948 data is from 1955 and could be used in combination with pond shore location and elevation to create a bathymetric surface for the pond. The 1948 point data documents a different location for the inlet from either 1942 or 1955 photography, emphasizing the volatility of inlet dynamics during periods of high water level (not shown in inlet history, Figure 48). 2001 topobathymetric LiDAR data set includes the shoal and inlet areas and was used to create a bathymetric surface in combination with a 2001 shoreline.

In 2016, direct measurement of the shoal area was completed using GPS. On 17 Sep 2016, students from Skidmore College measured the shoal to the shoal's edges that drop off sharply. GPS units were used to locate the position of individual above-water elevations and water depths. These measurements were added to a previous set of GPS measurements collected by Hart, Steadman, Bonanno and Fisher on 09 Aug 2016. Boat transport to and from the shoal was provided by Ron Fisher and Green Point Marina. Lake level measurements were compared to a known bench location at Ron Fisher's bulkhead and confirmed with the NOAA Oswego station gauge to estimate shoreline elevation during GPS measurements for each data collection date (Figure 68, Figure 69). All elevation measurements were calculated as offsets relative to observed lake elevation.

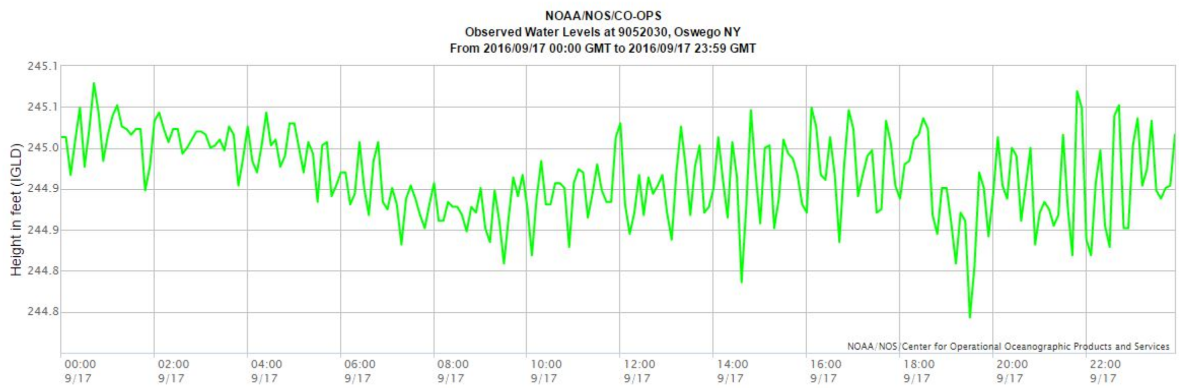

Figure 68: Lake level data during GPS Collection 17 Sep 16. Collection spanned from 11:00 - 14:00 hours. Observed elevation at Green Point was 245.0 IGLD.

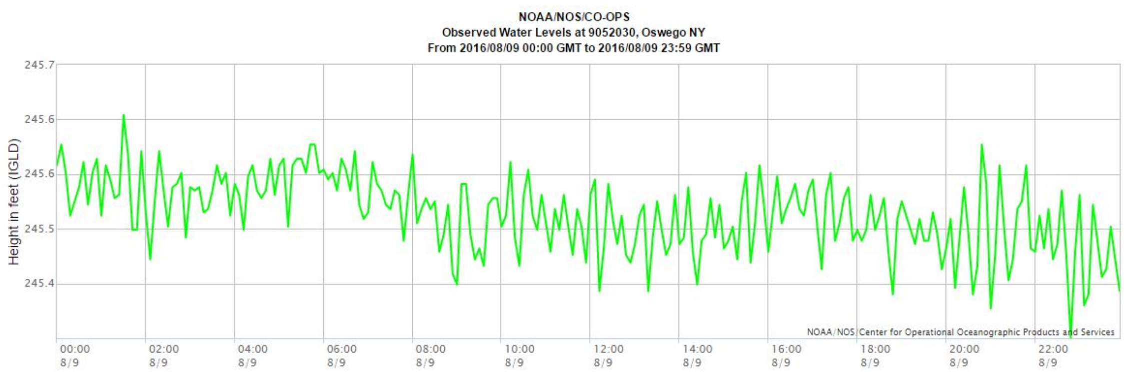

Figure 69: Lake level data during GPS Collection 09 Aug 16. Collection spanned from 11:00 - 14:00 hours. Observed elevation at Green Point was 245.5 feet IGLD.

Characterization of 2001, 2007 and 2011 LiDAR data sets

Volumetric change analysis was completed based on available LiDAR data. The 2006 Baird study created the first topobathymetric data set in 2001 forming the basis of the IJC study (supporting 4 m pixel). This data is suited to shoreline delineation and some barrier island volume estimates along with nearshore and channel volume measurements. Since then, higher resolution LiDAR data was obtained in 2007 and again in 2011 (both supporting 2 m pixel). The 2007 data set is accompanied by a corresponding orthomosaic data set and a bottom reflectance image set.

All three sets of LiDAR data were analyzed to generate bare earth and hydrographic surfaces to compare volume and progressive change over the 10-year period of coverage. The data was also evaluated for bathymetric surface calculations to estimate the volume of depositional shoals. It was possible to measure the volume of the modern inlet shoal directly using the topobathymetric LiDAR coverage that extends into the pond shoal area in 2001. For upland bare earth measurements, the 2001 data is limited due to low density of coverage combined with dense canopy cover in summer on the barrier beach. All three data sets supported analysis of channel migration and nearshore shoaling on the lake side of the coastal barrier. Data also document formation of dunes and changes in dune vegetation. After these analyses were completed, an additional LiDAR data set for 2015 became available, but has not been inspected.

Bare earth surface elevation created from LiDAR

LiDAR data includes multiple reflections from targets for each individual laser pulse. Each of these reflections is represented by a series of points with X, Y and Z coordinates, forming a point cloud. From these point clouds, multiple reflection returns allow for detection of vegetation canopy where present, and secondary or tertiary returns from ground. Where vegetation density is high, laser pulses may not reach the ground. Analysis of LiDAR starts with sorting out what signal returns represent ground features from above ground features such as trees, dune grass or structures.

Models are created for surface (digital surface model, DSM) or bare earth models (digital terrain or digital elevation models, DTM and DEM respectively). The difference between these models can be used to estimate vegetation volume or standing biomass. In the case of topobathymetric LiDAR, green laser pulses penetrate water to the extent allowed by water scatter, turbidity or suspended solids, vegetation, and entrained air bubbles associated with wave breaking near shore. Topographic LiDAR, using near-infrared lasers, does not penetrate water well, providing a sharp demarcation of the water's edge or shoreline. Similarly, returns from topobathymetric LiDAR over water are much less than those over land, and provides a sharp shoreline demarcation.

All three available LiDAR data sets were collected using the Compact Hydrographic Airborne Rapid Total Survey (CHARTS), providing both upland and shallow water depth information. Each LiDAR data set was processed using LASTOOLS. Data was tiled to within the study area and ground level data was extracted to create both digital elevation and surface models. The resulting DEMs were symbolized using a topographic color scheme based on 20 elevation classes
Figure 70). The 2001 data was unable to resolve ground surfaces below dense dune vegetation, but otherwise provided excellent results. The overflight included the entire extent of the 2001 shoal and Carl Island. Both the 2007 and 2011 data sets produced good results, with some limitations in dense vegetation areas. Once digital models are calculated from a single data set, the resulting digital surfaces can be compared to measure change over time either by direct elevation at points or along transect, but more importantly, by calculating volume differences (Figure 71). Notable changes are present showing significant dune building as linear upland features, changes in nearshore troughs and sand bars, and northward migration of the inlet channel. Slumping of high dune faces and sand buildup in exposed areas subject to wind

transport are shown on the north barrier island. Spurious results are also evident in areas of dense upland vegetation.

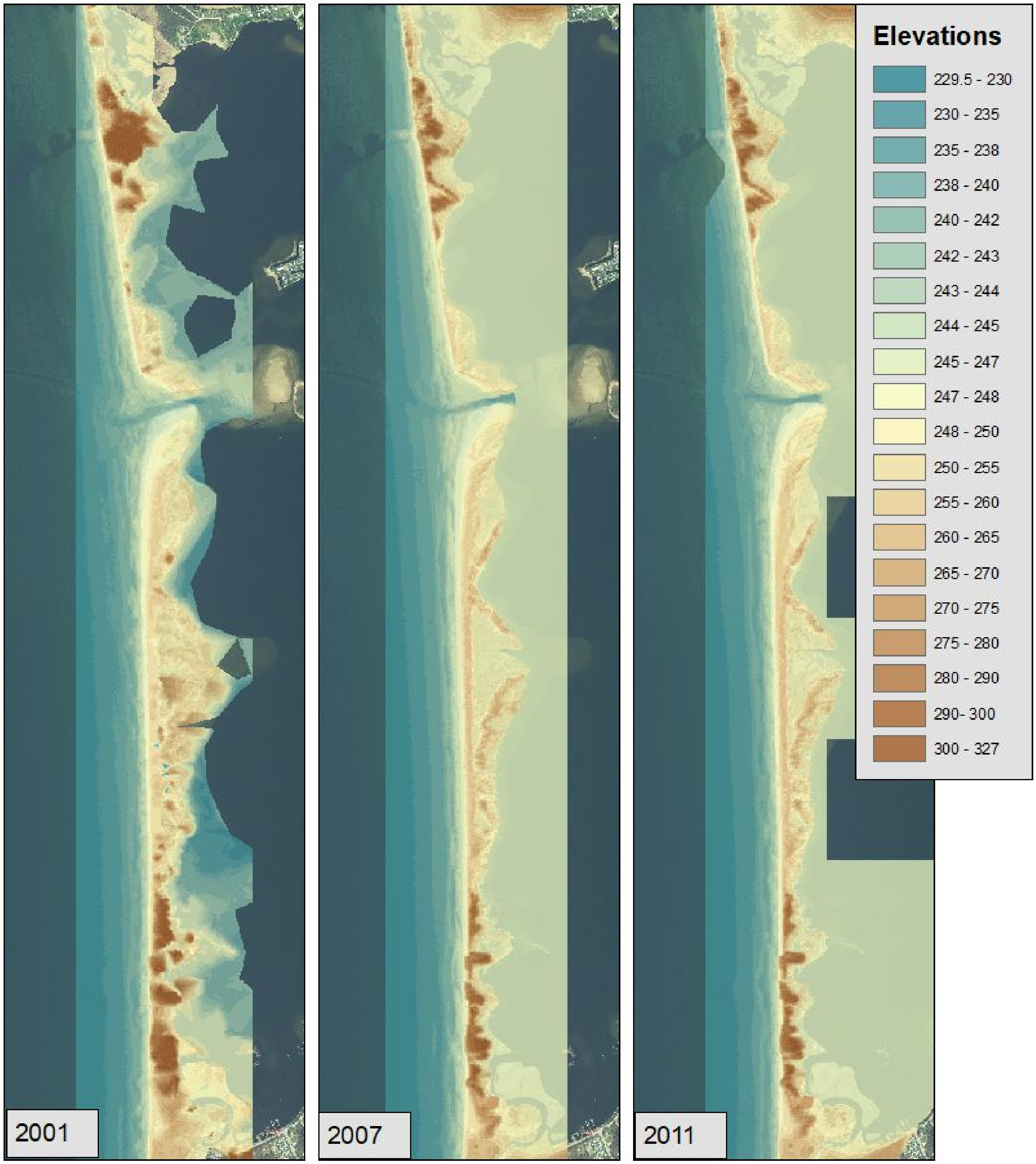

Figure 70: Digital terrain and hydrographic surfaces for the three available data sets.

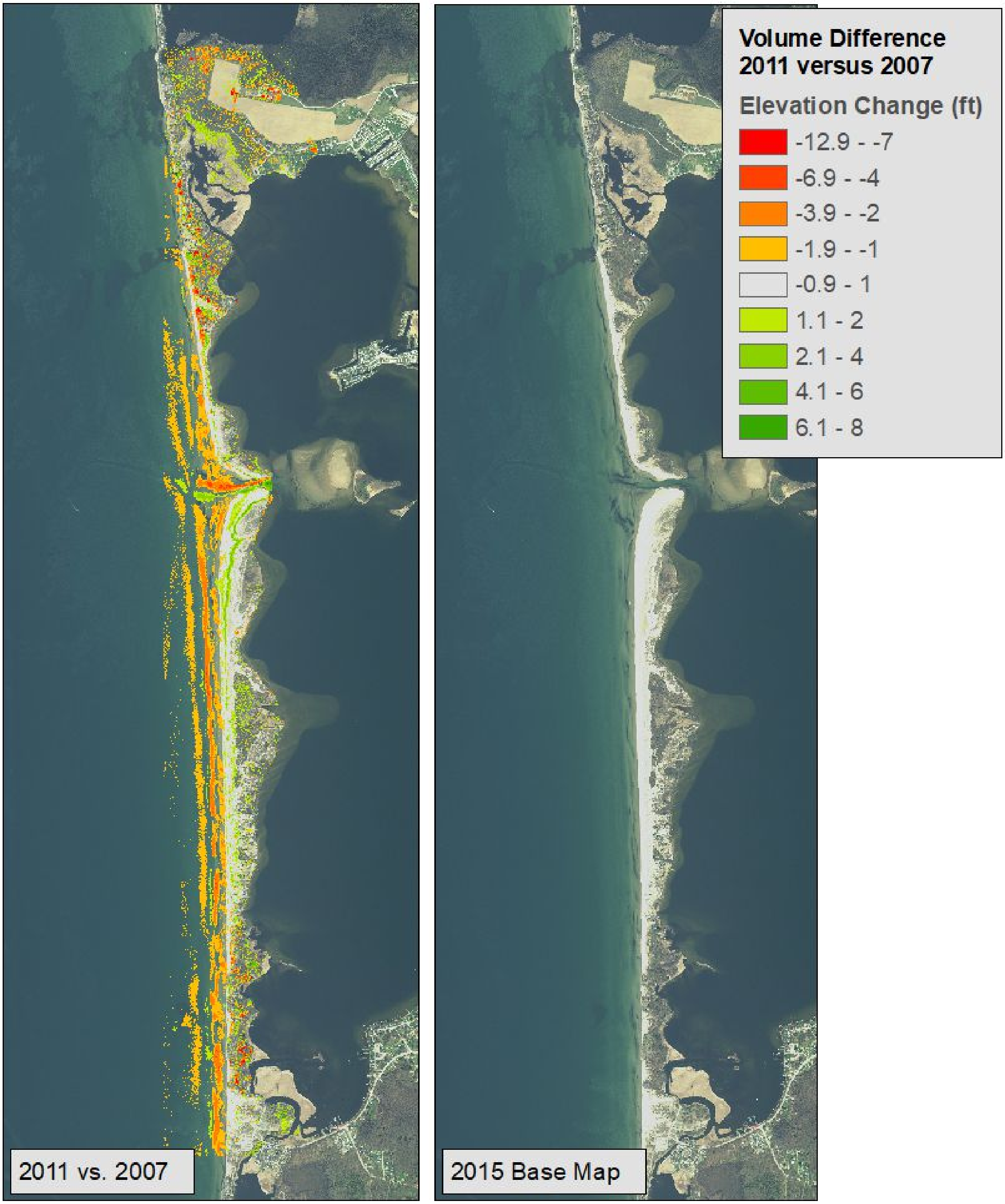

Figure 71: Volume Change based on difference in elevations. Green areas represent fill, while red and orange areas represent loss of mass.

