NIAGARA POWER PROJECT

RELICENSING

SHORELINE EROSION AND SEDIMENTATION ASSESSMENT STUDY UPSTREAM AND DOWNSTREAM OF THE POWER PROJECT

Volume 1: Public

Volume 2: Non-Internet Public

Niagara Power Project
FERC No. 2216

Prepared for:

New York Power Authority

Prepared by:

W.F. Baird & Associates Coastal Engineers Ltd.

Copyright © 2005 New York Power Authority

August 2005

New York Power Authority

TABLE OF CONTENTS

EXECUTIVE SUMMARY viii

1.0 INTRODUCTION 1-1

2.0 PROJECT DESCRIPTION 2-1

3.0 BACKGROUND ON EROSION AND SEDIMENTATION PROCESSES 3-1

3.1 Local Geology and Glacial Deposits 3-1
3.2 Cohesive Shore Processes 3-3
3.2.1 Definition of a Cohesive Shore 3-3
3.2.2 Principles of Erosion on Cohesive Shores 3-4
3.2.3 Underwater Erosion Processes 3-5
3.2.4 Sub-Aerial Erosion Processes - Bank and Bluff Erosion 3-8
3.3 The Driving Forces or Causal Factors of Erosion 3-10
3.3.1 Waves and Currents 3-11
3.3.2 The Role of Water Levels 3-11
3.3.3 Ice 3-13
3.4 The Role of Rooted Aquatic Macrophytes 3-13
3.5 Sedimentation Processes 3-14

4.0 METHODS 4-1

4.1 Field Studies 4-1
4.1.1 Shoreline Categorization 4-2
4.1.2 Shoreline Protection Inventory 4-2
4.1.3 Erosion Areas 4-3
4.1.3.1 Detailed Erosion Areas 4-4
4.1.4 Points of Interest (POIs) 4-5
4.1.5 Sedimentation Areas 4-5
4.1.6 Gorge Assessment 4-6
4.1.7 Jetboat Wake 4-7
4.2 Office Studies 4-7
4.2.1 Shoreline Characterization 4-7
4.2.2 Erosion Areas 4-8
4.2.2.1 Influence of US/Canadian Power Generation and Treaty Flows 4-9
4.2.2.2 Detailed Erosion Areas 4-10

Copyright © 2005 New York Power Authority

4.2.3 Sedimentation Areas 4-11
4.2.4 Gorge Assessment 4-12

5.0 ASSESSMENT OF EROSION 5-1
5.1 Upper Niagara River 5-1
5.1.1 Detailed Erosion Areas 5-5
5.1.1.1 Grand Island (near Tonawanda Island) 5-5
5.1.1.2 Buckhorn Island 5-6
5.2 Lower Niagara River 5-7
5.2.1 Detailed Erosion Area 5-8
5.3 Tributaries - Upper River 5-10
5.3.1 Gill Creek 5-11
5.3.2 Cayuga Creek 5-12
5.3.3 Bergholtz Creek 5-13
5.3.4 Tonawanda Creek 5-14
5.3.5 Ellicott Creek 5-15
5.3.6 Twomile Creek 5-15
5.3.7 Big Sixmile Creek 5-16
5.3.8 Burnt Ship Creek 5-17
5.3.9 Woods Creek 5-18
5.3.10 Gun Creek 5-18
5.3.11 Spicer Creek 5-19
5.3.11.1 Detailed Erosion Area 5-20
5.4 Tributaries – Lower River 5-21
5.4.1 Fish Creek 5-21
5.5 Gorge Area 5-22
5.5.1 Assessment of Video 5-22
5.5.2 Jetboat Wake 5-23
5.6 Summary of Shore Protection in the Study Area 5-24

6.0 ASSESSMENT OF SEDIMENTATION 6-1
6.1 Sediment Sources 6-3
6.1.1 Sediment from Lake Erie 6-3
6.1.2 Bank Erosion 6-4
6.1.3 River Downcutting 6-4
6.1.4 Watersheds, Canals and Creeks 6-7
6.2 Transport Pathways for Sediment 6-8
6.2.1 Dredging 6-8

Copyright © 2005 New York Power Authority

6.2.2 River Bed Deposition 6-9
6.2.3 Lewiston Reservoir 6-10
6.2.4 Welland River 6-10
6.2.5 Lake Ontario 6-10
6.3 Summary of Sediment Sources, Transport Pathways and Sediment Sinks 6-11
6.4 Power Generation Impacts on the Sediment Budget 6-11
6.5 Future Sedimentation Rates in the Lewiston Reservoir 6-11

7.0 SUMMARY AND CONCLUSIONS 7-1
7.1 Upper River 7-1
7.1.1 Tributaries 7-2
7.2 Lower River 7-2

REFERENCES 1

TABLES

Table 4.1.3.1-1 4-13
Classification Scheme for Historical Recession Rates 4-13

FIGURES

Figure 1.0-1 1-3
Study Limits 1-3

Figure 3.2.3-1 3-15
Downcutting of a Cohesive Profile, Scarborough Bluffs, Ontario, Canada 3-15

Figure 3.2.4-1 3-16
Bluff Recession after a Rotational Failure 3-16

Figure 4.1.2-1 4-14
"Good" Steel Sheet Pile Wall 4-14

Copyright © 2005 New York Power Authority

Figure 4.1.2-2 ..... **4-15**
"Fair" Steel Sheet Pile Wall 4-15

Figure 4.1.2-3 ..... **4-16**
"Poor" (or Failed) Timber Crib 4-16

Figure 4.1.7-1 ..... **4-17**
Jetboat Traveling Downstream Along the Canadian Shoreline 4-17

Figure 4.2.1-1 ..... **4-18**
Areas of Shore Protection for the Upper Niagara River and Tributaries 4-18

Figure 4.2.1-2 ..... **4-19**
Areas of Shore Protection for the Lower Niagara River and Tributaries 4-19

Figure 5.1-1 ..... **5-25**
Erosion Areas and POIs on the Upper Niagara River and Tributaries 5-25

Figure 5.1-2 ..... **5-26**
Erosion along Buckhorn Island on the Upper Niagara River 5-26

Figure 5.1-3 ..... **5-27**
Erosion along Grand Island opposite Tonawanda Island on the Upper Niagara River 5-27

Figure 5.1-4 ..... **5-28**
Erosion along the Mainland Side of Tonawanda Channel on the Upper Niagara River 5-28

Figure 5.1.1.1-1 ..... **5-29**
Grand Island Erosion Area (opposite Tonawanda island) – Conceptual Sketch of Typical Profile 5-29

Figure 5.1.1.2-1 ..... **5-30**
Buckhorn Island Erosion Area – Conceptual Sketch of Typical Profile 5-30

Figure 5.2-1 ..... **5-31**
Erosion Areas and POIs on the Lower Niagara River 5-31

Figure 5.2.1-1 ..... **5-32**
Lower Niagara River Erosion Area – Conceptual Sketch of Typical Profile 5-32

Copyright © 2005 New York Power Authority

Figure 5.2.1-2 ..... **5-33**
Lower Niagara River Erosion Area – Looking Downsteam 5-33

Figure 5.2.1-3 ..... **5-34**
Lower Niagara River Erosion Area – Looking Upstream 5-34

Figure 5.2.1-4 ..... **5-35**
Lower Niagara River Erosion Area – Existing Conditions 5-35

Figure 5.2-2 ..... **5-36**
Erosion along Clay Talus along the Lower Niagara River South of Lewiston (1) 5-36

Figure 5.2-3 ..... **5-37**
Erosion into Clay Talus along the Lower Niagara River South of Lewiston (2) 5-37

Figure 5.2-4 ..... **5-38**
Erosion of Queenston Shale Bluffs along the Lower Niagara River North of Lewiston 5-38

Figure 5.3.1-1 ..... **5-39**
Limits of Study Area for Gill Creek 5-39

Figure 5.3.1-2 ..... **5-40**
Limits of Erosion and Scarping on Gill Creek 5-40

Figure 5.3.2-1 ..... **5-41**
Limits of Study Area for Cayuga and Bergholtz Creeks 5-41

Figure 5.3.2-2 ..... **5-42**
Limits of Erosion and Scarping on Cayuga and Bergholtz Creeks 5-42

Figure 5.3.4-1 ..... **5-43**
Limits of Study Area for Tonawanda and Ellicott Creeks 5-43

Figure 5.3.4-2 ..... **5-44**
Limits of Erosion and Scarping on Tonawanda and Ellicott Creeks 5-44

Figure 5.3.6-1 ..... **5-45**
Limits of Study Area for Twomile Creek 5-45

Copyright © 2005 New York Power Authority

Figure 5.3.6-2 5-46
Limits of Erosion and Scarping on Twomile Creek 5-46

Figure 5.3.7-1 5-47
Limits of Study Area for Big Sixmile Creek 5-47

Figure 5.3.7-2 5-48
Limits of Erosion and Scarping on Big Sixmile Creek 5-48

Figure 5.3.9-1 5-49
Limits of Study Area for Woods Creek 5-49

Figure 5.3.9-2 5-50
Limits of Erosion and Scarping on Woods Creek 5-50

Figure 5.3.10-1 5-51
Limits of Study Area for Gun Creek 5-51

Figure 5.3.10-2 5-52
Limits of Erosion and Scarping on Gun Creek 5-52

Figure 5.3.11-1 5-53
Limits of Study Area for Spicer Creek 5-53

Figure 5.3.11-2 5-54
Limits Erosion and Scarping Spicer Creek 5-54

Figure 5.3.11.1-1 5-55
Spicer Creek Erosion Area – Conceptual Sketch of Typical Profile 5-55