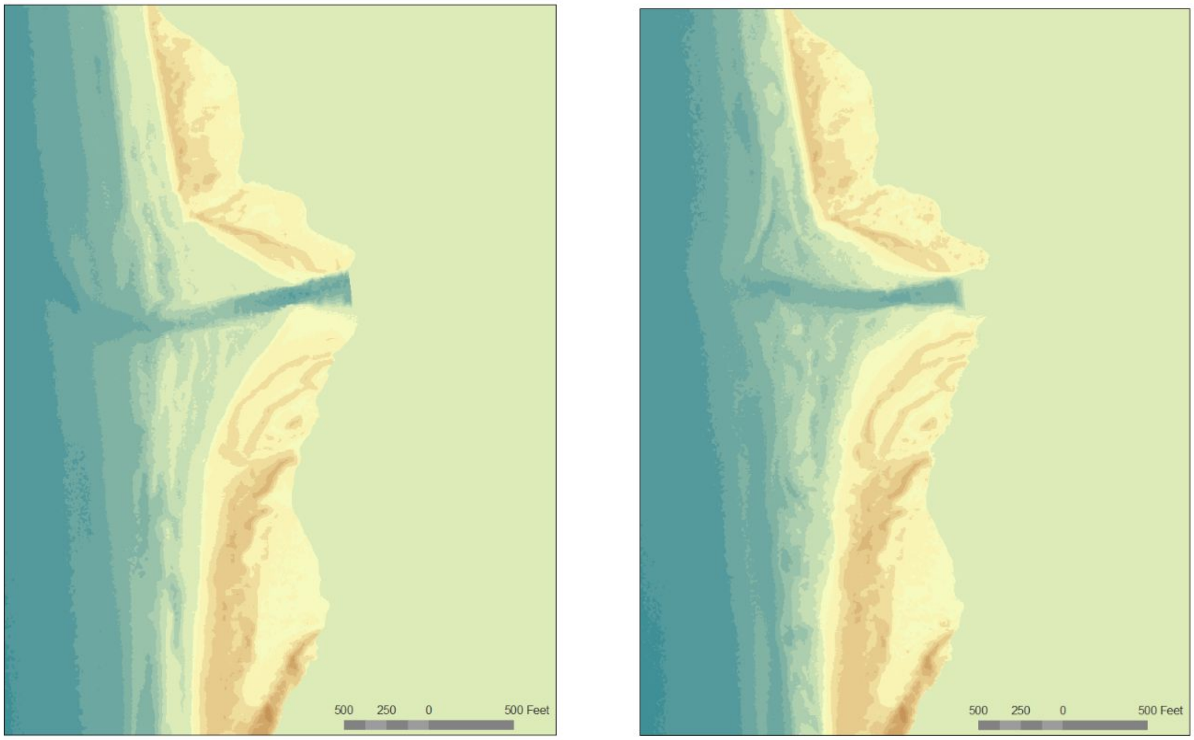

Figure 72: Elevations focused on inlet area 2007 (left) 2011 (right)

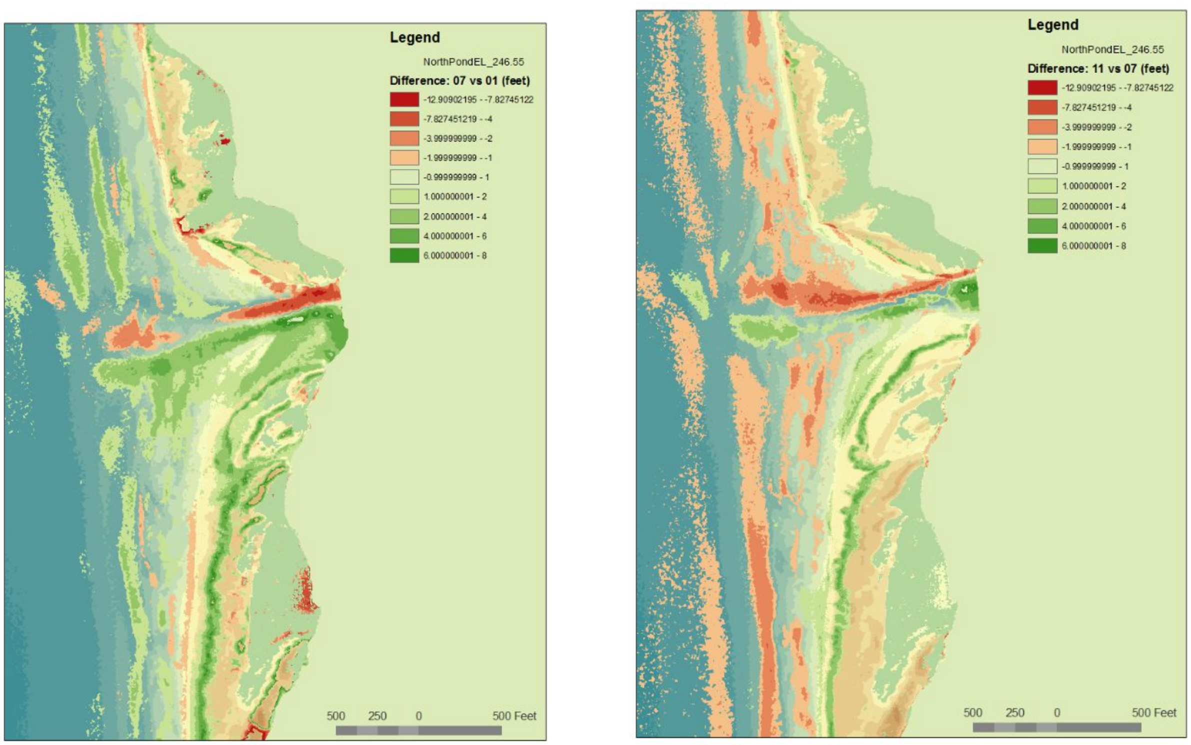

Figure 73: Volume changes near inlet. Difference between 2001 and 2007 (left). Difference between 2007 and 2011 (right)

Differences show a dynamic environment with progressive filling and cutting of the northward migrating inlet channel; building of flats and dunes on the southern barrier; and, continued loss of material from the northern barrier (Figure 72)(

Figure 73). Focusing on the channel alone illustrates its northward migration (Figure 74).

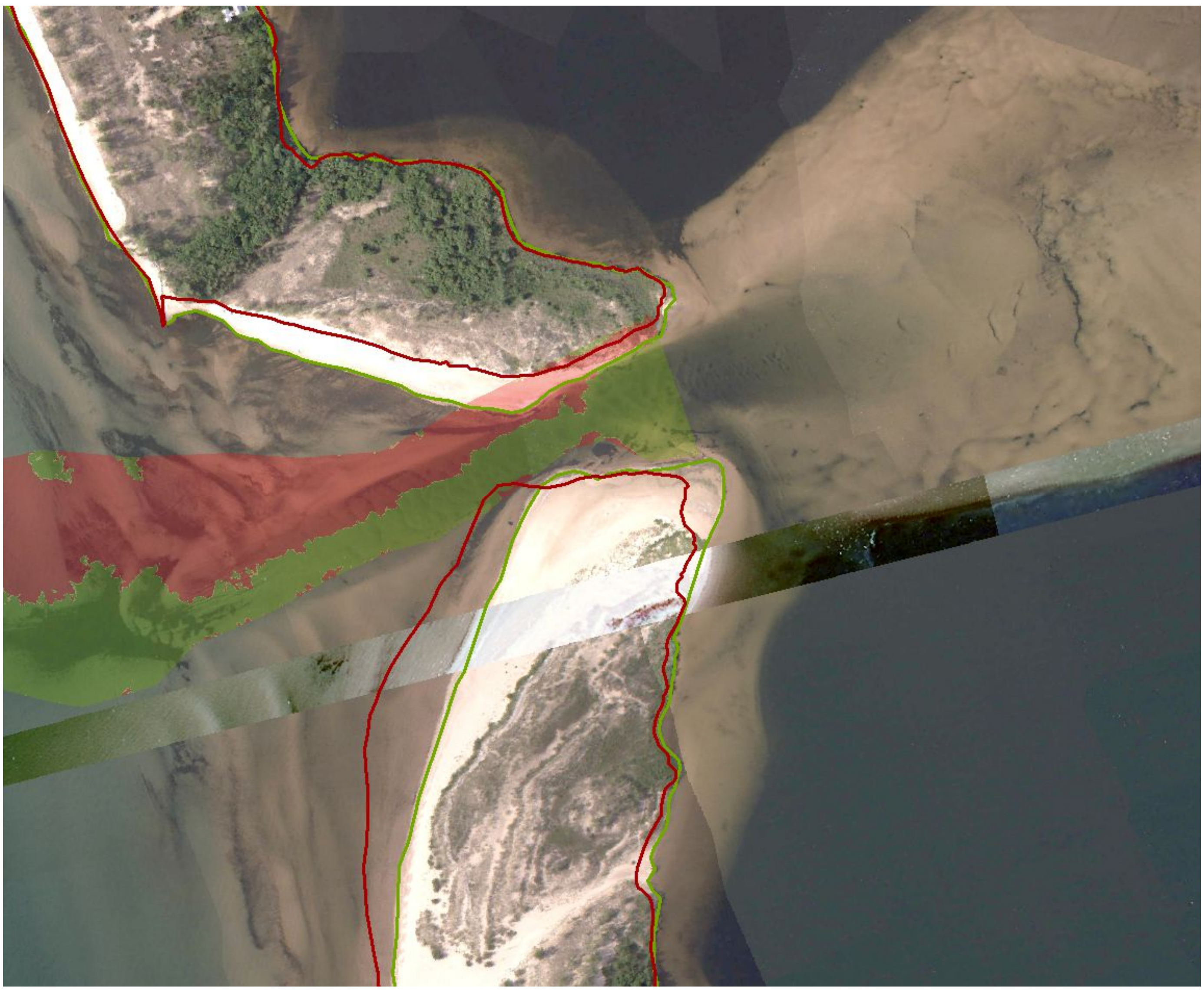

Figure 74: 2007 Base imagery with cut and fill overlay of channel location in 2007 and 2011 with corresponding shorelines. Uneven appearance is due to gap in imagery from 2007.

It would also be possible to calculate the total volume of the barrier system within the envelope of the DEM coverages from the pond shoreline to a depth of approximately 13 feet on the lake side. Masks would need to be applied to exclude ambiguous regions of the DEM with dense vegetation. It would also be possible to create a DEM from the 1895 topographic map to compare total volume change over the 116-year time frame to better understand what sediment gain or loss has occurred in the system.

Calculation of Current Shoal Elevation using Survey Data

Like LiDAR, bathymetric and GPS surveys create a series of points with X, Y and Z (elevation) values. Unlike LiDAR, a single depth or elevation value is provided for each observation. The number of point observations is relatively small, but may be adequate to create a digital surface model representing land elevations and water depths (Figure 75).

Figure 75: 1948 Bathymetric survey data with 1955 shoreline and shoal sketch from 2015 image.

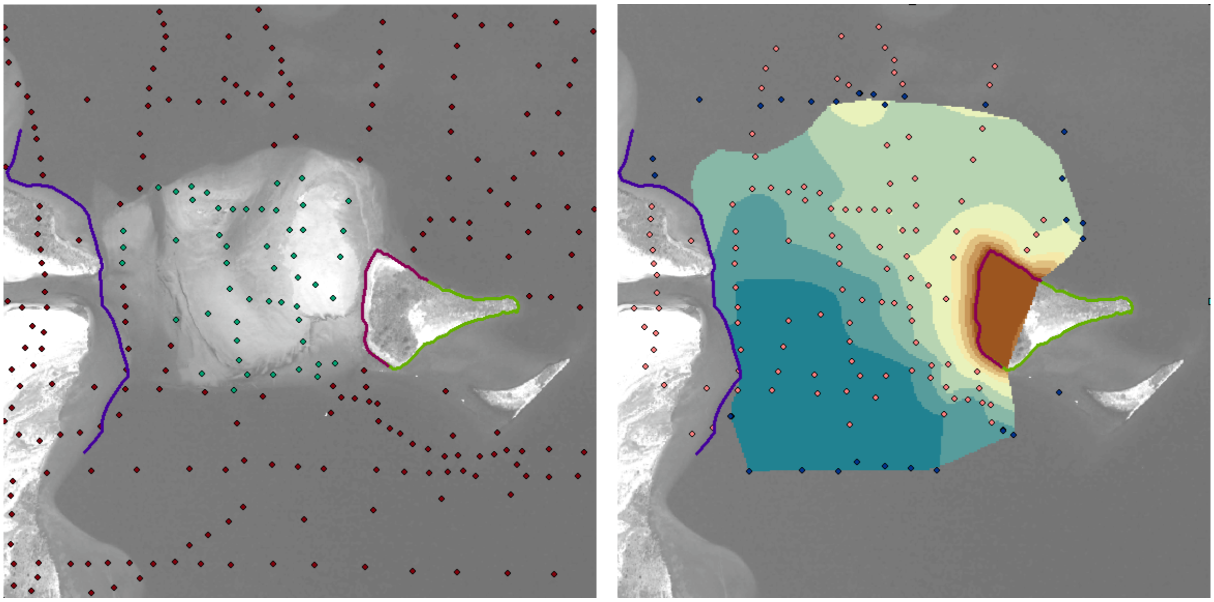

Figure 76: 1948 bathymetric points (left) and resulting bathymetry DEM (right)

1948 bathymetric survey points were converted from depth in meters to feet and compared against current (2015) nautical chart soundings in areas were little change was expected. Reported points from 1948 matched current navigation depths in areas away from shoaling. Perimeter points were defined from current nautical charts to better define the outer extent of a calculated DEM. The perimeter of the shoal was determined behind the inlet and along the face of Carl Island to provide break lines to limit the DEM calculation to the shoal area. A DEM was calculated from the 1948 points and then adjusted for a lake surface offset from 1948 lake elevation chart datum. The resulting DEM was clipped to an area covering the shoal area (Figure 76).