Figure 6.0-1 6-12
Niagara River Sediment Budget 6-12

Figure 6.1.3-1 6-13
Sample of Side-Scan Data 6-13

Figure 6.1.3-2 6-14
Study Sediment Layer and 2003 Side-Scan Tracklines 6-14

Copyright © 2005 New York Power Authority

Figure 6.1.3-3 ..... **6-15**
Cross-Section of the Tonawanda Channel, Profile 2 6-15

Figure 6.1.3-4 ..... **6-16**
Cross-Section of the Tonawanda Channel, Profile 11 6-16

Figure 6.3.2-1 ..... **6-17**
Side-Scan Image of the Turning Basin Immediately Downdrift of Tonawanda Island 6-17

Figure 6.3.2-2 ..... **6-18**
Side-Scan Image of the Intake Bay 6-18

Figure 6.3.2-3 ..... **6-19**
Observed River Bed Deposition at the Northwest Tip of Buckhorn Island 6-19

Figure 6.3.5-1 ..... **6-20**
Bar at the Mouth of the Niagara River (Lake Ontario) 6-20

APPENDICES

APPENDIX A **2**
Glossary 2

APPENDIX B **6**
Geophysical Study, Select Area of the Tonawanda Channel 6

Copyright © 2005 New York Power Authority

EXECUTIVE SUMMARY

The New York Power Authority (NYPA) is engaged in the relicensing of the Niagara Power Project in Lewiston, Niagara County, New York. The present operating license of the plant expires in August 2007. As part of its preparation for the relicensing of the Niagara Power Project, NYPA is developing background information related to the ecological, engineering, recreational, cultural, and socioeconomic aspects of the Project.

As part of this process, a Scope of Services was prepared to complete a qualitative assessment of erosion and sedimentation areas upstream and downstream of the Niagara Power Project. Baird & Associates was retained in 2002 to perform a comprehensive visual reconnaissance of the upper and lower Niagara River, as well as of select tributaries, as prescribed in the Scope of Services. Baird & Associates was retained in 2003 to address a second Scope of Services that prescribed additional data collection at selected erosion and sedimentation areas, as well as additional visual reconnaissance surveys of other major tributaries of the Niagara River system.

This report includes the combined Study Area of the 2002 and 2003 Scopes of Service. The Study Area includes portions of the American shoreline of the Niagara River, the Gorge, and the major tributaries. The upper Niagara Study Area extended from the Peace Bridge to the NYPA Project intakes, and included the Tonawanda and Chippawa Channels. Major tributaries assessed in the upper Niagara Study Area included Gill Creek, Little Niagara River, Cayuga Creek, Bergholtz Creek, Little River, Tonawanda Creek, Ellicott Creek, Twomile Creek, Big Sixmile Creek, Burnt Ship Creek, Woods Creek, Gun Creek, and Spicer Creek. The lower Niagara Study Area extended from just upstream of the Robert Moses Niagara Power Plant (RMNPP) tailrace to Lake Ontario along the American shoreline. The Gorge Study Area also included the upper river from the NYPA Project Intakes to the Falls and the gorge area extending from the Falls to the Robert Moses Niagara Power Plant tailrace. The only tributary assessed in the Gorge portion of the Study Area was Fish Creek. With the exception of Tonawanda Creek (for reasons described in Section 5.3.4), the upstream limit of the tributaries was determined based on the approximate location where Niagara River water levels cease to have an influence. The upstream limit is approximate or qualitative in most cases and was based on several factors including; (a) limits supplied by

Copyright © 2005 New York Power Authority

NYPA for selected tributaries (based on results of URS et al. 2005a), and (b) GIS analysis of local topographic information relative to water levels on the river.

Field investigations entailed documenting the type of shoreline within the Study Area, performing a preliminary inventory of shoreline protection features, identifying substantial erosion and sedimentation sites, and a number of "points of interest." Erosion sites are those areas where erosion is presently occurring. For each erosion site, preliminary comment of the causes of erosion is provided. For the detailed erosion areas, additional data was collected for further assessment of the sites. Points of interest are defined as areas that are not presently eroding but that have eroded in the past or that appear susceptible to future erosion. Points of interest also include areas where the shore protection is in an advanced state of deterioration, or locations on tributaries where a small erosion scarp was identified. This scarp is often less than one foot high and is not related to severe bank erosion or slope failures. Rather it is attributed to natural erosion processes in the tributaries, which are, by nature, erosional features. Sedimentation areas are locations where sand, silt and/or clay has "settled out" from the water due to several factors (as described in Section 4.1.5)

The shoreline within the Study Area was documented by:

- taking digital photographs of typical shoreline reaches;
- delineating areas that were "Protected" or "Unprotected";
- noting different types of protection;
- locating areas of poor or failing protection;
- geophysical surveys to identify surficial characteristics of the riverbed; and,
- topographic and hydrographic surveys at select erosion areas.

Digital photos were taken to document typical shoreline types, and were geo-referenced using GPS equipment. Together with the geo-referenced photos, all classifications (erosion areas, points of interest, sedimentation areas, and protected/unprotected reaches) were incorporated into a GIS to assist in the documentation and analysis of the Study Area.

Copyright © 2005 New York Power Authority

In summary, on the upper Niagara River, approximately 3 percent of the American shoreline inventoried was identified as actively eroding and 63 percent as protected in some manner. The lower river showed erosion along 14 percent of the shoreline, with 37 percent protected. For the total length of tributaries assessed in the upper river, approximately 4 percent of the creek banks were identified as actively eroding, and 40 percent as protected in some manner. Also, a majority of Tonawanda Creek is completely protected, which has an influence on the total protection value noted above.

The primary driving forces for erosion are wind-generated waves, ship/boat-generated waves and river currents on the upper and lower rivers. For the tributaries, erosion occurs when the bed shear stress generated by river currents exceed the resisting properties of the creek materials. Field observations suggest this condition only occurs during the spring freshet and following severe rainfall events. Summer and fall flow conditions, and any water level fluctuations that occur during these periods (natural or induced by U.S./Canadian power generation), do not appear to accelerate erosion. Many other processes play a secondary role in erosion of the rivers and tributaries, including ice, debris, surface runoff, groundwater flow, and weathering. The influence of these driving forces is modulated to different degrees by water level fluctuations depending on the nearshore profile shape, geology and natural/artificial shore protection characteristics. It is important to note that water level fluctuations in both the upper and lower Niagara River are caused by a number of factors in addition to US/Canadian power generation. These include wind, natural flow variations, ice conditions, the water levels of Lake Erie and Lake Ontario, and control of Niagara Falls flow for scenic purposes.

Water level fluctuations may influence erosion rates along two reaches of Grand Island, each about 3,000 feet long, that feature wide, shallow, nearshore shelves. The shelf is effective at dissipating wave energy at low, and possibly average water levels, but not at high water levels. These two sites were chosen as detailed erosion areas, and additional field data was collected at these sites during the 2003 study. Other possible areas of greater water level influence on erosion include some sections of the upper and lower river where shore protection features have deteriorated or are unsuitable for the local conditions.

A conceptual sediment budget was prepared for the Niagara River, including the tributaries and connecting channels. The sediment sources and sinks in the equation were identified and described in

Copyright © 2005 New York Power Authority

qualitative terms. Side scan sonar was collected for the Tonawanda Channel, between the north and south Grand Island bridges, and was used to document the substrate types for the river bed. Other data sets included in the analysis were existing mapping of the river substrate and habitat transects collected along the shoreline.

Sediment sources include suspended sediment from Lake Erie, river bank erosion, river bed erosion, and sediment from the tributaries and canals. The following sediment sinks within the study area were identified: dredging, river bed deposits, accumulation in the U.S. and Canadian reservoirs, losses to the Welland River, and deposition in Lake Ontario. The side scan data helped to identify potential locations of new sediment (i.e. sources), such as river bed erosion and sediment sinks, such as the Turning Basin at Tonawanda Island and the dredged bay at the Twin Intakes. The daily water level fluctuations in the Niagara River due to U.S./Canadian power generation will have some influence on the various sediment budget variables described above.

Copyright © 2005 New York Power Authority

In 2003, a Scope of Services was prepared to expand the previous study to include additional tributaries, and to document areas further upstream that were initially visited for the previous investigation. The Scope of Services also prescribed a more detailed survey of selected erosion areas upstream and downstream of the Niagara Power Project, as well as a more detailed assessment of sedimentation areas in the river.

The 2003 Study Area included the following tributaries; Fish Creek, Gill Creek, Cayuga Creek, Bergholtz Creek, Ellicott Creek, Twomile Creek, Big Six Creek, Burnt Ship Creek, Woods Creek, Gun Creek, and Spicer Creek. The upstream study limits of the tributaries was determined based on the location where Niagara River water levels cease to have an influence. With the exception of Tonawanda Creek (for reasons described in Section 5.3.4), the upstream limits of the tributaries were based on several factors including; (a) limits supplied by NYPA for selected tributaries (based on results of URS et al. 2005a), and (b) GIS analysis of local topographic information relative to water levels on the river.

The Study Area also included the upper river from the NYPA Project Intakes to the Falls and the gorge area extending from the Falls to the Robert Moses Niagara Power Plant tailrace. Figure 1.0-1 shows the limits of the Study Area for the combined studies.

The tasks undertaken in the earlier study were repeated in the present study for the expanded Study Area. A more detailed survey of erosion was also undertaken in selected areas of the upper and lower river at locations chosen from the earlier study. The detailed erosion surveys were also performed in selected tributaries of the upper river. In addition, a more detailed sedimentation survey was undertaken for a substantial portion of the Tonawanda Channel of the upper river. All of the data collected was incorporated into a GIS to assist in the documentation and analysis of the Study Area. This report presents the results of the combined studies.

Copyright © 2005 New York Power Authority

1.0 INTRODUCTION

The New York Power Authority (NYPA) is engaged in the relicensing of the Niagara Power Project in Lewiston, Niagara County, New York. The present operating license of the plant expires in August 2007. As part of its preparation for the relicensing of the Niagara Project, NYPA is developing background information related to the ecological, engineering, recreational, cultural, and socioeconomic aspects of the Project. As part of this process, a Scope of Services was prepared to assess erosion and sedimentation areas upstream and downstream of the Niagara Power Project.

Baird & Associates was retained in 2002 to perform a comprehensive visual reconnaissance of the upper and lower Niagara River, as well as of major tributaries on the American side of the river, that may be affected by water level fluctuations. The study involved the following tasks:

- identification and delineation of areas experiencing significant shoreline erosion;
- identification of areas that may be experiencing sedimentation;
- identification, in a qualitative manner, of the most likely causes of shoreline erosion; and
- a preliminary inventory of shoreline protection features.

The Study Area for the previous Shoreline Erosion and Sediment Assessment report prepared by Baird (Baird 2003a) included the American shoreline of the Niagara River and selected tributaries that may be affected by water level fluctuations. The lower Niagara River Study Area extended from just upstream of the Robert Moses Niagara Power Plant tailrace to Lake Ontario. The upper Niagara River Study Area included both the Tonawanda and Chippawa Channels, and extending from the Peace Bridge to the NYPA Project Intakes. Major tributaries in the upstream portion of the Study Area included Little Niagara River, Cayuga Creek, Little River, Tonawanda Creek, and Ellicott Creek. The upstream limits chosen for the tributaries in the previous study was based on two factors; a) a visual assessment in the field that active bank erosion was not present, and b) the physical limitations of the survey boat in narrow and shallow creeks/channels.

Copyright © 2005 New York Power Authority

Non-Internet Public (NIP) information has been removed from the following page(s).

This material is contained in:
Volume 2
Section: Shoreline Erosion and Sedimentation Assessment Study Upstream and Downstream of the Power Project

FIGURE 1.0-1

STUDY LIMITS

[NIP – General Location Maps]

Copyright © 2005 New York Power Authority

2.0 PROJECT DESCRIPTION

The 1,880-MW (firm capacity) Niagara Power Project is one of the largest non-federal hydroelectric facilities in North America. The Project was licensed to the Power Authority of the State of New York (now the New York Power Authority) in 1957. Construction of the Project began in 1958, and electricity was first produced in 1961. The information presented in this section was provided by URS or derived from URS et al. 2005b.

The Project has several components. Twin intakes are located approximately 2.6 miles above Niagara Falls. Water entering these intakes is routed around the Falls via two large low-head conduits to a 1.8-billion-gallon forebay, lying on an east-west axis about 4 miles downstream of the Falls. The forebay is located on the east bank of the Niagara River. At the west end of the forebay, between the forebay and the river, is the Robert Moses Niagara Power Plant (RMNPP), NYPA's main generating plant at Niagara. This plant has 13 turbines that generate electricity from water stored in the forebay. Head is approximately 300 feet. At the east end of the forebay is the Lewiston Pump Generating Plant (LPGP). Under non-peak-usage conditions (i.e., at night and on weekends), water is pumped from the forebay via the LPGP's 12 pumps into the 22-billion-gallon Lewiston Reservoir, which lies east of the plant. During peak usage conditions (i.e., daytime Monday through Friday), the pumps are reversed for use as generators, and water is allowed to flow back through the plant, producing electricity. The forebay, therefore, serves as headwater for the Robert Moses plant and receptor of tailwater from the Lewiston Plant. South of the forebay is a switchyard, which serves as the electrical interface between the Project and its service area.

For purposes of generating electricity from Niagara Falls, two seasons are recognized: tourist season and non-tourist season. As required by international treaty, at least 100,000 cubic feet per second (cfs) must be allowed to flow over Niagara Falls during tourist season (April 1 – October 31) daytime hours, and at least 50,000 cfs at all other times. Canada and the United States are entitled by international treaty to produce hydroelectric power with the remainder.

Copyright © 2005 New York Power Authority

It is important to note that water level fluctuations in both the upper and lower Niagara River are caused by a number of factors other than the US/Canadian power generation. These include wind, natural flow variations, ice conditions, the water levels of Lake Erie and Lake Ontario, and control of Niagara Falls flow for scenic purposes. Water level fluctuations in the Chippawa-Grass Island Pool are limited by an International Niagara Board of Control (INBC) directive to 1.5 feet per day within a 3-foot range for normal conditions. For unusual conditions (i.e., high flow, low flow, ice, etc.), the allowable range of Chippawa-Grass Island Pool water levels is extended to 4 feet. The effect of ponding in the Chippawa-Grass Island Pool is detectable upstream and varies with river conditions. At most, this backwater influence can extend to somewhere between Frenchman's Creek and the Peace Bridge.

Water-level fluctuations in the lower Niagara River (upstream of the RMNPP tailrace) from all causes can be as great as 12 feet per day. Most of this daily fluctuation is due to the change in the treaty-mandated control of flow over Niagara Falls. Water level fluctuations downstream of the RMNPP tailrace are much less. The average daily water level fluctuation 1.4 miles downstream of the RMNPP tailrace, during the 2002 tourist season, was approximately 1.5 feet. The daily fluctuations decrease progressively at the temporary gages located further downstream. At the most downstream temporary gage SG-04A, the average daily fluctuation during the tourist season was 0.6 feet. From the data collected, it appears that manmade regulation for Treaty flows and Canadian and U.S. hydroelectric generation have an effect on water levels and flows in the lower Niagara River to its mouth at Lake Ontario.

Copyright © 2005 New York Power Authority

3.0 BACKGROUND ON EROSION AND SEDIMENTATION PROCESSES

This section presents an overview of erosion processes for the types of shorelines encountered on the upper and lower reaches of the Niagara River. This section also includes a brief discussion of the geology and glacial geomorphology of the Study Area.

Open coast and river shorelines in the Great Lakes Basin may be broadly grouped into three categories:

- sandy shores, including beaches backed by dunes and barrier beach complexes;
- cohesive shores, including consolidated glacial till, lacustrine clay and erodible sedimentary rocks such as dolomite, limestone, sandstone and shale from the Paleozoic era; and
- erosion-resistant bedrock shores, such as the Precambrian granite found in the Thousand Islands Region of the St. Lawrence River.

All eroding shorelines in the Study Area fall into the second category, namely, cohesive shores. The erosion processes associated with cohesive shores are fundamentally different from the erosion of sandy shores. It is essential that these differences be recognized in the implementation of shore stabilization measures. This section discusses erosion and sedimentation processes associated with cohesive shores. This description has been adapted from a chapter on this topic prepared for the new U.S. Army Corps of Engineers (USACE) Coastal Engineering Manual by Dr. R. Nairn of Baird & Associates (CEM Part III, Chapter 5). Many of the technical terms used are explained in the glossary presented in Appendix A of this report.

3.1 Local Geology and Glacial Deposits

The geology, glacial deposits and surficial soils within the study area are described in Chapter 10 of the First-Stage Consultation Report (NYPA 2002). Additional details can also be found in several

Copyright © 2005 New York Power Authority

historical references, including Grabau (1901) on the Paleozoic rocks, Kindle and Taylor (1913) for a description of the glacial history and Johnston (1964) for information on the water bearing characteristics of the bedrock. These references will be summarized briefly below to provide context for the following discussion of erosion processes. The reader should refer to these references for additional details if required.

The underlying bedrock within the Study Area is from the Paleozoic era, dips slightly to the south, and was formed 500 to 350 million years ago (Johnston 1964). North of the Niagara Escarpment, the surficial deposits are underlain by Queenston Shale, which outcrops along the banks of the Niagara River near Lewiston. Above the Escarpment, the final bedrock layer is Lockport Dolomite, which is generally 5 to 15 feet below the glacial deposits and modern soil horizons. Between these two formations are layers of limestone, sandstone, and shale, which can be observed in the Niagara Gorge.

The completion of the Paleozoic era, approximately 300 million years ago, marked the transition to the Quaternary period when the landscape in the Great Lakes Basin was influenced by a glacial epoch known as the Pleistocene. This was followed by the post-glacial Holocene, which began approximately 10,000 years ago, and continues today. During the Pleistocene, several continental glaciers advanced south and retreated north across the Study Area. The final glacial event is known as the Wisconsin, and this period is responsible for the deposition of the cohesive sediments found above the Queenston Shale and Lockport Dolomite within the Study Area.

The deposits related to the Wisconsin Glaciation can be generally grouped into three categories for the purpose of this erosion investigation: 1) glacial till, which consists of varying distributions of clay, silt, sand, cobbles, and pebbles, and is formed under pressure at the base of the glacier, 2) lacustrine clay, which forms at the bottom of temporary lakes located along the ice margin when sediment-laden meltwater is transported to the lakes from the glacier, and 3) isolated deposits of sand and gravel that have been eroded from the till and clay, then sorted and transported by glacial streams from the retreating glacier. In general, the glacial till is found directly on top of the bedrock, then capped by the lacustrine deposits, and occasionally followed by sands and gravels.