GPS-located depth measurements were used to generate a 2016 DEM along with perimeter points derived from nautical chart values (also used for 1948 data to create the same depth closure in each DEM). A GPS-derived shoreline was also collected on the shoal to distinguish upland from submerged lands – the shoreline was assigned the lake elevation at time of collection as the Z value. Outer margins of the current shoal area were determined by depth measured from boat and visual interpretation on 2015 photography. A defining ring of pond weed (*Potamogeton spp.*) fringe marked the sharp drop from the current shoal in many locations and was visible in imagery. In addition, the same break lines used in the 1948 DEM were used with appropriately assigned elevations. The resulting DEM was symbolized with the same classification scheme for comparison with 1948 DEM (Figure 77).

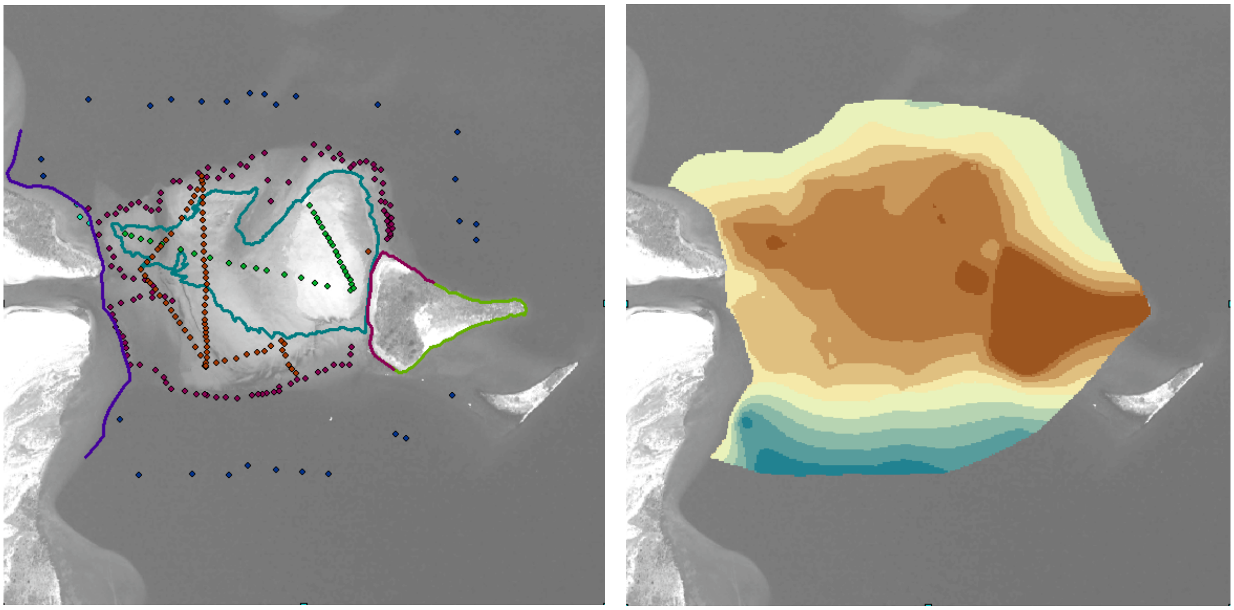

Figure 77: 2016 GPS points and lines (left) along with closure points from 1948 bathymetry. Resulting topobathymetry DEM (right)

Shoal Dynamics: Measuring Growth of the Shoal Over Time

The 1948 and 2016 DEMS were adjusted to cover the same areas and then compared using a digital cut and fill process to calculate volume differences between the two periods. The time period for actual shoal creation (and this volume measurement) would be from 1978 with the formation of the new inlet to 2016. Cut and fill output includes tabular quantitative values for gains (fill) and loss (cut). The volume of the shoal is estimated at 727,735 cubic yards or 29,100 cubic yards per year of accumulation since the opening of the inlet 25 years prior to 2016 (Figure 78).

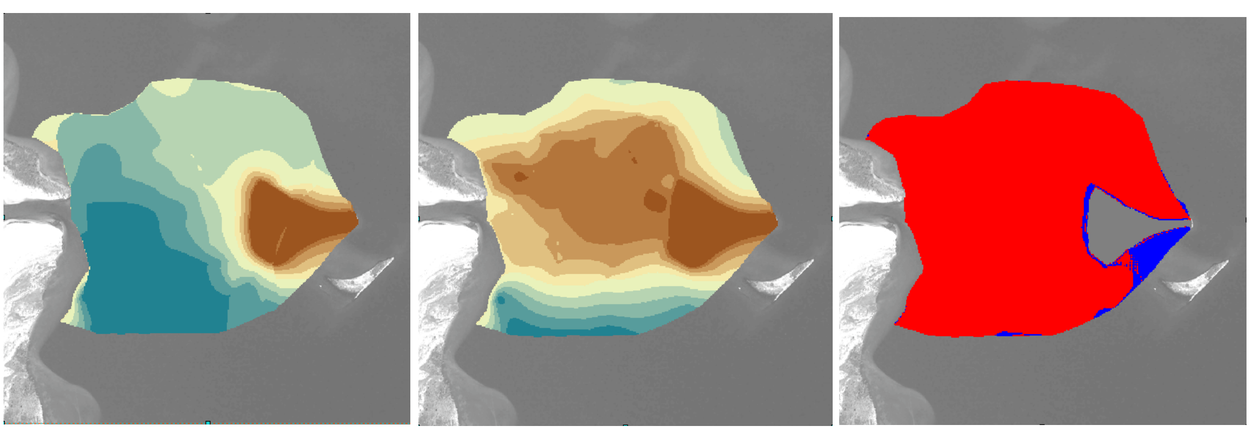

Figure 78: 1948 DEM (left), 2016 Shoal DEM (middle), Raw cut and fill output (right). Loss is indicated in blue, fill is shown in red.

LiDAR data for the shoal area in 2001 does not extend to include the outer margins of the shoal, but is useful to explore as an intermediate measure in the shoal's development. A 2001 DEM was produced and all three coverages were clipped to the same area as defined by the limits of the LiDAR data. The resolution of the 2001 data shows substantially more detail than either 1948 or 2016 DEMS based on the greater point density (Figure 79).

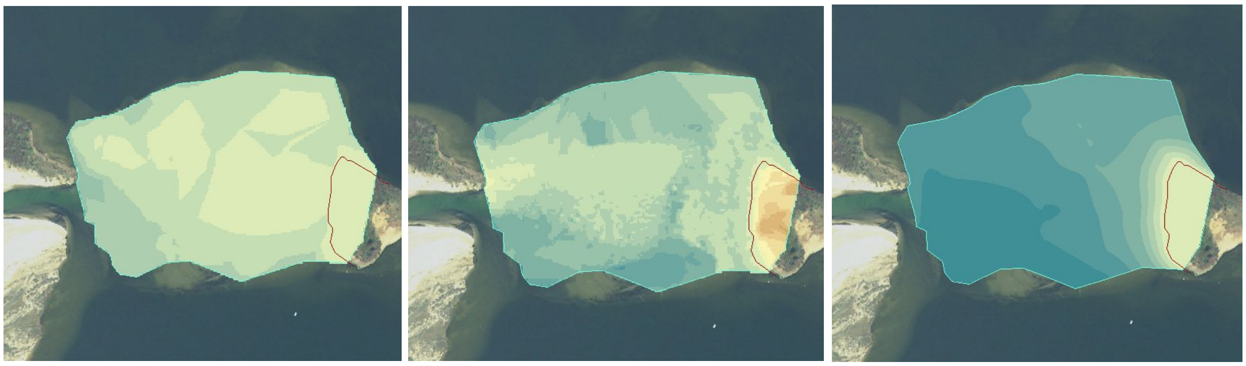

Figure 79: DEMs adjusted to extent of 2001 LiDAR data. 2016 (left), 2001 (middle), 1948 (right)

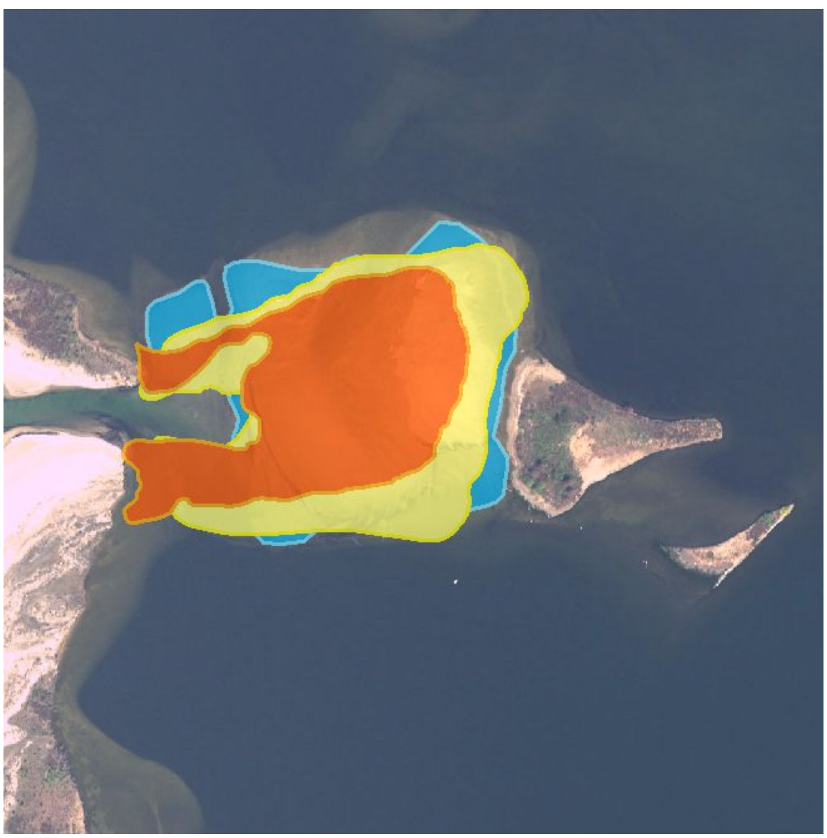

Figure 80: Shoal outlines derived from imagery by year - 2001 (Orange), 2011 (yellow), 2016 (blue). Shoal areas are similar for 2016 and 2011 (147,000 and 151,000 sq yds) while 2001 is less (99,000 sq yds)

Volumetric difference analysis found the total volume gain from 1948 to 2016 in this smaller area was 475,725 cubic yards, or 65 percent of the total found in the larger solution for the entire shoal. The 1948 data set represents the pond bottom elevation well before deposition from the new inlet began forming a shoal behind the inlet in 1978. Comparing 2001 to 2016 DEMS within this same area produced a gain of 94,140 cubic yards, or 20 percent of the total accumulation over this 15-year period.

Why is this important? The bulk of the shoal growth, perhaps 80 percent, may have occurred in the first ten years of its formation. Although it is possible that additional deposition may have occurred outside the envelope of the 2001 LiDAR coverage area, evidence for a large amount of accumulation is not present (Figure 80). The implication is that recent year's accumulation of sand to the shoal has been less than in prior year's, amounting to an increase in average depth of no more than 1.4 feet, while in the first ten years the average increase in shoal depth would have been near 7.0 feet. This means that the shoal is relatively static compared to early years with a lower current rate of growth. Hydrologically, the shoal is nearing a static state and sand is more likely to fill the inlet more quickly than it did when the inlet first formed since there is not an effective sink to trap sand behind the inlet.

Barrier System Vulnerability Analysis

Where is the barrier system vulnerable to overwash or breaching? LiDAR-derived DEMs are used to assess low points in the barrier system. Using the 2001 DEM, a lake elevation simulation at 249 can be identify potential low or weak points. Three such areas on the northern barrier are revealed when only lands higher than 249 IGLD are displayed (Figure 81).

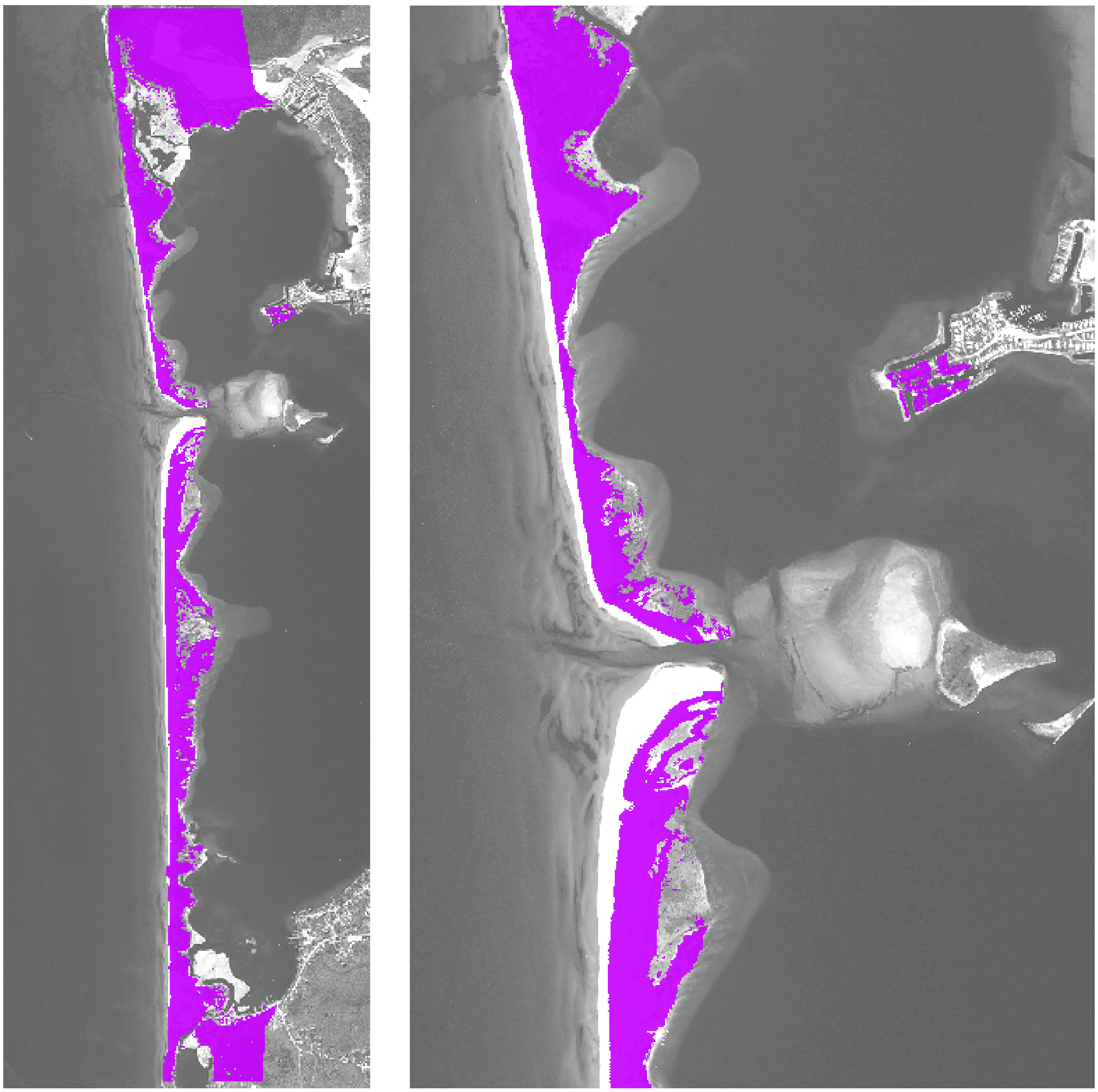

Figure 81: Land at elevation greater than 249 ft IGLD. Overall study area (left), Inlet area (right).