Copyright © 2005 New York Power Authority

3.2 Cohesive Shore Processes

3.2.1 Definition of a Cohesive Shore

A shore is defined as cohesive when the erosion process is directly related to the irreversible removal of a cohesive sediment substratum (i.e., glacial deposits, ancient lagoon peats, tidal flat muds, valley and bay fill muds, lacustrine clays, flood deltas consisting of fine sediments, soft Paleozoic or sedimentary rocks, and other consolidated or over-consolidated deposits). Even when sand beaches are present over cohesive soils, the soils under the sand beach play the most important role in determining how these shores erode and evolve in the long term. This differs fundamentally from sandy shores where erosion (or deposition) is directly related to the net loss (or gain) of unconsolidated sediment (i.e., sand and gravel) from a given surface area. Erosion on a sandy shore is a potentially reversible process while erosion on a consolidated cohesive shore is irreversible.

A further distinction may be made between "mud," or unconsolidated cohesive sediment that has been recently deposited ('recently' may be a matter of several years, for example), and hard or consolidated cohesive sediments. For this study, the eroding cohesive shores consist of consolidated glacial till and lacustrine clay (which, in some areas, will have been softened by subaqueous and sub-aerial erosion processes) observed in the upper Niagara River, and erodible sedimentary rock, such as shale observed in the lower Niagara River.

A thin veneer of sand and gravel, sometimes forming a beach at the shore, usually covers the consolidated or partially consolidated sediments that constitute cohesive shores. Such a shoreline, although sandy in appearance, does not consist of an infinitely thick pile of sand, and, in such instances, conventional coastal engineering principles are often not applicable. Cohesive shorelines may be associated with an eroding bluff or bank face such as Buckhorn Island, or they may consist of a transgressive barrier beach perched over older cohesive sediments (no examples of this shoreline type are found along the Niagara River). The presence of the sand veneer often disguises the underlying consolidated substratum, and therefore, at many locations, cohesive shores are incorrectly assumed to behave as sandy shores. Along the lower Niagara River in the vicinity of Lewiston, the talus slopes at the base of what once would have been high sedimentary rock cliffs constitute a special case of cohesive

Copyright © 2005 New York Power Authority

shore. Because these cliffs generally consist of very weak Queenston Shale, the talus consists of eroded and partially consolidated shale debris.

Cohesive shores are found over a large part of the Great Lakes, Arctic, Atlantic, Pacific, and Gulf coasts of North America, over a large part of the North Sea coast of England, and in sections of coastline along the Baltic and Black Seas. Estimates from the International Joint Commission (IJC) Erosion Processes Task Group Report (1993) suggest that more than 50 percent of the lower Great Lakes and connecting channel shores may be classified as cohesive. As the awareness of this shore type grows, and as sub-bottom investigations become more prevalent, more examples are being identified. As Riggs et al. (1995) note, in many cases, the shore is not just a "thick pile of sand."

3.2.2 Principles of Erosion on Cohesive Shores

Erosion processes on cohesive shores are distinctly different from those on sandy shores. On consolidated cohesive shores, the erosion process is irreversible because, once eroded in an energetic coastal environment, cohesive sediment cannot be reconstituted in a consolidated form. Furthermore, since the sand and gravel content is usually low in these deposits (often less than 20 percent), the volume eroded is not balanced by the volume of deposition within the littoral zone. The eroded fine sediments (silt and clay) are winnowed, carried offshore, and deposited downstream in deeper water or sheltered bays. Even on the sedimentary-rock shores of the lower Niagara River, much of the Queenston Shale is so weak that it quickly breaks down to clay-sized particles that are lost into deep water. The sand and gravel fraction, on the other hand, usually remains in the shallow littoral zone.

Consolidated cohesive sediment is eroded by at least four mechanisms:

- through abrasion by sand particles entrained in hydraulic flow;
- through pressure fluctuations associated with turbulence generated at various scales, such as wave-breaking-induced turbulence that reaches the riverbed, or large-scale eddies that may develop in the surf zone (the area where wave breaking occurs);

Copyright © 2005 New York Power Authority

- through chemical and biological influences; or
- through wet/dry and freeze/thaw cycles, when exposed to the atmosphere (desiccation) or in shallow water.

Sand and gravel (or shingle) can also provide a protective cover to the underlying cohesive substratum. However, only when the sand cover is of sufficient thickness to protect the cohesive substratum at all times will the shore revert to a sandy classification (i.e., truly a "thick pile of sand"). This condition likely never develops along the Niagara River. On consolidated cohesive shores, the rate of lake or riverbed downcutting determines the long-term rate at which the bluff or bank retreats at the shoreline. In other words, while sub-aerial geotechnical processes may dictate when and where a slope failure will occur over short periods (1 to 25 years), the rate of shoreline retreat over the long term (>50 years) is determined by the rate at which the nearshore underwater profile is eroded (i.e., the downcutting rate).

3.2.3 Underwater Erosion Processes

An extensive study of nearshore profiles on the north-central shore of Lake Erie, described by Philpott (1984), revealed that the profile shape remained relatively constant over an eighty-year interval despite dramatic shore recession. For this to occur, erosion must be distributed across the full width of the nearshore profile. This led Philpott (1984) to conclude that the controlling process in bluff or cliff recession on cohesive shores is not restricted to wave action at the toe (as proposed by Sunamura (1992) for eroding rocky coasts), but by the erosion of the nearshore profile by waves. Boyd (1992) cites many earlier references that also suggest that nearshore erosion has a controlling influence on shoreline recession. The shoreward shift of the dynamic equilibrium profile implies that erosion or downcutting is proportional to the gradient of the nearshore profile and is, therefore, greatest close to shore. Davidson-Arnott (1986) describes field measurements of downcutting for a till profile (through the deployment of micro-erosion meters across a transect) at a site near Grimsby on Lake Ontario. The results confirm the hypothesis on downcutting, namely, that the rate increases towards the shore in a manner related to the local bed slope, allowing for the preservation of the profile shape as it shifts shoreward with time. The downcutting hypothesis has now been confirmed by many other field investigations, including nine years of profile retreat data at Maumee Bay State Park in Ohio (Fuller 2002). Hutchinson (1986) and Sunamura

Copyright © 2005 New York Power Authority

(1992) also note that the rate of lowering (or downwasting) of the intertidal platform on erodible rocky coasts likely determines the long-term rate of cliff retreat in most instances. The key point is that erosion of a bluff is an effect of the erosion of the nearshore profile. The shore materials and erosion processes found at the above mentioned sites are similar to the Niagara River shoreline and therefore the findings are relevant to this study.

In general, it has also been shown that the underlying cohesive profile, for cases where the properties of the cohesive sediment are uniform, follows an equilibrium profile shape as defined by Dean (1977). The morphology of the nearshore profile is a product of the local wave climate, the water level regime, and the resisting properties of the bottom substrate. The combination of local driving forces and sediment properties at a site will produce an unique profile shape that varies spatially along the shore.

The downcutting process is illustrated in Figure 3.2.3-1 for a cohesive shore site located east of Toronto along the Scarborough Bluffs, on Lake Ontario. The bluff face has retreated approximately 100 feet (30 meters) over a 37-year period, for an average long-term recession rate of 2.7 feet/year (0.8 meters/year). The underlying cohesive profile shape of 1952 is very similar to that of 1989; it has simply shifted shoreward by 100 feet. The long-term bluff or cliff retreat rate is equivalent to the long-term profile retreat rate. This figure also shows that erosion can continue even if there is a significant quantity of sand covering an underlying cohesive sediment profile. The position of the underlying cohesive profile shown in Figure 3.2.3-1 was estimated based on observations that the cohesive sediment is usually exposed or very thinly covered in the troughs between the sandbars. Also, it is known that the till is exposed at the toe of the bluff (i.e., at the back of the beach).

Figure 3.2.3-1 demonstrates that there is not a cross-shore balance of erosion and deposition; most of the eroded material from the cohesive profile and the bluff is either winnowed offshore (for the clay and silt fractions) or transported alongshore/downstream (for the sand and gravel fractions).

The profile retreat model for cohesive shores implies that the amount by which the driving forces of erosion exceed the resisting forces is inversely proportional to the water depth. In other words, the most active subaqueous erosion occurs at the shoreline and, therefore, the potential for erosion must increase in the shoreward direction. However, there is evidence that sediment becomes less erosion-

Copyright © 2005 New York Power Authority

resistant in deeper water due to the increased role of softening between storm events (Davidson-Arnott and Langham 2000). These observations highlight the complexity in the relationship between the driving forces and cohesive profile erosion.

During the past five years Baird & Associates (2001, 2003b) has completed extensive studies on shoreline response to fluctuating water levels for the Lake Michigan Potential Damages Study. Baird has also participated in the International Joint Commission's study on Lake Ontario and the St. Lawrence River (Baird 2002a, Baird 2002b). For cohesive shorelines, these investigations have focused on quantifying historical shoreline recession and downcutting rates over both the short and long term. In addition, numerical modeling has been applied to predict future shoreline response for scenarios of high and low lake levels. The purpose of this modeling is to investigate the role of water levels on erosion over periods of months to over 100 years.