Another elevation analysis provides a clearer illustration where only elevations between 249 and 251 are highlighted, two feet above 2017 high lake levels (Figure 82). One potential breach point is located at the northern spit elbow, while three are located at the low point of land 490 to 750 meters to the north of the current inlet. Any of these low areas are candidates for new inlet locations. Three of these are backed by relatively deep water on the pond side that may add to the hydraulic efficiency of a new inlet. In each case, a new inlet would create a central island. If the breach is at the elbow of the current northern recurved spit, the resulting island would likely be reworked by wave and current action to either join the southern barrier or the inlet shoal, or a combination of both. This process would take several years and would be like the process described for the inlet in 1974 (see Modern Inlet Dynamic section).

If a new inlet were to form further north at any of the three sites highlighted, the inlet formation may be more like that experienced in 1955 where the inlet jumped northward, leaving the intervening section of barrier beach relatively unchanged. These are only possible scenarios based on guidance provided by prior inlet formation history. In any event, the likelihood of one of these scenarios occurring seems very high – when that might occur may be relatively soon, or well off in the future. If it were to occur soon, it may depend on lake level in the 2017 fall storm season in combination with storm-associated wind and waves, especially if accentuated by external seiches after summer thermal stratification breaks down.

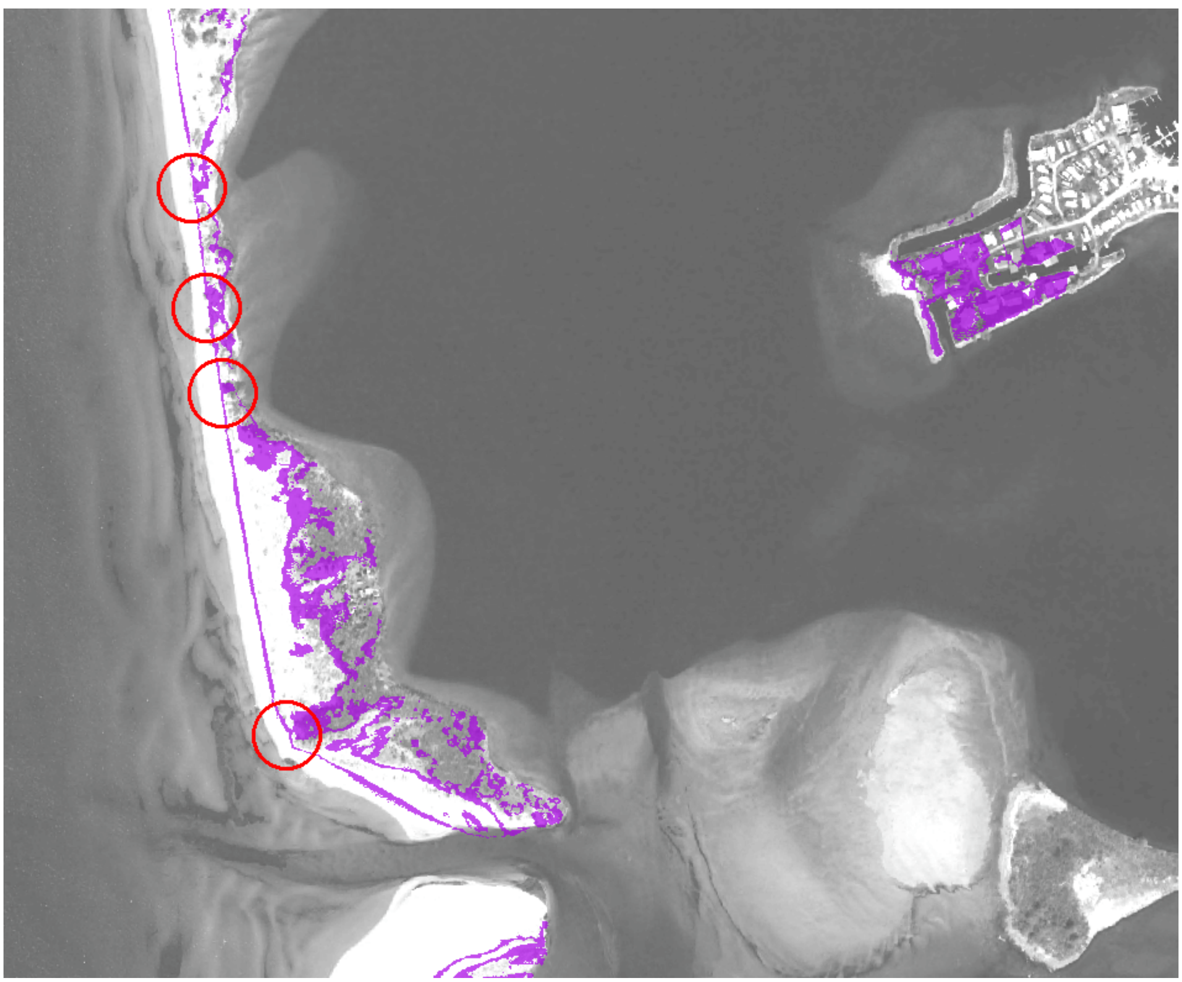

Figure 82: Elevations between 249 and 251 IGLD in purple. Four areas where the barrier is no more than 2 feet above high-water simulation at 249 feet are highlighted.

Recent aerial survey imagery illustrates the barrier beach during lake level elevation 249 on 13 June 2017, corresponding to low sections in elevation analysis (Figure 83).

Figure 83: Low elevation sections of northern barrier. Low strand 625 m north of inlet (left), section at inlet northern elbow (right). Photography by Steadman and Hart.

High water in June 2017 (Figure 84) and storm driven waves in early August 2017 (Figure 85) overwashed one of the the low points illustrated in the vulnerability elevation analysis, expanding an initial 3-foot-wide breach through dunes to an 8-foot wide channel. The likelihood of a future channel forming in this location seems very high.

Figure 84: Overwash channel on North Spit Barrier, 16 July 2017. Dimensions: 3’ wide, elevation 1.5’ above lake level. Dimensions and photo by D.Youman.

Figure 85: Same overwash channel shown in Figure 84 following August 4-5 storm. Photograph date: 16 August 2017. Dimensions 8' wide and 1.5' above lake level. Dimensions and photo by D. Youman

Elevation analysis also illustrates the effect of shoreline armoring. The armored sections arrest the shoreline's advance, while the adjacent areas are subjected to higher than normal erosion on shore features, both shorelines and dunes. Land above 249 shows shoreline offsets, verified by field conditions in aerial survey photography (Figure 86). The shoreline offset is the break in a natural shoreline where the armored section of shore remains in its lakeward position, while the shoreline around these areas retreat. The result is the hardened shoreline prevents erosion at the immediate structure location, but causes greater erosion on adjacent barrier shore.

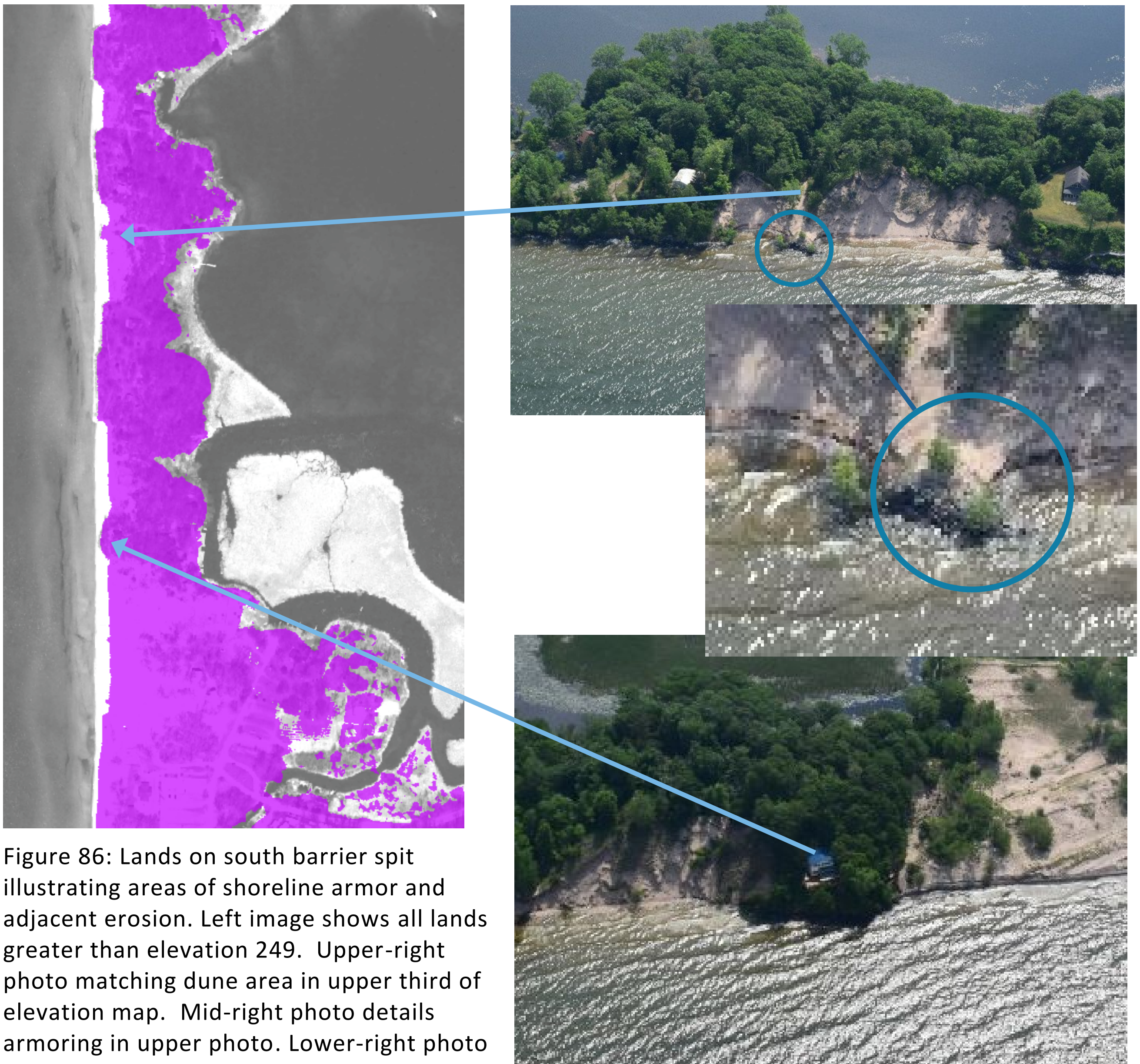

Figure 86: Lands on south barrier spit illustrating areas of shoreline armor and adjacent erosion. Left image shows all lands greater than elevation 249. Upper-right photo matching dune area in upper third of elevation map. Mid-right photo details armoring in upper photo. Lower-right photo showing area in lower third of map.

Findings and Recommendations

Findings

1. *Lake Ontario's water level* is the predominant factor influencing coastal processes along the coastal barrier shoreline of the Dune and Wetland System at North Pond, including littoral drift, erosion and deposition of sediment, and inlet formation processes.

2. The North Pond Resiliency Project has documented the *sequence of inlet formation* from 1895 through 2015, thereby filling knowledge gaps in prior reports. Records referenced in other studies suggest an inlet was present in the mid-1800's north of the high dunes on the south spit; aerial photography of a depositional shoal supports that observation. It is very likely that other inlets existed prior to the mid-1800's, as suggested by apparent channels on the back side of the current barrier, especially noted on the north spit. Evidence of prior inlets is limited, ostensibly due to possible inland migration of the barrier since that time; historic records of prior inlets were not found.

3. Four major and well-documented *inlet regimes* are identified:
   a. 1895 at the south end of North Pond
   b. 1929 - 1955
   c. 1954 - 1970
   d. 1978 – 2016

   Although these are the main inlet periods, the Project has identified no fewer than 19 identifiable separate inlets since 1929.

4. *Early lake level controls* have been in place since the 1800's. Canada's construction of the Gut Dam (1908) in the St. Lawrence River may have resulted in higher lake levels. The Gut Dam was removed in 1953 after it was alleged to have exacerbated high lake levels causing associated property damage in 1951/52. While the actual extent of the Gut Dam's influence on lake levels is unclear, the dam may have played some role in erosion and formation of the 1929 and 1954 inlets at North Pond. The dam's role in lake levels was sufficient to result in payments for damages and removal of the dam.

5. The *St. Lawrence Seaway and Power Project* constructed in the late 1950's provided greater ability to control water levels based on larger channel dimensions (25-foot depth throughout) and water control facilities that were designed to accommodate discharge

levels consistent with 1950's era maximum lake levels. Regulation Plan 1958-D recommended by the International Joint Commission and approved by the governments of the United States and Canada dampened variation and extremes in water level. Even with greater ability to control lake discharges, naturally occurring high lake levels during the 1970's exceeded the ability of the system to maintain the lake at target levels. Without the Seaway improvements, lake levels in the 1970's would likely have been much higher than those that were actually experienced.

6. Inlets on the North Pond coastal barrier invariably *form during high water* periods, often accompanied by defining storm events or periods of increased storms.