Collectively, these investigations, which evaluated recession rates over multiple temporal scales using historical data and numerical modeling, have advanced the state of the science. Over short periods (one month to several years), the rate of erosion of cohesive shores is very sensitive to wave attack at the bluff toe during high water levels. However, over the long term (>50 years), the downcutting of the river or lakebed is the sustaining process that allows cohesive shoreline to recede. Without downcutting of the bed offshore of the bluff toe, the slopes would eventually stabilize. More details on the potential influence of fluctuating water levels on erosion processes for the Niagara River are presented in Section 5.1.

Special consideration must be given to cohesive shorelines that feature a high concentration of cobbles and boulders in the soil matrix. While the clays, silts, and sands are washed away by waves and currents, the larger cobbles and boulders are left behind in a lag deposit whose effect is to self-armor the river or lake bottom. These shore types often feature a wide, flat shelf. The width of the shelf is directly related to the length of time the shoreline has been eroding. Due to the attenuating effect of the shelf on waves, shoreline recession rates for these shore types are very sensitive to fluctuating water levels over any period. This type of shore condition is not present in the Niagara River or its U.S. tributaries. When water levels are low or average, a significant amount of wave energy is expended on the shelf (without

Copyright © 2005 New York Power Authority

causing erosion). However, when water levels are high, the shelf is less effective at attenuating energy, and large waves can attack the toe of the bluff or riverbank.

A riverbed in lacustrine clay or glacial till will also erode with time until it reaches some equilibrium depth where the bed shear stresses, even under the most extreme flow, do not exceed the critical shear stress that leads to erosion.

3.2.4 Sub-Aerial Erosion Processes - Bank and Bluff Erosion

On consolidated cohesive shores, the primary sub-aerial erosion process is slumping of oversteepened bluffs or cliffs. Along actively eroding shorelines, bluff faces are generally in a perpetually oversteepened state (i.e., with slopes greater than approximately 2.5[H] to 1.0[V], where 2.5 is the horizontal, or run, component of the slope angle, and 1.0 is the vertical, or rise, component of the slope angle). For the weak, eroding shale cliffs along the lower Niagara River, cliff-face erosion is also influenced by weathering (wet/dry and freeze/thaw), since these slopes generally remain too steep for soil to accumulate and, thus, inhibit the development of a protective layer of vegetation.

The long-term bluff or cliff retreat rate is determined by the rate of profile downcutting. In a review of erosion data from the Lake Erie shoreline, Kamphuis (1987) states that cliff height does not exert much influence on the process (in fact, a distinct lack of correlation was noted). This is due to the fact that erosional debris from a shore cliff is quickly swept away, winnowed offshore and deposited in deep water. Exceptions to this generalization include locations where the cliff failure debris is not easily removed from the toe of the cliff by erosion (e.g., in the case of eroded rock cliffs or blocks of frozen sediment along Arctic shores). The primary reason for slope failures along a cohesive shore is the oversteepened nature of the slope owing to the ongoing nearshore and toe erosion, removal of previous slope failures by wave action, and toe erosion at the base of the slope. This process was observed at Buckhorn Island. Although some slope failures may be attributed to local groundwater conditions (such as perched water tables) and climatic sequences (such as rapid precipitation), a slope would not continue to fail over multiple years/decades if wave action had not removed the debris from the previous failure. In other words, the nearshore downcutting and toe erosion due to wave forces provides a feedback or setup mechanism that allows slope failure to continue indefinitely.

Copyright © 2005 New York Power Authority

Although sub-aerial processes do not generally determine the rate of shoreline recession on cohesive shores over the long term (>50 years), these processes are critical in determining when and where a slope failure will occur over much shorter periods (i.e., months to years). Slope stability is a function of the balance between the force of gravity and the strength of the geologic materials in a bluff or bank. The strength of the geologic materials depends on the cohesion of particles and the presence or absence of groundwater. The stratigraphy of a bluff or cliff can have a significant influence on slope stability. Weak clay layers can provide slip planes for slope failures, or can serve to confine groundwater to more pervious upper layers, resulting in the development of a perched water table. If the tablelands slope toward the water body, groundwater will flow toward the shoreline in the perched water table and exit the upper reaches of the slope. At the point of emergence, the forces due to groundwater flow can exceed the strength of the soil and dislodge soil particles on the bank face. This process is known as piping or sapping, and was observed in the lower Niagara River in the vicinity of Lewiston.

Groundwater can also exit the bluff face as a confined or isolated spring, leading to seepage erosion and, depending on the sequence of the local geology, increase pressures within the slope and contribute to the overall slope instability. This can occur when groundwater or seepage pathways at the bluff face are blocked by talus from a previous slide further up slope. Failures may be classified as: (1) falls and topples; (2) rotational (i.e., circular) and translational slides; and (3) spreads and flows. The type of failure is a function of the geological conditions at the site. The conditions in the lower River downstream of Lewiston are conducive to these types of groundwater processes. In some instances the combination of surface runoff, rainfall, drainage over the bluff face, and wave spray, will lead to the development of small rills or drainage channels. Continuous drainage in small rills will eventually lead to the development of larger gullies capable of transporting significant quantities of water to the shoreline or river. Although the influence of surface erosion is generally secondary to larger slope failures, they can contribute to the long-term erosion of a bluff or river bank. This is not a major process in the Upper Niagara River, but rills and gullies have been observed in the Lower River.

Edil and Bosscher (1988) present a Great Lakes perspective overview of forces influencing cohesive slope erosion, which result in mass movement (i.e., sliding, flow, and creep) and particle movement (i.e., wave, wind, ice, rill, and sheet erosion, and sapping through seepage flow). This reference provides useful information for assessing site-specific causes of bluff face erosion.

Copyright © 2005 New York Power Authority

Shoreline processes can often trigger bluff failures. For example, notching or scarping at the toe of the bluff is caused by wave action, particularly at higher water levels. This process can result in an oversteepened bluff or cliff face that is susceptible to slope failures. The banks of the lower Niagara River exhibit these conditions (wave and current action erode the material at the water line which maintains a steep bank).

In some areas where shoreline recession rates are low and the bluff height is high (and particularly for areas susceptible to rotational failures), bluff failure becomes a more important mechanism to address in the design of shoreline stabilization. This is illustrated in Figure 3.2.4-1. For a 50-foot-high bluff that is susceptible to rotational failures, a single bluff failure may result in 100 feet of erosion or more. In contrast, for a bluff that has a low-to-moderate recession rate of 1 foot/year, the same 100 feet of erosion might take 100 years to occur. This is an oversimplification because of the complex interaction between shoreline processes and bluff failures. Nevertheless, in some cases it is important to carefully consider bluff-failure mechanisms when determining long-term recession rates or when designing shoreline stabilization features. These types of bluffs are not found in the study area.

3.3 The Driving Forces or Causal Factors of Erosion

It was explained in the previous section that the rate of erosion of cohesive shores is primarily determined by the rate of downcutting or lowering of the nearshore profile over the long term. The two main agents contributing to the erosion of submerged cohesive material are abrasion by sand and gravel, and pressure fluctuations associated with hydrodynamic flow. Other factors include chemical/biological influences and gouging by ice and debris. The primary driving forces of erosion, therefore, are the movement of water and the shear stresses exerted at the lakebed or river bed (Nairn and Southgate 1993). On the Niagara River and its tributaries, shear stresses can arise from wind- and/or boat-generated waves, as well as from river flow.

Copyright © 2005 New York Power Authority

3.3.1 Waves and Currents

Wind-generated waves are the dominant driving force for erosion on lakes and larger rivers. Breaking waves result in unsteady flow (orbital velocities), steady flows (cross-shore and longshore currents) and turbulence, particularly under plunging breakers.

Ship-generated waves must also be considered. Ofuya (1970), Baird (1973) and Kamphuis (1984) have investigated the role of ship waves on bank and bluff erosion, including sites on the St. Lawrence River. In general, their findings suggest that ship and boat waves (including both short and long waves) are dominant only in areas where fetches for wind-wave generation are limited (i.e., less than about 0.6 miles [1 kilometer]).

While maximum currents in the center of the Niagara River can be as high as 6 to 10 feet/second, in areas of bank erosion that are characterized by flat nearshore slopes and shallow water, currents are generally an order of magnitude lower than the main channel, and much less important than impacts of wave-generated fluctuating or steady currents, on river bank erosion. Erosion of the river bed in deep water (i.e. > 10 feet) will be influenced by flow generated currents, not waves.

3.3.2 The Role of Water Levels

The manner in which the shear stresses generated by waves and currents are distributed across the nearshore profile is strongly influenced by the water level. At higher water levels the erosion will be focused near the bluff toe while at lower water levels the erosion will mostly occur across the nearshore shelf.

When water levels are high, erosion at the toe of the bluff or bank may lead to more immediate bluff face retreat, while downcutting of the shelf has a longer-term influence in that deeper water allows larger waves to reach the bluff toe. In situations where the nearshore shelf is protected from erosion (i.e., by a cobble/boulder lag deposit or even the perennial presence of macrophytes), erosion will occur only during periods of higher than average water levels (see Section 3.2.1).

Copyright © 2005 New York Power Authority

The sensitivity of bluff erosion to water level fluctuations is dependent on the shape of the nearshore profile. For sites that feature a wide, shallow shelf, low water levels will result in considerable wave attenuation across the profile, such as portions of Grand Island. However, during higher water levels, the shelf will have less influence on wave attenuation, allowing larger waves reaching the bluff toe. Sites that feature a deep and steep nearshore profile, such as the lower Niagara River in the vicinity of Lewiston, will not have significant wave attenuation across the nearshore profile and are, therefore, less sensitive to fluctuating water levels than the wide, shallow-shelf type profiles. More specific discussion on the role of fluctuating water levels on the Niagara River is presented in Section 5.1.

Occasionally water levels on the Niagara River are elevated due to a process on Lakes Erie and Ontario known as storm surge. When strong winds persist across the long axis of the lake basin, large waves will develop and propagate towards the shore. In addition, the winds will artificially elevate the lake surface at the shoreline above the still water condition. The difference between the still water level and storm elevated surface is known as a surge. When the storm subsides, the lake surface will return to the pre-storm level and in some cases even lower as the water begins to oscillate back and forth in the basin until a stable condition is reached.

Due to the long axis and shallow depths of Lake Erie, a severe storm surge can elevate the water surface along the eastern shore of the lake by up to 10 feet. This process will have a direct impact on water levels and currents in the upper Niagara River. For example, an elevated Lake Erie water level at Buffalo due to a severe storm surge will increase the head difference between the Niagara River at the Peace Bridge and Niagara Falls. The increased head difference will accelerate the flow in the river, increase current velocities, and possibly elevate the water level.

Maximum recorded surges for the eastern and western basins of Lake Ontario are generally less than 2 feet. Therefore, a surge in the eastern basin (i.e. Burlington, Ontario) may artificially raise the level of the Lower Niagara River. However, the magnitude of this elevation change would be much smaller than the impacts of a Lake Erie surge on the upper river.

Copyright © 2005 New York Power Authority

3.3.3 Ice

The impact of ice on shoreline erosion is dependent on many factors, including ice thickness, the strength of the ice at the time of breakup, geometry and composition of the shoreline, water level (both prior to, and during breakup), river currents, and water depth.

Shorefast ice can act to gouge the riverbed or it can raft sediment away as it lifts from the shore at spring breakup. Ice can also reduce long term recession rates by protecting the shore from wave attack and erosion when the river is frozen.

An ice boom near the mouth of the Niagara River acts to reduce the amount of lake ice floes entering the Niagara River.

3.4 The Role of Rooted Aquatic Macrophytes

Submerged and emergent aquatic vegetation (i.e., rooted aquatic macrophytes) can act as natural dissipaters of wave energy, in some circumstances protecting a shoreline against wave action. The presence of rooted aquatic macrophytes can also inhibit erosion through the presence of the root structure and encourage sedimentation by the creation of quiescent areas.

The presence or absence of rooted aquatic macrophytes is determined in part by the level of wave energy. Baird & Associates (1996a, 1996b, 1997) have found that rooted aquatic macrophytes can survive in areas where the significant wave height during the growing season does not exceed 1.5 feet. Depending on the local wind conditions and fetch orientation, this translates a 1- to 3-mile fetch. Minns et al. (1995) have indicated that the three other criteria defining the survivorship of rooted macrophytes are: (1) depth less than twice the Secchi depth (i.e., water clarity); (2) surficial substrate of sand or finer; and (3) maximum slope of less than 15 percent.

Shorelines protected by rooted macrophytes can nevertheless be susceptible to erosion when water levels are high (due to the reduced effectiveness of the vegetation in dissipating wave energy). In

Copyright © 2005 New York Power Authority

addition, aquatic vegetation is not present in the winter and early spring (i.e., Dec. to April) when wind waves can be large.

3.5 Sedimentation Processes

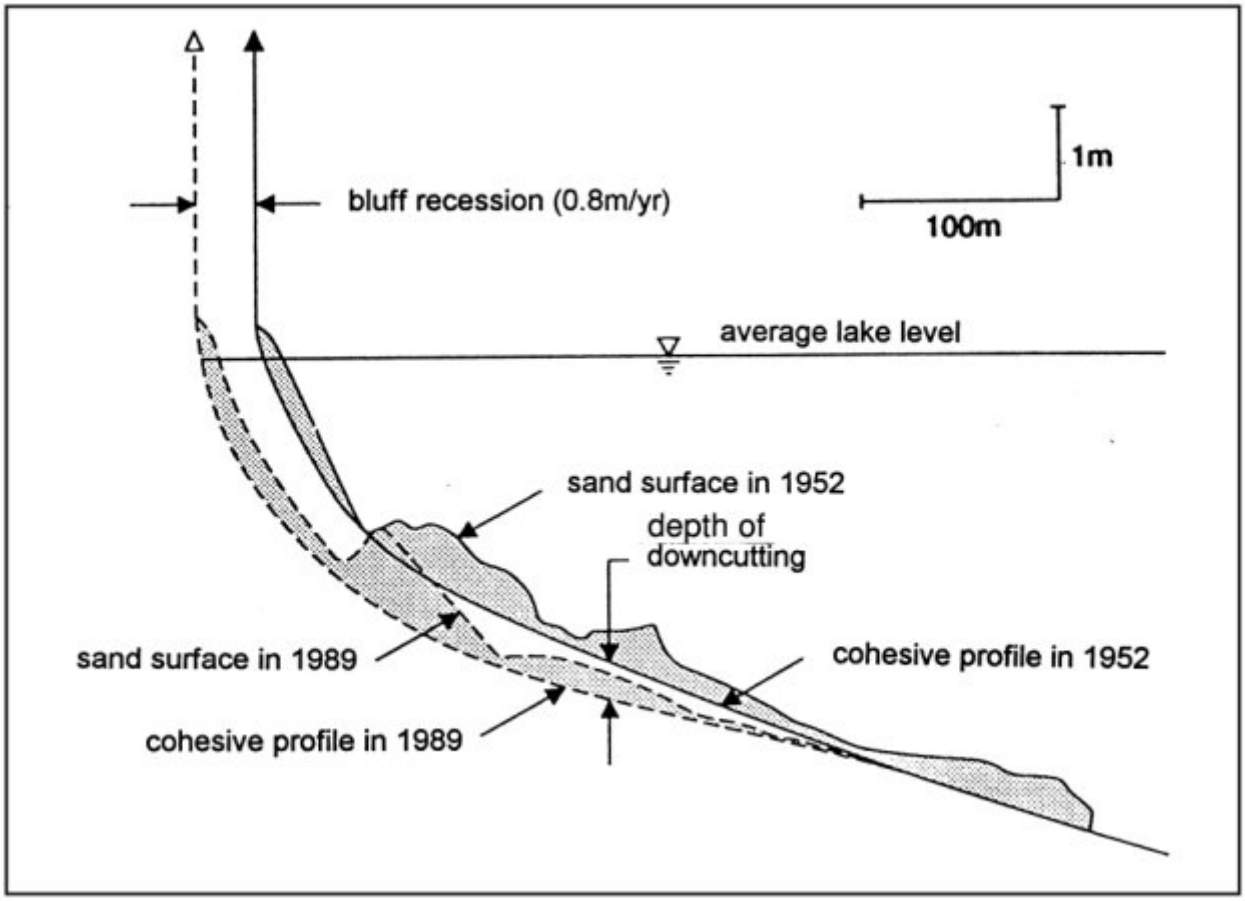
Sedimentation is defined as the deposition of sand, silt, and clay particles in water. It occurs in areas where water velocities are low or decreasing. The primary sources of sediment in a large river are loads from tributaries, and erosion of the riverbed and banks. If the sediment that is carried down a tributary is predominantly sand, it is deposited at the mouth of the tributary (i.e., within the nearshore zone of the water body). However, if the sediment is silt or clay, which is the case for tributaries of the Niagara River, it is deposited in deeper water, since these particles are lighter and are, therefore, likely to be carried further into the main river.

Sand and gravel eroded from river banks is transported along and close to the shore. Deposition occurs in zones where alongshore transport rates are diminished due to decreasing wave energy or reduced river flows (i.e., in bays, areas with submerged/emergent aquatic vegetation, and abrupt changes in river orientation); or natural obstructions such as headlands or river mouths; or manmade obstructions such as breakwaters, jetties, groins, or navigation channels. The finer silts and clays eroded from shorelines or riverbanks are generally deposited downstream in deeper water, or within large areas of submerged or emergent vegetation. In general, the existing surficial substrate at a given location provides an indication of the type of material that is stable at that location. In other words, it is unlikely that silt and clay would be permanently deposited over cobbles unless there has been a change in the hydrodynamic conditions.