7. The *current inlet*, formed in the late 1970's, is functioning under different littoral conditions than existed during prior inlet regimes. Differences are evident when considering the current relative abundance of sand in upland dune formations on the barrier - widening of the south spit that has occurred since the 1970's - and formation of the significant, unprecedented depositional shoal (Inlet Shoal) between the inlet and Carl Island in North Pond. In addition, substantial dune protection and restoration initiatives have been implemented by resource managers and property owners since the late 1980's, taking advantage of available sand from wider beaches.

8. Areas with *high dunes show loss* due to erosion along the shoreline. These areas of the coastal barrier, however, have been more resistant to landward movement.

9. The Project's *shoreline change analysis* has documented significant landward movement of the Lake Ontario shoreline throughout the entire reach of the North Pond coastal barrier.

10. Significant *loss of sandy beach* areas at the northern and southern ends of the coastal barrier occurred during the high water of the 1970's have not been re-established. Sand from those beaches is likely now located in the central reach of the barrier system within filled inlet structures and upland dunes. At that time, and later, significant cobble beaches and deposits were noted, representing lag materials remaining after sand was depleted. Ongoing erosion of glacial drumlin formations would have provided sand that was also lost from the beach front and additional cobbles originally held in the upland sand matrix. Regardless of where sand has migrated, shoreline retreat has depleted sand and more cobbles remain in areas previously supporting beaches.

11. Former Inlets, the current inlet, and the coastal barrier itself are *significant sinks for sand deposition*. Although the upland component of sand deposition was not calculated for the

Project for the entire barrier, estimated deposition of the 1938 (759,000 cy) and 1955 (327,000 cy) filled inlets combined with the estimated volume of the Inlet Shoal (728,000 cy) account for 1.8 million cy of sand (inlet fill volumes were calculated in Mattheus; Inlet Shoal volume was calculated for this Project). Subsequent dune growth, barrier widening, and development of the recurved spits at the current inlet have increased this volume, probably substantially. Even with increased sediment availability from the off-shore sand plain due to glacial rebound as suggested by Baird, the inlet is likely to continue to act as a sand sink. To appreciate the amount of sand lost from the beach and nearshore area over this period, it is useful to visualize that a container four yards deep, 100 yards wide and almost three miles long would be needed to contain the two million cubic yards of sand deposited in shoals, the inlet, and on the barrier.

12. *Shoreline recession rates are substantial* throughout the study area, ranging from 50-80m in front of the high dunes on the north and south spits, to 200-280m in the dynamic inlet formation areas. Prior inlet locations show substantial gain in sand and shoreline recovery. Also, each inlet, as it formed, resulted in deflection of the barrier shoreline away from a straight north-south line, creating a pocket or basin along the eastern end of the Lake, centered on the inlet. Formation of each inlet also changed shoreline orientation, resulting in higher, Lake-generated erosive forces being applied north of the inlet.

13. *Inlet formation dynamics* have been consistent since the formation of the 1929 inlet, with northward movement of inlets. Each prior inlet formation has been saltatory, meaning that successive inlets have jumped to new northern positions, rather than progressing by continuous migration. Formation of each inlet varied in time and evolution. The 1929 inlet formed in a matter of months after high water increased to 247.8 feet IGLD. Formation of the 1957 inlet may have taken multiple years of high water, with high lake levels in 1951 and 1952 preceding the high water in 1956 and 1957. Formation of the 1978 inlet occurred over the course of eight years starting with record high water levels in 1970.

14. As *inlets formed farther north*, the longer time needed for inlet formation and the most recent continuous migration of the current inlet suggest coastal processes have changed their effect on the barrier system. The most significant result is the offset or landward migration of the barrier system from the lake in dynamic response to high water levels. One possible result of the barrier system having moved back (retreated) from the lake is that it is now more resistant to change, that is, more resilient because of its prior dynamic response to lake forces. For example, the 2017 record high waters at near 249 IGLD did not result in a breach while, in contrast, the 1929 inlet formed within a short period after only several months of high water at 248 IGLD.

15. Unlike the saltatory evolution of prior inlets*, the current inlet, formed in 1978, has been migrating northward* over a period of 29 years. It is also accompanied by the Inlet Shoal feature not seen in prior inlets. Carl Island may be influencing this process by "anchoring" the shoal or altering hydrology, although the controlling processes are not known or even hypothesized. Analysis for this Project suggests another hypothesis based on deflection of the shoreline landward which has altered the shoreline angles significantly with the north spit shoreline offset at nearly 7 degrees. This is a substantial difference from early shorelines that had less than a 2-degree shore angle. One way to visualize this change is that from a person's vantage looking to the north from the inlet, the current shoreline is no longer almost a straight-line north to Montario Point as it would have been 100 years ago; rather, the inlet is much further inland, meaning that person must turn slightly west (5°), looking more towards the lake to see Montario Point. The result of this may be to accentuate the capture of sand in the eastern end of the lake by creating a basin to retain sands carried in littoral drift. This may increase the opportunity for shoal formation, both within the inlet and in the Pond, and may explain why the Inlet Shoal formed here and similar shoals are not associated with prior inlets.

16. *Formation of the existing Inlet Shoa*l has not occurred at a constant rate. Roughly 80 percent of the shoal deposition occurred in the first ten years after formation of the inlet, while the last 15 years have added only 20 percent. This suggests that the shoal is nearing a comparatively static state, reducing the inlet's efficiency at trapping sand and thus, shoaling within the inlet occurs more readily. Further evidence of increased shoaling in the inlet may come from dredging histories showing that previous dredging operations provided two boating seasons of navigable depth, while recent dredging has resulted in less than one season of sufficient depth. An increase in lake elevation as occurred in 2017 will allow for greater shoal growth relative to prior low water periods when the shoal was not submerged.

17. As they formed, *each historical inlet changed the barrier processes* to increase erosive forces on the barrier north of the inlet. Prior inlets "jumped" to their locations, while the current inlet has migrated into the north spit. Significant erosive forces are evident on the north spit, while sand deposition continues to occur on the south spit. It is likely that a new inlet will form in the north spit as it continues to be depleted. It is also likely that the new inlet would compete with the current inlet and that an island between the two inlets would be dissolved over time to either join the south spit, the current Inlet Shoal or both. High storm activity, especially in late fall and early winter if high waters persist and after lake stratification breaks down, may be particularly significant in this process.

18. *Long-term flooding impacts* result from high lake level with loss of property use, property damage, and business losses. Short-term flooding is associated with episodic increase in lake level which typically does not last long and is associated with short-term weather events. Short term flooding can also result from ice dams in the inlet. Pond level can increase rapidly due to the combined effect of the ice dam and amount of stream runoff.

19. *Water quality* in the North and South ponds is an ongoing concern. Among other issues, levels of phosphorous exceed State pollution standards. Algal blooms are likely related to elevated phosphorous. The most likely source is human waste from failing or inadequate household septic systems. Flooding exacerbates this problem by promoting entry of waste into surface waters.

20. *Recreational boating* on the North and South Ponds has been a way of life since the 1800's. The number of boats using this area and berthed at residential and commercial facilities in the pond may be more than 1,000 as estimated during this Project. Continuation of this traditional recreational use depends in large part on the inlet's navigability, although boating opportunities are also reduced by continued shoaling of navigable areas in the Pond.

21. The barrier system, including its ponds and inlets, constitute a *unique natural environment* providing essential habitat to both rare and abundant wildlife and plants. The area has a unique history of outdoor recreational use and appreciation including fishing and hunting that depends on this resource. Effective protection and recovery programs for habitats and species are in place and play an important role in the future of several species, most notably the endangered piping plover. The relative concentration of high habitat values nearest newer landforms on the coastal barrier south of the inlet is documented in this report.

22. *Recovery of the barrier system* from 2017 high water conditions is likely, but the long-term resiliency of the system is not known. Natural processes will begin dune-building again once lake levels drop to expose the beach to wind forces, but this effect is likely to be less significant on the north spit. Sand lost from the north spit is not as easily replaced as there is less sand fronting the high dunes, although erosion of the dunes themselves will contribute some sand. The depth of offshore sand may be less to the north, as indicated by the extensive areas of exposed bedrock visible in early imagery to the north of the high dunes.

23. If a *new inlet* forms at areas indicated on the north spit, immediate impacts from wave exposure to the pond shoreline opposite the new inlet can be expected. Shoal formation may be rapid at a new inlet as the processes that led to formation of the existing Inlet Shoal may still be in place.

24. Lake Ontario *ice cover is likely an important protective feature* for the barrier system. Ice cover can directly protect the shore from wave attack and likely reduces littoral movement of sand. Ice cover also affects management of lake levels. Repeated and unprecedented thaws in February and March of 2017 were cited as a contributing factor in not being able to discharge water through the St. Lawrence River, which requires a solid ice cover on the lake to avoid ice pack dams in the River. In addition, ice formations can exert hydraulic pressure on the back side of the barriers by rapidly increasing pond water elevations.

25. Information is available to continue to advance understanding the North Pond barrier complex, including aerial imagery from existing digital orthoimagery programs. The availability of drone imagery is now adding to the base of information, especially if undertaken for a pre-determined purpose. Collection of LiDAR imagery was essential, providing the greatest value data for documenting volumetric three-dimensional information. The Project has demonstrated a rich history of data is available that can be integrated into modern technology to reveal much of an area's natural history.

Recommendations

1. *Ecosystem-Based Planning.* Recovery from 2017 high water conditions underscores the need for thorough understanding and review of current plans and policies for ecosystem-based management of coastal resources in the North Pond Inlet Management Study Area. Consideration should be given to new or modified plans and public policies to guide decisions affecting: inlet maintenance (including dredging); new inlet formation; shoreline protection; flood preparedness, response, and recovery; flood-caused water quality impacts; and habitat protection, enhancement, and restoration.

   Consideration should be given to incorporating information and findings from the North Pond Resiliency Project into existing plans and policies and new ecosystem-based management plans. Such planning initiatives should address both geographically defined planning needs (e.g., North Pond Inlet, North Pond coastal barrier; North and South Ponds Resource Management Area6; eastern Lake Ontario watershed) and institutionally defined planning needs (e.g., Sandy island Beach State Park; Town of Sandy Creek municipal planning jurisdiction; Sandy Creek Critical Environmental Area).

   Suggested ecosystem-based goals and strategies for consideration by town, county, and state agencies and officials are included in the following section on Suggested Planning Approach. These goals and strategies are intended to provide a basis for development of more detailed plans and public policies for ecosystem-based management in the IMSA.

2. *Inlet management.* The Project's shoreline change analysis, documenting the history of inlet formation at North Pond, provides strong support for a recommendation to consider the North Pond Inlet as a priority geographic area for ecosystem-based planning. Accordingly, the agencies and organizations with planning and regulatory responsibilities affecting the inlet, along with Town of Sandy Creek officials, should work cooperatively to prepare an Inlet Management Plan (Plan). The Plan should include a proactive sand management strategy addressing, among other things, beneficial placement of dredged material from channel maintenance operations, time-of-year opportunities and constraints for dredging, habitat protection and enhancement, and policies to guide governmental decisions affecting the inlet. It also should address the extent to which human intervention,

[6] The North and South Ponds Resource Management Area is delineated in the 1989 report New York's Eastern Lake Ontario Sand Dunes: Resources, Problems and Management Guidelines and the 2007 report New York's Eastern Lake Ontario Dune and Wetland System: Guidelines for Resource Management in the 21st Century. These two reports funded and published by the New York State Department of State are known as the "Dunes reports."

through dredging and other actions, should be applied to maintain the current inlet (see the following section on Suggested Planning Approaches).

3. *Shoreline restoration*. Substantial landward migration of the North Pond barrier over time, with concurrent movement of sand through the inlet and deposition into the Inlet Shoal, highlights the opportunity for relocating sand from the shoal to nourish (restore) sections of the barrier. When considering such opportunities, it should be recognized that: a) projects to mine sand from the inlet for shoreline restoration purposes should be integrated with projects for inlet dredging for navigation and inlet stabilization purposes; b) removal of sand from the west side of the shoal will create a depositional area for capturing sand transported through the inlet by littoral processes, therefore likely extending the life of the inlet but requiring maintenance (additional sand removal) for long-term utility; and c) removal of sand from the center or eastern side of the shoal would not be expected to extend the life of the inlet but the sand so removed could be used to restore areas farther from the inlet.

   A recommended goal when considering shoreline restoration initiatives on the North Pond barrier is to avoid significant interference with the natural drift of sand, and therefore structural (hard) solutions for shoreline stabilization on the barrier, including groins, jetties, and revetments, are not recommended. It should be recognized that such structural solutions may provide temporary relief from erosion in limited areas but accelerated erosion of adjacent shoreline areas is also expected. Nonstructural (soft) shoreline restoration and protection approaches, including beach nourishment, are recommended and should be expected to provide continued benefits as evidenced by effective placement of sand from the 2013 and 2016 channel dredging projects resulting in greater stability of the barrier during 2017 high water. Well-planned placement of inlet dredged material for shoreline restoration purposes should be continued.

4. *Responding to Ice Formations*. Additional attention should be given to planning for proper emergency response to formation of ice dams in the North Pond Inlet. Insofar as pond flooding caused by ice dams may result in significant property damage as well as impacts on environmental quality (caused by flooding of household sanitary waste facilities, for example), additional consideration should be given to the conditions under which intervention to remove inlet ice dams is beneficial and feasible. While experience from the January 2014 ice dam event is instructive, additional knowledge concerning the formation, characteristics, and impacts of inlet ice dams is needed, including the effects of lake level, temperature, wind, lake ice, and watershed precipitation. Real-time monitoring of water level rise in the pond should be established to inform emergency response decisions.

Ideally, when a rapid rise in pond water level occurs, an equally rapid intervention response should ensue. Delays in response would limit opportunities to respond effectively or at all. Response with heavy equipment would likely need to occur the day after a rise in pond levels was detected. It is recommended that when a rise of nearly one foot in pond level occurs independent of lake elevation change, immediate intervention steps should ensue. Conditions affecting safe and effective use of heavy equipment for removal of ice dams should be considered in the formation of an emergency response plan by the Town of Sandy Creek prepared with assistance from other agencies.

5. *Water quality.* Ecosystem-based planning for the Inlet Management Study Area should give priority attention to water quality issues, recognizing that: a) the North Pond's several tributaries drain substantial areas of agricultural land in the eastern Lake Ontario watershed, carrying nutrients, bacteria, and other runoff pollutants into the pond; b) inadequate or poorly functioning household sanitary waste facilities surrounding the pond are also a potential source of nutrients, bacteria, and other pollutants; and c) a diminished hydrologic connection between the pond and lake would reduce water circulation and pose significant adverse impacts on water quality in the pond. Accordingly, a principal goal of any ecosystem-based plan should be to achieve and maintain the highest reasonably attainable quality of surface water in North Pond and to pursue that goal through all feasible measures to reduce or eliminate point and nonpoint sources of pollution (including stormwater runoff from roads, bridges, parking areas, lawns, agricultural lands, and other surfaces as well as seepage from residential septic systems). In this regard, the water quality initiatives included in the section Recommended Actions for Environmental and Resource Protection in the 2013 draft "Comprehensive Plan, Town of Sandy Creek, Village of Sandy Creek, Village of Lacona" are encouraged and supported, including testing and retrofitting of septic systems around the pond, implementing "green infrastructure" practices for runoff reduction, and tracking upstream sources of nutrients in the pond's tributaries. In addition, the following water quality initiatives are recommended for consideration:

   i. An effective, ongoing program of water quality monitoring in the IMSA and upstream in the North Pond tributaries by qualified governmental and nongovernmental organizations should be encouraged and supported to identify existing and potential sources of pollution and to establish and maintain a data base of information to support water quality improvement efforts by town, state, and federal agencies with water quality-related responsibilities and authorities. Among other pollutants, phosphorous, optical brighteners (from laundry detergents) and coliform bacteria should be monitored to assess the level of sanitary waste-related pollutants.

ii. The use of suitable best management practices (BMPs) to manage, reduce where feasible, or otherwise control stormwater runoff into North Pond should be encouraged and supported, including but not limited to establishment and maintenance of: buffer zones of natural vegetation to naturally filter polluted runoff draining into the pond; appropriate buffer/setback distances around wetlands in and adjoining the pond; cost-effective and sustainable Low Impact Development (LID) strategies, including rain gardens, vegetated swales, permeable pavements, and vegetated riparian buffer areas; public outreach and education initiatives; and other BMPs for site planning, source control, and stormwater treatment identified in the New York State Stormwater Management Design Manual.

iii. The feasibility of utilizing alternative treatment methods for sanitary waste should be evaluated, including composting facilities and other methods that meet public health requirements, lifestyle and property size limitations; consideration should be given to requirements for end-of-season pumping of sanitary waste from seasonal residences to avoid possible flood impacts and leaching to pond waters.

6. *Habitat.* Habitat protection and enhancement for native fish, wildlife, and plant species in the Inlet Management Study Area should be another principal goal of any ecosystem-based plan, including the above-recommended Inlet Management Plan and for Sandy Island Beach State Park. Planning to protect and enhance habitat should recognize that: a) the highest concentration of habitat values associated with the North Pond barrier are associated with the most recent landforms, including dunes, beaches and swale areas, and nearshore flats and shoals; and b) these high habitat value areas are also desirable areas for recreation. Accordingly, recreational use at SIBSP and elsewhere in the IMSA requires active management to avoid adverse impacts on habitat values. Recent experience with inlet dredging operations demonstrates that with informed management, recreational use and certain other human interventions can be coordinated with protection and enhancement of habitat values. Management of the South Spit sand flat as a bird sanctuary within SIBSP is an example of such effective coordination and should be continued. The current large expanse of this habitat type would likely diminish significantly should a new inlet form and is another factor to consider when preparing the recommended Inlet Management Plan. Planning for maintenance dredging operations should ensure that dredged material is placed in pre-determined locations to enhance habitat value, including habitat for the piping plover, and that dredging operations are carefully monitored and adjusted as necessary to protect this endangered shorebird species. It also appears that placement of dredged material on the South Spit during 2016 channel dredging operations may have contributed to stabilizing this section of barrier beach during 2017 high water conditions.

7. *Economic Analysis.* Consistent with the Stewardship Vision for Resource Conservation and Beneficial Use of the Eastern Lake Ontario Dune and Wetland System set forth in the 2007 Dunes Report and the goals of the New York Coastal Management Program, ecosystem-based plans affecting the Inlet Management Study Area should advance the dual purpose of conservation and beneficial use of the area's coastal resources. Effective planning therefore requires good understanding of the economic impacts (measured as revenues or expenditures) associated with year-round recreational, residential, and other uses of the IMSA. While it is generally recognized that use of the IMSA for recreational and other beneficial purposes, including traditional boating activities and recreational uses at Sandy Island Beach State Park, provides positive economic impacts of local and regional significance, substantial data concerning those impacts currently is not available. The 2013 draft "Comprehensive Plan, Town of Sandy Creek, Village of Sandy Creek, Village of Lacona" mentions that summer tourism is strong due to the presence of Sandy Island Beach State Park and the area's unique coastal resources (DWS resources), but the recreational boating sector of the economy is not described in any detail. Additional information concerning the economic impacts of recreational boating on North Pond should be developed and used to help provide justification for continued maintenance of the North Pond Inlet navigation channel. The extent of boating activity, including any observable trends, should be documented, along with more detailed information concerning the area's boating facilities and water-enhanced businesses deriving economic benefits from recreational boating.

8. *Coastal Processes.* The North Pond Resiliency Project has expanded the base of knowledge and information needed for effective ecosystem-based planning, and has generated an increased appreciation for the complexity of the littoral processes affecting the Inlet Management Study Area. In addition, the Project validates the "lesson" put forth in the 2007 Dunes Report that no matter how experienced or expert one may be, it is not possible to definitively chronicle all interactions among the different natural phenomena involved nor predict their long-term effects with any great certainty. Accordingly, continuation of these investigations is recommended to further expand the knowledge and information on which to base management decisions and initiatives, especially as conditions and circumstances affecting the North Pond Inlet continue to evolve. Recommended topics of further study include: the influence of lake level on littoral processes; the effects of water level regulation; impacts of Lake Ontario shore-hardening structures on the eastern shore sediment budget; water quality conditions evaluated on a watershed-wide basis; re-evaluation of floodplain delineations; and changes in the coastal barrier volume.

In addition, continuation and updating of the Project's shoreline change analyses, including continued collection of photographic surveys, aerial imagery, and elevation data sets (topobathymetric LiDAR), should be a priority in response to the 2017 high water conditions and the apparent evolution of the inlet toward closure. As of April, 2017, plans to obtain new LiDAR data via the Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALB) call for elevation data overflights in 2018 and 2019. Elevation data from JALB in 20011, 2007 and 2011 was essential for analysis of the DWS for this Project. To assist with analysis of the impact of high water in 2017, efforts to enlist acquisition of new topobathymetric LiDAR data in 2018 or even Fall 2017 should be undertaken. Providing an updated JABL topobathymetric data set would allow for comparison with elevation analyses performed for this Project. In addition to these robust data sets, drone-collected aerial videography should be pursued to provide more frequent surveys of shoreline conditions.

9. *Public Outreach.* The methods, data, and interpretations developed for the North Pond Resiliency Project, in addition to providing information to agencies and officials in support of ecosystem-based planning, including the recommended Inlet Management Plan, have substantial educational value for other interested parties and the general public. They can increase the awareness and understanding of local residents concerning natural processes affecting the shore and help develop public support for planning efforts. They also can contribute to and stimulate similar research efforts in other Great Lakes locations. A strategy for public outreach and dissemination of the Project's key elements should be developed by the Eastern Lake Ontario Dune Coalition. That strategy should include online (e.g., Story Maps) and public presentations, published articles, press releases, photographic exhibits, and other initiatives.

10. *Application of methods in other Great Lakes locations.* New analytical methods developed for the North Pond Resiliency Project, including comprehensive use of digital imagery, applications of LiDAR data, and managing lake level data in shoreline change analysis, can be used to advance quantitative measures of shoreline landform change and understanding of related coastal processes in other Great Lakes locations, including the entire US shoreline of Lake Ontario, and should be shared with other researchers to help advance the state of research on these important topics.

Suggested Planning Approach

This section focuses on suggested goals and strategies to tie elements of the North Pond Resiliency Project's Findings and Recommendations with the implementation structures identified in the Institutional Framework section of this report. Not all report recommendations are addressed here, but two priority focus areas are presented to promote action. The *first focus area* concerns development of public goals and strategies to guide ecosystem-based land- and water-use decisions throughout the Inlet Management Study Area, and to provide the basis for more detailed policies and recommendations. The *second focus area* concerns inlet management; a recommended framework for preparing an inlet management plan is presented. Other ecosystem-based management issues warrant similar treatment through, for example, recommendations for: watershed planning and stream restoration; beach restoration and shoal management; and water quality protection and pollution avoidance. Each of these topic areas warrant specific planning attention that is beyond the scope and resources of this Project.

North and South Ponds Management Area

More detailed public policies on the local, county, and state levels are needed to address the identified coastal management issues, including coastal resiliency issues, in the Inlet Management Study Area. Those policies, to help guide land- and water-use decisions affecting the IMSA, should be consistent with: the goals and objectives first considered by the Town of Sandy Creek in the 1989 "Sandy Pond Resource Management Study"; the Stewardship Vision set forth in the 2007 report "New York's Eastern Lake Ontario Dune and Wetland System: Guidelines for Resource Management in the 21st Century"; and the recommended community goals in the 2013 draft "Comprehensive Plan, Town of Sandy Creek, Village of Sandy Creek, Village of Lacona." The following statement of suggested goals is presented for consideration by town, county, and state agencies and officials, and intended to provide a basis for development of more detailed public policies.

The suggested goals and strategies, numbered below for reference purposes and not to denote priority, would establish a vision for safe and beneficial use and conservation of the area known as North and South Ponds Resource Management Area (RMA)[7]. The goals and strategies are consistent with: the goals and objectives first considered by the Town of Sandy Creek in the

7 The North and South Ponds Resource Management Area referred to herein is coterminous with the North Pond Inlet Management Study Area defined for the North Pond Resiliency Project. For the purpose of considering and establishing resource management goals for inclusion in town, county, and state planning documents, the North and South Ponds Resource Management Area is considered a more appropriate name for this geographic area.

1989 “Sandy Pond Resource Management Study”; the Stewardship Vision set forth in the 2007 report “New York’s Eastern Lake Ontario Dune and Wetland System: Guidelines for Resource Management in the 21st Century”; and the recommended community goals in the 2013 draft “Comprehensive Plan, Town of Sandy Creek, Village of Sandy Creek, Village of Lacona.” The goals would help provide a guiding framework for decisions and initiatives by local, county, and state agencies and officials with authorities and responsibilities affecting the RMA.
The goals and strategies are directed toward achieving balance among a number of equally important public purposes, including: protection and enhancement of environmental quality and the quality of life associated with the RMA; provision of opportunities for water-dependent recreational activities and public access to the area; and maintenance of the health, safety, and welfare of those who use the area.

Implementation of the goals and the vision they represent would be based in large part on the concept of committed stewardship whereby local, county, and state agencies, private organizations, governmental officials, and local residents with an interest or authority pertaining to the RMA would recognize their responsibilities for care of the area in the public interest. That care—or stewardship—would be for ensuring that the natural, cultural, and economic values of the area are sustained for the future.

Suggested Goals for Resource Management

1. Recognition of Coastal Resources, Values, and Ecological Systems
2. Active and Coordinated Resource Management
3. Management Balance
4. Public Health, Safety, and Welfare
5. Coastal Resiliency
6. Environmental Conservation and Enhancement
7. Recreational Uses
8. Sustainable Economic Benefits
9. Preservation and Enrichment of Community Character
10. Public Access to Coastal Waterways
11. Educational and Scientific Use
12. Public Interest, Support, and Participation
13. Effective Response to Changing Conditions

The goals and accompanying strategies also are intended to provide a foundation for developing more detailed resource management policies, guidelines, and recommendations to be included in town, county, and state plans and policy statements concerning the RMA.

Goal 1: Recognition of Coastal Resources, Values, and Ecological Systems

Achieve widespread public recognition that the coastal resources in the North and South Ponds Resource Management Area have vital environmental, economic, and cultural values that contribute considerably to the quality of life; that use and conservation of these resources should be properly managed in the public interest; and that the RMA is an integral part of a larger ecological system encompassing the Eastern Lake Ontario Dune and Wetland System and the watershed of eastern Lake Ontario.

Implementation Strategies. Continue to promote and emphasize the concept of environmental stewardship with respect to actions by public officials, governmental agencies, and the general public; encourage and support public outreach and education initiatives to provide information to the public regarding the RMA and public plans and policies for ecosystem-based management in the RMA (see no. 2). Encourage and support educational and scientific use of the RMA to increase understanding of natural functions and values and provide information to inform management decisions (see no. 11). Continue to emphasize, through public outreach and education initiatives and land-and water-use decisions, that the RMA is part of a larger ecological system of inter-dependent parts, and that recognition of this ecological system and of the human impacts on the system should be a guiding principle of resource management programs and initiatives.

Goal 2: Active Management of Areas and Resources

Actively manage use and conservation of the North and South Ponds Resource Management Area in the public interest, for the benefit of all local residents, visitors, and the general public. Establish and maintain an effective town role (acting in coordination with county, state, and federal agencies) for ecosystem-based management through local land- and water-use decisions.

Implementation Strategies. Encourage and support effective ecosystem-based management through: a) preparation and implementation of effective town, state, and regional *plans* to guide beneficial public and private use along with the conservation of natural coastal resources; b) adoption and enforcement of effective land- and water-use *regulations* for plan implementation; and c) *non-regulatory measures* for coastal resource management, including but not be limited to, personal stewardship actions and continued education and information initiatives. Prepare plans with substantial public input to reflect the general will of the citizens, and with provisions for amendment as needed to respond to changing conditions and circumstances. Evaluate the effectiveness of existing laws and regulations and consider new and/or modified laws and regulations, including town land- and water-use controls, as necessary. Encourage and support coordination, communication, and cooperation among all town, county, state, and federal agencies, private organizations, volunteer groups, and landowners with responsibilities, interests, and authorities concerning the RMA for the purpose of ensuring the most active and effective management of the area.

Goal 3: Management Balance

Achieve and maintain an appropriate balance between beneficial use and conservation and among several broad goals of equal importance, including goals to: a) maintain the public health, safety, and welfare; b) protect and enhance environmental quality; c) provide opportunities for recreation and other beneficial uses; and d) encourage and support continued residential and other private uses of the North and South Ponds Resource Management Area.

Implementation Strategies. Establish the concept of management balance in duly adopted ecosystem-based management plans affecting the RMA and in the decisions by agencies and groups with interests and responsibilities concerning the area. Promote the concept of balance to advance the national and New York State interests (set forth in the federal Coastal Zone Management Act and the New York Coastal Management Program, respectively) for promoting environmental conservation as well as the economic development of coastal resources. When pursuing an appropriate balance between equally important goals for beneficial use and conservation, recognize that that, due to the sensitivity of some ecosystem resources, a balance accommodating both recreational activities and habitat conservation cannot be achieved in all areas and at all times.