Copyright © 2005 New York Power Authority

FIGURE 3.2.3-1

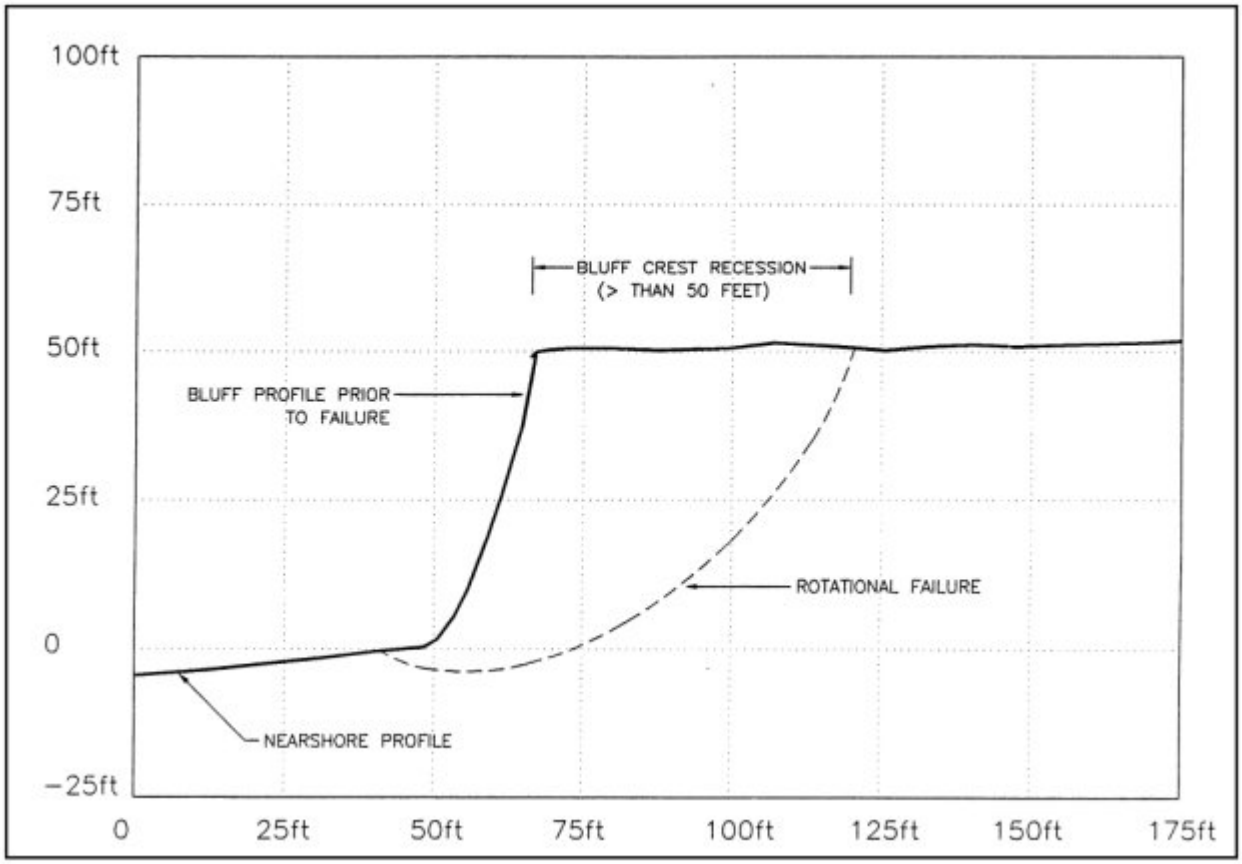
DOWNCUTTING OF A COHESIVE PROFILE, SCARBOROUGH BLUFFS, ONTARIO, CANADA



Copyright © 2005 New York Power Authority

FIGURE 3.2.4-1

BLUFF RECESSION AFTER A ROTATIONAL FAILURE



Copyright © 2005 New York Power Authority

4.0 METHODS

One of the issues to be assessed for the relicensing of the Niagara Power Project are the effects of water level fluctuations on shoreline erosion and sedimentation in the Niagara River and surrounding tributaries.

A first step in this assessment for the Study Area involved conducting a visual reconnaissance survey to identify areas experiencing erosion or sedimentation and, where possible, identifying the most likely causes of erosion or sedimentation. In addition, a preliminary inventory of shoreline protection features was undertaken. A more detailed survey of erosion was also undertaken in selected areas of the upper and lower river, and in selected tributaries of the upper river. Also, a more detailed sedimentation survey was undertaken for a substantial portion of the Tonawanda Channel of the upper river. All of the data collected was incorporated into a GIS to assist in the documentation and future analysis of the Study Area.

4.1 Field Studies

The visual reconnaissance survey was performed using a small boat, personal water craft, kayaks and, where necessary, by foot. Shoreline conditions were documented using digital photographs and were categorized into "protected" and "unprotected" areas. A preliminary inventory of shoreline protection features was also undertaken. In addition, identification of potential sedimentation areas, erosion sites, and a number of "points of interest" (POIs) was performed. Erosion sites are those areas where erosion is presently occurring. POIs are defined as areas that are not presently eroding but that have eroded in the past, or that appear susceptible to future erosion (such as reaches where shore protection features are in an advanced stage of deterioration). Detailed data collection at erosion and sedimentation sites was also performed at selected locations along the upper and lower river, as well as several tributaries.

The tasks undertaken at each site during the field studies are presented in the following sections.

Copyright © 2005 New York Power Authority

4.1.1 Shoreline Categorization

The visual reconnaissance survey enabled the documentation of "typical" shoreline reaches along the Niagara River within the Study Area. Digital photographs were taken of such reaches and geo-referenced using GPS equipment. GPS equipment was also used to document the limits of shoreline protection structures, which made possible the categorization of the shoreline into "protected" and "unprotected" areas (as described in Section 4.2.1).

4.1.2 Shoreline Protection Inventory

As a refinement of the shoreline categorization process, the limits of various shoreline protection features were, wherever possible from the boat, documented using GPS equipment. An estimate of the material, height, slope, and status (good, fair, poor [or failing]) of the shoreline protection features was made. Whenever possible, areas with poor or failing shoreline protection features were documented separately with geo-referenced digital photos.

The status documentation for the shoreline protection structure is very qualitative, as it is based on the visual assessment of the protection, rather than on scientific analysis (e.g., structural stability and integrity). In general, a structure was considered "good" if it was newly constructed or did not have many visible flaws. Figure 4.1.2-1 provides an example of a "good" steel sheet pile wall. Protection structures were considered "fair" if they provided the necessary protection, but were showing signs of disrepair (e.g., cracking of concrete, tilting of sheet pile wall, sporadic coverage of stones on slopes). Figure 4.1.2-2 provides an example of a "fair" steel sheet pile wall. "Poor" protection areas offered little or no protection and often included protection structures that were failing or that had failed. Figure 4.1.2-3 provides an example of a timber crib wall that has failed. The shoreline protection evaluation at each location, therefore, related to the visual condition of the structure and not its potential performance relative to design criteria.

Documentation of every shoreline protection structure in densely populated areas such as Cayuga Island and Little River was not possible, as documenting the limits, type, and status of shoreline protection structures for every 30- to 50-foot property frontage in these areas was beyond the scope of this

Copyright © 2005 New York Power Authority

study. In densely populated areas, therefore, geo-referenced digital photos were taken only at intervals along the shoreline. In Little River, five panoramic, geo-referenced, digital photographs were also taken to provide a general overview of shoreline protection structures. The status of these areas was noted as "Varies".

In summary, the assessment of the protection structures was intended to give a generalized overview of the status at selected areas. As such, some areas listed as "good" may also contain small pockets of "fair" protection. However, if the selected area was predominantly in good condition, it was labeled as such. Similarly, areas labeled as "fair" may have small pockets of "good" protection. Whenever possible, pockets of "poor" (or failing) protection were documented separately rather than including them in a predominantly "good" or "fair" section.

4.1.3 Erosion Areas

The primary objective of the visual reconnaissance survey was to identify and delineate areas experiencing significant shoreline erosion. At each erosion site, the following tasks were undertaken:

- the location and extent of erosion was mapped using GPS equipment;
- digital photographs were taken offshore of the site and geo-referenced using GPS equipment;
- riverbank or bluff height and slope were visually estimated;
- wherever possible from the boat, a description of shore material (e.g., rock and soil type, etc.) was made;
- a preliminary qualitative assessment was made regarding the forces causing erosion at the location; and
- a preliminary opinion was provided regarding the influence of water level fluctuations on erosion, including natural levels and those due to US/Canadian power generation.

Copyright © 2005 New York Power Authority

4.1.3.1 Detailed Erosion Areas

Several erosion locations were chosen for more in-depth data collection. These locations were chosen based on the results of the Baird (2002) Shoreline Erosion and Sedimentation Assessment Study, as well as erosion areas determined during the 2003 study of the tributaries.

At each detailed erosion area, a nearshore underwater profile was measured. For sites located along the main river (upper and lower), an echosounder was used in combination with GPS equipment in order to provide accurate water depths and horizontal location. The depths were referenced to the water level at the time of the survey. For detailed erosion areas in tributaries, profiles were measured relative to the water level at the location. Adjusting the water depths to a local datum is discussed in Section 4.2.2.2.

For detailed erosion areas on the main river, an onshore profile was determined using GPS to define the horizontal locations of pertinent features (i.e., waterline, toe of bluff, top of bluff), and the elevations of the features were referenced to the water level at the time of the survey. Onshore profile information in the tributaries was measured relative to the waterline at the site (both horizontal and vertical distances). Adjusting the vertical dimensions to a local datum is discussed in Section 4.2.2.2.

A qualitative assessment of the long term recession rate was also determined based on field observations. Table 4.1.3.1-1 summarizes the classification scheme used to describe bank recession. For example, if the estimated long term bank recession rate was 1.5 feet per year, erosion is classified as moderate and given a severity rating of 2. The descriptive classification used in the table is adapted from a similar scheme published by the Ontario Ministry of Natural Resources (OMNR 1997).

Additional tasks undertaken at each site included;

- digital photographs were taken offshore of the site, at the waterline, and of the shore material. The photos were geo-referenced using GPS equipment;
- a description of shore material (e.g., rock and soil type, etc.) was made;

Copyright © 2005 New York Power Authority

- a preliminary qualitative assessment was made regarding the forces causing erosion at this location; and
- a preliminary opinion was provided regarding the influence of water level fluctuations on erosion, including natural levels and those due to US/Canadian power generation.