Goal 4: Public Health, Safety, and Welfare

Achieve and maintain safe, orderly, and efficient use and development in the North and South Ponds Resource Management Area, and provide for the continued public health, safety, and welfare for all persons who use and enjoy the area.

Implementation Strategies. Encourage and support effective enforcement of applicable local, state, and federal laws, regulations, and ordinances to maintain public safety, including boating safety, in the RMA; address the potential impacts of flooding and erosion through appropriate measures to increase coastal resiliency (see no.5 below); maintain public safety at shorefront park and beach areas and other locations providing opportunities for public access to the shoreline; provide facilities and services to support effective response to emergency situations in the area, including water access facilities to accommodate emergency services vessels; encourage and support measures to maintain navigation safety for all vessels operating in the area, including motorized and non-motorized vessels navigating on and between North Pond and Lake Ontario (see no. 7 below).

Goal 5: Coastal Resiliency

Encourage and support measures to reduce the vulnerability of the North and South Ponds Resource Management Area, including its developed shoreline and coastal resources, to natural hazards, including but not limited to, flooding, erosion, wind, and ice hazards caused by coastal storms, high lake levels, and other weather and climate-related events and phenomena. Accelerate recovery and reduce the amount of resources, including public expenditures, needed to completely restore municipal services, public infrastructure, and community functions damaged by natural hazards.

Implementation Strategies. Allow natural forces to continue to shape and modify the Lake Ontario shoreline. Generally, avoid measures intended to "fortify" the shoreline against the effects of natural forces and processes except in those instances where: a) no other reasonable alternative exists for protecting existing development; and b) the structures employed do not result in significant adverse impacts on adjacent properties and natural resources and values. Encourage and support effective nonstructural erosion control and shore protection measures, including: beach and dune nourishment using dredged sand from suitable borrow locations; planting and placement of dune-stabilizing vegetation; relocation of threatened structures out of high risk areas where feasible; application of, and compliance with, effective and well-planned land-use controls; and enforcement of applicable laws and regulations, including the Coastal Erosion Hazards Area Act. Encourage Low Impact Development approaches to land development and storm water management where feasible to reduce impervious surfaces and otherwise mitigate the impact of development on coastal resources and hydrology.

Goal 6: Environmental Conservation and Enhancement

Conserve and, where feasible, improve the environmental quality, including scenic quality, and ecological functions of coastal resources in the North and South Ponds Resource Management Area.

Implementation Strategies. Maintain and, where feasible, restore the natural integrity of the coastal barrier elements of the Eastern Lake Ontario Dune and Wetland System, including the barrier beaches and sand dunes providing protection for the North and South pond wetlands and embayments; maintain and enhance natural and significant habitat for native fish, wildlife, and plant species. Achieve and maintain the highest reasonably attainable quality of surface water through reduction of all sources of pollution, including nonpoint sources of pollution (NPS pollution); encourage and support initiatives to protect and improve water quality that are planned and implemented on a watershed-wide basis. Continue to identify and assess threats to coastal resources; identify specific resource areas requiring protection from those threats; and continue to develop and apply measures to avoid or otherwise mitigate adverse impacts on coastal resources.

Goal 7: Recreational Uses

Maintain and enhance opportunities for water-dependent and other recreational use of the North and South Ponds Resource Management Area, in balance with other public purposes and beneficial uses, and consistent with the area's capacity to support those uses without the occurrence of significant adverse impacts on environmental quality or on public health, safety, welfare, and enjoyment.

Implementation Strategies. Encourage and support water-dependent uses and facilities that individually and collectively enhance the environmental quality associated with the RMA, the local and regional economy, and the overall quality of life associated with the area, including but not limited to boating, fishing, and beach recreation activities. Maintain a variety of public and commercial boating services and facilities for resident and visiting boaters, making North Pond a center of recreational boating activity on the eastern shore of Lake Ontario and a regional destination point for visiting boaters. Maintain and enhance opportunities for non-boating recreational use of the RMA and the public lands contiguous to the area, including opportunities for swimming, land-based fishing, walking, bicycling, picnicking, nature observation, enjoyment of water views, special public events, and other beneficial activities. Maintain a navigation channel providing safe and efficient navigation between North Pond and Lake Ontario, sufficient to meet the needs of vessels operating in the RMA and to maintain the viability of water-dependent businesses in the area.

Goal 8: Sustainable Economic Benefits

Recognize and pursue opportunities for local and regional economic benefits associated with use and development in the North and South Ponds Resource Management Area; achieve sustainable economic benefits through uses and development that are consistent with town and regional character and quality of life and in harmony with conservation and enhancement of the natural environment.

Implementation Strategies. Support year-round uses of the RMA, including history-based and nature-based tourism, boating and other water-dependent recreational uses, and environmental education programs. Support beneficial use and development of commercial waterfront areas, consistent with Town goals and objectives for encouraging water-dependent uses and conserving and enhancing the environmental quality associated with the shoreline. Emphasize environmentally sustainable economic benefits that rely on but do not degrade the natural environment.

Goal 9: Preservation and Enrichment of Community Character

Protect and enhance the existing quality of life and traditional community character associated with the North and South Ponds Resource Management Area; preserve coastal resources with cultural significance, including historic, scientific, and archaeological significance.

Implementation Strategies. Encourage and support continuation of the traditional uses of the RMA, including boating, fishing, beach recreation, hunting, and other uses. Protect and enhance the traditional character of shorefront residential neighborhoods. Preserve the existing character and cultural heritage associated with Lake Ontario and its eastern shore when reviewing development proposals and promoting local, regional, and state-wide tourism initiatives. Provide a forum for all public concerns, including those of shorefront residents, related to the quality and character of the RMA and shorefront neighborhoods.

Goal 10: Public Access to Coastal Waterways

Provide safe and enjoyable opportunities for long-term public access to the navigable waters in the North and South Ponds Resource Management Area for active and passive recreational uses, consistent with the capacity of coastal resources to accommodate public access in an environmentally sound manner.

Implementation Strategies. Maintain and where feasible improve the quality of existing water access areas, including publicly owned properties and water-access right-of-ways, and provide new areas, as such need may arise, in appropriate locations. Ensure that opportunities for use of coastal waters in the RMA, including opportunities for navigation, are available to all on a fair and equitable basis, consistent with the Public Trust Doctrine and all applicable laws, regulations, and ordinances. Plan and maintain opportunities and facilities for public access to the RMA in a manner that is consistent with and does not unduly conflict with the rights of the owners of waterfront properties and underwater lands, including the littoral right for reasonable access to navigable water.

Goal 11: Educational and Scientific Use

Encourage and support use of the North and South Ponds Resource Management Area for educational and scientific purposes, in a manner consistent with the capacity of the natural environment to support those purposes.

Implementation Strategies. Increase the awareness and understanding of individuals and groups concerning the natural resources and values of the RMA through educational and scientific activities that also will provide valuable information for science-based management decisions by public officials and resource management agencies. Plan and coordinate scientific investigations and research initiatives to the greatest extent possible to increase their utility.

Encourage and support environmental education programs and appropriately designed and located educational facilities to attract visitors to the RMA on a year-round basis and provide sustainable economic benefits of local and regional significance.

Goal 12: Public Interest, Support, and Participation

Develop and maintain substantial public awareness of the significant environmental, economic, and cultural benefits provided by the North and South Ponds Resource Management Area and maintain public support for effective implementation of resource management plans, regulations, programs, and other initiatives.

Implementation Strategies. Provide continuing opportunities for expression of public interests related to the RMA; encourage and support special programs and events to increase public awareness of coastal resources and benefits, and support for implementation of resource management plans; prepare and implement effective outreach programs to inform and educate residents and visitors concerning resource values and opportunities for personal stewardship initiatives; encourage and support educational and scientific uses in appropriate locations.

Goal 13: Effective Response to Changing Conditions

Adapt to changing conditions and circumstances influencing implementation of resource management plans, regulations, programs, and other initiatives concerning the North and South Ponds Resource Management Area.

Implementation Strategies. Monitor conditions in the RMA, including the condition of natural and developed features and the status and effectiveness of stewardship initiatives, on an ongoing basis. Amend or otherwise modify resource management plans, regulations, programs, and other initiatives with public input to respond most effectively to changing conditions and circumstances, including conditions and circumstances regarding the physical features of the RMA and the institutional framework for managing the area.

Inlet Management Area

Town of Sandy Creek officials and the agencies and organizations with planning and regulatory responsibilities affecting inlet management should recognize that: 1) the North Pond Inlet's recent and current geomorphology indicate that it is tending toward closure; 2) significant adverse economic and environmental impacts would be associated with inlet closure without concurrent establishment of a new inlet providing a similar hydrologic connection between the pond and Lake Ontario; and 3) currently no long-range town or agency plan or policies exist to guide governmental decisions regarding the inlet, including decisions concerning maintaining the inlet in its present location or, should the inlet close, decisions concerning responses to new inlet formation connecting the pond with the lake. Accordingly, those officials, agencies, and organizations should commit to working cooperatively to prepare an Inlet Management Plan (Plan), including a proactive sand management strategy, to guide those decisions.

The following recommended steps are intended to provide a useful roadmap for preparing the Plan. While it is recognized that stakeholders' consideration of these recommendations may also result in modified or alternative approaches to achieve desired results, the recommendations are intended to help initiate the planning process.

1. *Initial Inlet Management Issues*. An initial discussion of inlet management questions and issues should take place at a regular or special meeting of the Eastern Lake Ontario Dune Coalition. That discussion may be based on the Resource Management Issues and Planning Considerations section of this North Pond Resiliency Project report. A basic question to consider in the inlet management planning process is whether substantial human intervention is warranted to deter both closure of the existing inlet and anticipated formation of a new inlet on the north spit, recognizing that this would likely involve: 1) significant excavation of sand from the inlet and Inlet Shoal; 2) placement of that sand on the lake side of the barrier beach; dune construction; and 3) possibly sand placement on the pond side of the barrier beach.[8] This question need not be answered definitively at the outset of the planning process but should be discussed prior to proceeding with designation of a Plan coordination agency or committee as recommended in no. 2 below.

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[8] This question represents the site-specific application of the fundamental question of interest to resource managers and governmental officials concerning the overall Eastern Lake Ontario Dune and Wetland System: *"To what extent should natural forces be allowed to shape and modify the system without human intervention to try to stabilize the shoreline?"*

Some related questions follow.

- Given the predominant influence of lake levels on the littoral processes affecting inlet formation, is human intervention to maintain the existing inlet and deter new inlet formation likely to be of long-term utility?
- Can continued maintenance dredging of the existing navigation channel prolong the life of the existing inlet for a significant period of time in a cost-effective manner?
- What are the likely impacts of natural formation of a new inlet on the North Spit, perhaps evolving over a period of five to eight years, on coastal resources, shorefront properties, and navigation?

2. *Plan Coordination Agency/Committee; Means of Plan Adoption.* From among the members of the ELODC, an Inlet Management Plan coordination agency or committee should be designated/established with responsibility to oversee preparation of the Plan. In addition, initial consideration should be given to the appropriate vehicle for adopting or otherwise establishing the Plan as public policy, including: adoption as a formal planning document of the Town of Sandy Creek, perhaps as a separate element of the Town of Sandy Creek Comprehensive Plan; incorporation in the State of New York Coastal Management Program and Management Plan for Sandy Island Beach State Park, or other appropriate means. These matters could be a specific agenda item for discussion and action at a regular or special meeting of the ELODC.

3. *Initial List of Stakeholders.* An initial list of inlet management stakeholders should be prepared, including but not limited to, governmental agencies with coastal regulatory and planning authorities, conservation organizations, local businesses supporting recreational boating in North Pond, and private landowners. This matter also could be a specific agenda item for discussion and action at the above-noted regular or special meeting of the ELODC. The Institutional Framework section of this Project report should be used as a starting point for preparing the stakeholders list.

4. *First Public Meeting.* With assistance from ELODC as necessary, the designated Plan coordination agency/committee should organize and conduct a public meeting in the Town of Sandy Creek to: 1) present relevant findings and recommendations from the Resiliency Project; and 2) hear public comments pertinent to preparation of the Inlet Management Plan. When publicizing this meeting, notifications should be provided to the agencies, organizations, and property owners included on the initial list of inlet management stakeholders. In coordination with the first public meeting, an appropriate public opinion survey to assess opinions and interests regarding inlet management should be considered.

5. *Work Program and Initial Goal Statement.* Following the public meeting, the Plan coordination agency/committee should meet to review comments from the public meeting and survey, continue to consider inlet management questions and issues, and establish the work program for preparing the Inlet Management Plan. Prior to preparing the work program, the coordination agency/committee should make a preliminary decision regarding the extent to which the Plan should support continued human intervention, through dredging, beach nourishment, and other means, to maintain the existing inlet. Then when preparing the work program, the coordination agency/committee should consider whether professional engineering services or other consultant services are needed for Plan preparation, and identify potential sources of any needed funding assistance. In addition, the coordination agency/committee should establish, subject to later public review and comment, initial goals for guiding development of the Plan, giving consideration to the "Goals and Strategies for Resource Management in the North and South Ponds Resource Area" recommended in this Project report. Recommended Plan goals for consideration by the Plan coordination agency/committee include:

1. To maintain safe and efficient navigation between North Pond and Lake Ontario;
2. To maintain the viability of local businesses supporting recreational boating;
3. To protect public health, safety, and welfare though improved resilience to coastal hazards affecting the Lake Ontario and North Pond shorelines;
4. To maintain traditional boating and shoreline uses in the pond and Lake Ontario, including residential uses on and near the North Pond shoreline and on the North Pond barrier;
5. To protect and enhance water quality and the environmental quality of coastal resources, including beaches, dunes, wetlands, and fish and wildlife resources; and
6. To utilize any public funds allocated for inlet management in the most responsible and cost-effective manner.

6. *Content of Plan*. The form of the Inlet Management Plan will depend in part on the vehicle or vehicles for Plan adoption. Provisions to be adopted, however, may be drawn from a larger Plan document consisting of several basic elements, some of which may be adapted from sections of the North Pond Resiliency Project report. The recommended basic elements of the Plan include: 1) description of inlet history and existing physical conditions, including littoral processes affecting inlet formation; 2) review of the institutional framework for inlet management; 3) discussion of inlet management issues; 4) goals and policies for inlet management; 5) implementation strategies, including sand management recommendations;

and 6) responsibilities for Plan implementation. Implementation strategies and recommendations should address the following considerations (not listed in any order of priority), among other pertinent matters:

1. Locations on the coastal barrier and nearshore area for placement of beach nourishment sand dredged from the inlet channel and, to the extent feasible, from the Inlet Shoal, for beneficial purposes, including increased resiliency and habitat enhancement;
2. Means and methods of dredging, with consideration given to both mechanical and hydraulic dredging;
3. Seasonal issues affecting inlet dredging projects, including seasonal constraints necessary to protect fish and wildlife resources, and determination of optimum dredging seasons for maximizing project longevity, including navigation benefits;
4. Requirements for topographic and bathymetric surveys, volume computations, and sediment analysis for planning and regulatory purposes;
5. The extent to which nonstructural (soft) solutions, including beach nourishment and dune creation, are cost-effective and otherwise feasible to increase the resilience of developed shorelines and coastal resources;
6. Identification and evaluation of inlet management alternatives and order of magnitude cost estimates for alternatives;
7. Identification of potential funding sources for dredging and other inlet management initiatives;
8. Responsibilities for submitting regulatory permit applications;
9. Habitat mitigation planning to avoid adverse impacts on rare, threatened, and endangered species, including piping plovers, and with special attention given to early succession habitat created by dredge material placement and establishment of new beach and dune areas;
10. Opportunities and constraints for excavating sand from the Inlet Shoal for beach nourishment and other beneficial purposes throughout the RMA;
11. Adequacy of navigational markers for boating safety;
12. Affected vessels and boating facilities, including navigation usage patterns, vessel characteristics, number of affected vessels; and boating services;
13. Requirements for a comprehensive beach and inlet monitoring program to evaluate inlet management performance and impacts over time; and
14. Coordination with habitat management and recreational use plans prepared by the New York OPRHP for Sandy Island Beach State Park.

7. *Second Public Meeting*. With assistance from ELODC as necessary, the designated Plan coordination agency/committee should organize and conduct a second public meeting in the Town of Sandy Creek to: 1) present suggested inlet management goals, policies, and strategies; 2) present suggested vehicles for Plan adoption; and 3) hear public comments on the suggested Plan provisions. When publicizing this meeting, notifications should be provided to the identified stakeholders.

8. *Plan Adoption.* Following the public meeting, the Plan coordination agency/committee should meet to review comments from the public meeting and make any changes the agency/committee believes are needed to the draft Plan, including the inlet management goals, policies, and strategies. The Plan coordination agency/committee should then proceed with the process of Plan adoption by the appropriate vehicle or vehicles identified in the planning process.

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Appendix A

Table 2: Shoreline change metrics for complete analysis. All shoreline transect metrics. Individual statistics are included for each transect: end point rate (m/yr), net shoreline movement (m), linear regression rate (m/yr), regression r-squared, regression standard error, and regression confidence interval 95%

Appendix B

Remote Sensing Data Set Inventory and Interpretation (separate document).

	Transect offset from north (m)	Shore Change Envelope (m)	End Point Rate (m/yr)	Net Shoreline Movement (m)	Linear Regression Rate (m/yr)	Regression R-squared	Regression Standard Error	Regression Confidence Interval 95%
2	50	26	-0.3	-16	-0.2	0.12	10.51	0.66
3	100	28	-0.3	-17	-0.2	0.14	0.57	0.66
4	150	23	-0.2	-11	-0.1	0.02	7.51	0.35
5	200	20	-0.2	-10	0.0	0.02	6.03	0.28
6	250	22	-0.2	-9	0.0	0.00	6.59	0.31
7	300	21	-0.2	-9	0.0	0.01	5.82	0.27
8	350	14	-0.1	-3	0.0	0.00	5.00	0.23
9	400	10	0.0	1	0.1	0.09	3.63	0.14
10	450	14	0.0	2	0.1	0.08	3.91	0.15
11	500	24	0.0	1	0.2	0.47	5.16	0.17
12	550	32	0.2	11	0.4	0.73	5.06	0.17
13	600	30	0.4	19	0.4	0.83	4.02	0.14
14	650	30	0.3	16	0.4	0.77	4.37	0.15
15	700	32	0.2	8	0.4	0.60	5.91	0.20
16	750	30	0.2	11	0.4	0.70	5.03	0.17
17	800	28	0.2	10	0.3	0.60	4.64	0.16
18	850	31	0.2	10	0.4	0.71	5.06	0.17
19	900	30	0.3	16	0.4	0.79	4.31	0.15
20	950	30	0.2	9	0.3	0.60	5.44	0.18
21	1000	31	0.1	6	0.3	0.46	6.20	0.21
22	1050	37	0.2	9	0.4	0.50	7.00	0.24
23	1100	57	0.8	57	0.6	0.81	7.20	0.19
24	1150	65	0.8	61	0.7	0.88	6.38	0.13
25	1200	63	0.8	62	0.7	0.89	5.94	0.12
26	1250	65	0.8	61	0.7	0.85	7.09	0.14
27	1300	66	0.8	60	0.7	0.82	7.43	0.15
28	1350	69	0.8	61	0.7	0.78	8.54	0.17
29	1400	71	0.9	66	0.7	0.74	9.71	0.19
30	1450	72	0.8	59	0.7	0.64	11.81	0.24
31	1500	76	0.8	64	0.8	0.67	12.40	0.25
32	1550	74	0.8	63	0.8	0.67	12.37	0.25
33	1600	78	0.9	68	0.8	0.69	11.88	0.24
34	1650	74	0.9	68	0.7	0.67	10.80	0.21
35	1700	79	0.9	70	0.7	0.57	13.20	0.26
36	1750	80	0.9	69	0.7	0.55	13.60	0.26
37	1800	81	0.9	72	0.7	0.56	13.27	0.26
38	1850	75	0.9	70	0.6	0.51	13.28	0.26
39	1900	78	1.0	73	0.7	0.60	12.90	0.25
40	1950	86	1.0	74	0.8	0.60	13.86	0.27
41	2000	86	1.0	75	0.8	0.62	13.42	0.26
42	2050	85	1.0	76	0.7	0.62	13.35	0.26
43	2100	80	1.0	75	0.7	0.58	13.38	0.26
44	2150	77	1.0	74	0.7	0.57	12.96	0.25
45	2200	87	1.0	75	0.8	0.64	13.30	0.26
46	2250	77	1.0	75	0.7	0.58	13.44	0.26
47	2300	85	1.0	80	0.8	0.62	13.75	0.27
48	2350	94	1.0	80	0.9	0.69	13.70	0.27
49	2400	94	1.1	82	0.9	0.75	12.27	0.24
50	2450	94	1.0	80	0.9	0.72	13.00	0.25
51	2500	96	1.0	80	0.9	0.70	13.54	0.26
52	2550	92	1.0	77	0.9	0.69	13.20	0.26
53	2600	93	1.0	78	0.8	0.65	13.94	0.27
54	2650	92	1.0	78	0.8	0.68	13.02	0.25
55	2700	90	1.0	77	0.8	0.61	13.83	0.27
56	2750	138	1.0	77	0.3	0.07	26.27	0.51
57	2800	98	1.0	77	0.5	0.31	17.48	0.34
58	2850	90	1.0	76	0.5	0.28	16.28	0.32
59	2900	97	1.0	74	0.4	0.17	19.04	0.37
60	2950	221	0.9	70	0.0	0.00	37.09	0.72
61	3000	147	0.9	67	0.1	0.02	24.49	0.47
62	3050	104	0.9	66	0.2	0.06	19.23	0.37
63	3100	210	0.8	63	-0.1	0.01	35.78	0.69
64	3150	96	0.8	59	0.1	0.01	18.92	0.37
65	3200	219	0.7	56	-0.2	0.01	37.68	0.73
66	3250	90	0.7	53	0.2	0.04	18.16	0.35
67	3300	80	0.7	50	0.1	0.02	17.11	0.33
68	3350	82	0.6	46	0.1	0.01	16.18	0.31
69	3400	102	0.5	40	0.0	0.00	20.09	0.39
70	3450	96	0.4	34	0.0	0.00	20.05	0.39
71	3500	113	0.4	28	-0.2	0.03	23.20	0.45
72	3550	129	0.3	21	-0.4	0.08	28.18	0.55
73	3600	161	0.0	3	-0.5	0.12	32.27	0.62
74	3650	185	-0.4	-32	-0.9	0.22	39.26	0.76
75	3700	290	-1.1	-84	-1.6	0.27	59.46	1.15
76	3750	345	-3.5	-272	-2.8	0.40	76.50	1.48
77	3800	349	-3.5	-267	-2.8	0.42	74.97	1.45
78	3850	193	-0.9	-72	-1.3	0.31	43.52	0.84
79	3900	184	-0.1	-7	-0.8	0.17	39.00	0.75
80	3950	170	0.3	25	-0.4	0.07	33.65	0.65
81	4000	135	0.4	34	-0.2	0.04	25.98	0.50

82	4050	83	0.6	44	0.2	0.05	18.87	0.37
83	4100	88	0.7	53	0.3	0.14	19.07	0.37
84	4150	105	0.9	67	0.4	0.20	19.08	0.37
85	4200	116	1.0	75	0.4	0.20	20.25	0.39
86	4250	152	1.1	84	0.3	0.05	26.70	0.52
87	4300	203	1.2	89	-0.3	0.02	42.41	0.82
88	4350	230	1.3	97	-0.7	0.08	50.65	0.98
89	4400	265	1.4	106	-0.7	0.05	61.57	1.25
90	4450	307	1.4	108	-0.9	0.06	74.57	1.51
91	4500	338	1.5	112	-1.0	0.06	82.96	1.69
92	4550	414	1.5	115	-0.7	0.03	88.04	1.79
93	4600	372	1.6	121	0.0	0.00	77.34	1.50
94	4650	287	1.6	126	0.5	0.04	52.96	1.02
95	4700	231	1.7	133	1.2	0.31	39.77	0.77
96	4750	234	1.8	142	1.9	0.61	35.02	0.68
97	4800	338	2.0	153	2.2	0.49	51.36	0.99
98	4850	334	2.2	172	2.7	0.61	50.21	0.97
99	4900	330	2.4	187	3.2	0.60	60.24	1.17
100	4950	399	2.6	199	4.3	0.62	75.37	1.46
101	5000	481	3.1	235	5.4	0.63	94.34	1.82
102	5050	482	5.9	455	7.2	0.86	65.28	1.22
103	5100	472	6.1	471	6.2	0.88	53.26	1.03
104	5150	302	3.5	272	4.2	0.82	44.49	0.86
105	5200	228	2.5	192	3.0	0.91	21.02	0.41
106	5250	170	2.1	158	2.4	0.94	13.99	0.27
107	5300	161	1.9	148	2.2	0.93	14.02	0.27
108	5350	154	1.9	142	2.1	0.93	13.39	0.26
109	5400	150	1.8	138	2.0	0.92	14.06	0.27
110	5450	145	1.7	134	2.0	0.92	13.77	0.27
111	5500	144	1.6	122	2.0	0.92	13.56	0.26
112	5550	139	1.6	119	1.9	0.92	12.91	0.25
113	5600	135	1.5	118	1.8	0.91	13.22	0.26
114	5650	134	1.5	117	1.7	0.92	11.91	0.23
115	5700	130	1.5	116	1.8	0.93	11.22	0.22
116	5750	128	1.5	114	1.7	0.91	11.85	0.23
117	5800	121	1.4	106	1.6	0.91	11.39	0.22
118	5850	121	1.3	101	1.6	0.90	11.82	0.23
119	5900	116	1.3	98	1.5	0.89	12.25	0.24
120	5950	112	1.2	95	1.5	0.90	11.21	0.22
121	6000	111	1.2	91	1.5	0.91	10.55	0.20
122	6050	108	1.2	89	1.4	0.90	10.46	0.20
123	6100	107	1.2	90	1.3	0.90	10.37	0.20
124	6150	101	1.2	89	1.3	0.89	10.18	0.20
125	6200	101	1.1	87	1.3	0.89	10.16	0.20
126	6250	96	1.1	85	1.3	0.90	9.39	0.18
127	6300	97	1.1	82	1.2	0.91	8.78	0.17
128	6350	93	1.0	78	1.2	0.90	8.88	0.17
129	6400	85	0.9	72	1.1	0.83	10.90	0.21
130	6450	82	0.9	67	1.0	0.87	8.54	0.17
131	6500	79	1.0	77	1.0	0.92	6.62	0.13
132	6550	75	0.9	67	0.9	0.87	7.73	0.15
133	6600	70	0.8	64	0.8	0.87	7.18	0.14
134	6650	69	0.8	63	0.8	0.87	6.91	0.13
135	6700	73	0.8	61	0.8	0.84	7.69	0.15
136	6750	74	0.9	65	0.9	0.88	7.06	0.14
137	6800	66	0.7	56	0.7	0.82	7.53	0.15
138	6850	63	0.7	54	0.7	0.82	7.25	0.14
139	6900	55	0.6	46	0.6	0.76	7.18	0.14
140	6950	55	0.6	48	0.6	0.77	6.97	0.14
141	7000	46	0.5	39	0.4	0.68	6.58	0.13
142	7050	45	0.5	40	0.4	0.68	6.50	0.13
143	7100	42	0.5	38	0.4	0.69	6.05	0.12
144	7150	39	0.4	33	0.4	0.78	4.72	0.09
145	7200	37	0.4	31	0.4	0.79	4.82	0.10
146	7250	35	0.4	31	0.5	0.78	5.68	0.12
147	7300	33	0.3	20	0.3	0.48	6.39	0.13
148	7350	29	0.2	13	0.1	0.15	7.50	0.16
149	7400	23	0.2	15	0.1	0.11	5.87	0.13
150	7450	21	0.1	9	0.0	0.00	5.63	0.12
151	7500	31	0.1	9	0.0	0.00	6.92	0.15
152	7550	39	0.1	6	0.0	0.01	8.42	0.18
153	7600	28	0.2	14	0.1	0.07	6.69	0.15
154	7650	25	0.2	14	0.2	0.29	5.43	0.15
155	7700	25	0.2	13	0.1	0.19	6.00	0.16
156	7750	23	0.1	9	0.1	0.13	5.73	0.15
157	7800	19	0.1	9	0.1	0.15	4.97	0.13
158	7850	25	0.1	5	0.1	0.06	6.13	0.16
159	7900	23	0.1	4	0.1	0.03	6.03	0.16
160	7950	23	-0.1	-9	-0.2	0.49	5.04	0.16