4.1.4 Points of Interest (POIs)

As mentioned above, POIs are defined as areas that are not presently eroding but that have eroded in the past, or that appear susceptible to future erosion. The tasks undertaken at each erosion site (as noted in Section 4.1.3) were also undertaken at each POI, with the exception that the extent of the POI was not defined. For large POIs, GPS equipment was used to locate the limits of each area. For small areas, the length of the POI was visually estimated.

Points of interest also include areas where the shore protection is in an advanced state of deterioration, or locations on tributaries where a small erosion scarp was identified. This scarp is often less than one foot high and is not related to severe bank erosion or slope failures. Rather, it is attributed to natural erosion processes in the tributaries, which, are by nature, erosional features.

4.1.5 Sedimentation Areas

Initially, during the 2002 field survey, potential sedimentation areas were documented with GPS equipment. The following criteria was used to identify these locations:

- proximity of the site to erosion areas;
- predominant direction of currents and waves;
- shoreline features and orientation that would promote sedimentation (e.g., jetties, wharves, headlands, etc.); and,
- water depth.

Copyright © 2005 New York Power Authority

Based on this data, and a review of existing bathymetric data for the Tonawanda Channel upstream of the Twin Intakes, a geophysical survey was designed for the 2003 field study. The objectives of the survey included:

1. Identification of surficial substrate at multiple river cross-sections located strategically between the South Grand Island Bridge and the NYPA Intake Structures,
2. Categorization of substrate conditions at two probable sedimentation areas: Turning Basin for the Federal Navigation Channel immediately downstream of Tonawanda Island and the Intake Bay downstream of the North Grand Island Bridge, and
3. Collection of high resolution bathymetry data for all river cross-sections to compare with historical depth data.

Baird retained the services of a marine geotechnical expert, Geophysics GPR International Inc., to complete the survey of the Tonawanda Channel. Differential Global Positioning Software was utilized on board the survey vessel for horizontal control. A Reson Navisound 215 Digital echo-sounder was attached to a standard beam transducer to record bathymetric soundings. Side scan sonar was used to record the surficial conditions of the riverbed. In total, 33 miles of tracklines were collected on the Niagara River, recording both the surficial substrate and river depths.

4.1.6 Gorge Assessment

Attempts were made to assess the gorge area of the Niagara River from the Falls, to just upstream of the Robert Moses Niagara Power Plant tailrace and the upper river from the NYPA Project Intakes to the Falls. For example, the riverbanks were accessed at several locations between the Whirlpool and the RMNPP tailrace. However, due to safety concerns, it was not possible to walk along the waters edge and observe the bank conditions. The established trail was located higher up the slope and the shoreline was not visible from this vantage point. In its place, a video of the gorge area (taken by helicopter in April/May 2002) was reviewed to provide a visual assessment of the area.

Copyright © 2005 New York Power Authority

4.1.7 Jetboat Wake

Concern has been raised over the possibility of erosion of the riverbank due to the wake from jetboats that operate between Lewiston and the Whirlpool on the lower river and gorge area. As part of this study, a preliminary visual assessment of the jetboat wake was undertaken.

The lower river was accessed at two locations in order to document the jetboat operations. One site was located midway between the Whirlpool and the RMNPP tailrace, and the second location was just south of Lewiston. Since the survey was undertaken near the end of the jetboat season (October), only two jetboats were viewed as they cruised the lower river. A visual assessment was completed and photographs of the boat wake impacting the American shoreline were taken. Figure 4.1.7-1 shows a typical jetboat and its wake as it travels downstream along the Canadian shoreline.

4.2 Office Studies

The information collected during the field study was analyzed and incorporated into GIS layers summarizing the results of the study.

The following sections outline the analysis of the survey data undertaken during the office studies.

4.2.1 Shoreline Characterization

The documentation of "typical" shoreline reaches enabled the categorization of the shoreline into "protected" and "unprotected" areas. For the purposes of this study, "protected" areas include shorelines that have some form of protection (e.g., stone, concrete, timber, etc.), regardless of the quality of the protection structure. "Unprotected" shorelines were defined as those areas having no form of manmade protection structures. Figures 4.2.1-1 and 4.2.1-2 present the extent of "protected" and "unprotected" shoreline for the upper and lower Niagara River, respectively (including tributaries).

Copyright © 2005 New York Power Authority

4.2.2 Erosion Areas

The documentation of detailed erosion areas provided more field data to support a qualitative assessment of the causes of erosion. For example, following the incorporation of the survey data into GIS layers, it was possible to view the various areas of interest in plan view, superimposed on aerial photos. This made possible an increased appreciation for the range of exposure at the erosion sites to waves, currents, potential water level fluctuations (with respect to US/Canadian power generation operations), and potential ice impacts.

With this information, it was possible to identify a list of probable driving forces for river bank erosion at each site, and to rank them according to their possible relative contribution to erosion. The potential causes of erosion in the Study Area included:

- Waves. River bank areas open to large fetches are susceptible to wind-generated waves, while areas in creeks are more susceptible to boat-generated waves;
- Currents. Areas located on the "outer" banks at bends in the river/creek, the river bed/bottom and areas directly downstream of U.S./Canadian tailraces are subject to erosion induced by currents;
- Water levels. Although not a primary driving force of erosion, water level fluctuations transfer the zone of breaking waves and thus the most intense erosion forces, up and down the profile. During low river levels, the majority of the energy dissipation occurs on the profile and is spread over a wide zone. During high river levels, the breaking waves and energy dissipation is focused on the beach and bank toe. It is important to understand that erosion is always occurring at some location on the profile – water levels just transfer this location from the lake bed to the bank toe. The characteristics of the water level fluctuations (i.e. frequency, duration, and magnitude of highs) will also influence the bank erosion rate);
- Ice (and other debris). Thawing of shore fast ice sheets can dislodge pieces of the river bed in the spring and ice floes transported by river currents can scour the banks;

Copyright © 2005 New York Power Authority

- Surface runoff. Rainwater flowing down exposed riverbanks and bluffs can carry away soil and other material. (No areas of groundwater flow impacts on bank erosion were identified);
- Weathering. Freezing/thawing of water in clay and rock can cause cracking and erosion; and
- Public access. Removal of vegetation along the riverbank, whether by mechanical means (e.g., tree felling, lawn mowing, etc.), or by overuse (e.g., repeated walking in one area) can facilitate erosion.

The primary factors at the observed bank erosion areas on the upper and lower rivers are onshore waves (wind- and boat-generated) and currents. In smaller, navigable tributaries, boat waves are the primary factor at the observed erosion areas. In non-navigable tributaries, erosion occurs when the bed shear stresses generated by river currents exceed the resisting properties of the creek materials. Field observations suggest this condition only occurs during the spring freshet and following severe rainfall events. Summer and fall flow conditions, and any water level fluctuations that occur during these periods (natural or induced by U.S./Canadian power generation), do not appear to accelerate erosion. The other factors identified above play a secondary role.

4.2.2.1 Influence of US/Canadian Power Generation and Treaty Flows

As noted in Section 4.2.2, erosion is always occurring. Water levels affect the location of erosion across the profile, not whether it occurs. In the process of generating electricity, the US/Canadian power projects store water from the Niagara River and release it back to the river. In addition, water levels in the lower river are also affected by the daily change in scenic flows over the Falls between 50,000 cfs and 100,000 cfs during the tourist season. Therefore, the power generation operations and Treaty flows have the largest influence on the water levels in the vicinity of the U.S./Canadian power project tailraces and intake structures. This influence decreases in the upper river with distance upstream of the intakes and decreases in the lower river with distance downstream of the tailraces.However, as stated in Section 2.0, it is also important to note that water level fluctuations in both the upper and lower Niagara River are caused by a number of factors in addition to hydropower generation and Treaty flows. These include wind, natural flow variability, ice conditions, surge events, and water levels of Lake Erie and Lake

Copyright © 2005 New York Power Authority

Ontario. It is, therefore, not possible at this time to quantitatively assess the influence of U.S./Canadian power generation with respect to the erosion areas.

The possible influence of water level fluctuations (due to US/Canadian power generation and Treaty flows) on the erosion sites was categorized with a qualitative ranking of "high", "moderate", "low", or "none" (and a combination of categories – i.e., "low to none"). For the lower river, the average daily water level fluctuation 1.4 miles downstream of the RMNPP tailrace, during the 2002 tourist season, was approximately 1.5 feet. Therefore, erosion sites and POIs within that distance were considered to be under a "high" influence. The influence level decreases the further downstream a site is located. Similarly, sites in the immediate vicinity of the Chippawa-Grass Island Pool in the upper river were under a "high" influence of US/Canadian power generation. Water level fluctuations due to power generation have less influence for sites located further upstream than Cayuga Island. Therefore, the U.S./Canadian power generation influence evaluation is essentially related to the relative location of an erosion site or POI to the areas of highest water influence of the Project (namely, the tailrace on the lower river and the intakes on the upper river). A qualitative discussion of the possible influences of fluctuating water levels on erosion is presented in Section 5.1.

4.2.2.2 Detailed Erosion Areas

The profile information collected at the detailed erosion areas during the field study was referenced to the waterline at each site. In order to relate the elevations to the preferred local datum (USLS'35), the water levels at each site were determined. The water level information was obtained for several gages, both permanent and temporary, in order to determine the water level at each site at the time of the field study. The profile data recorded in the field was adjusted to the appropriate water level.

In the case of detailed erosion areas along the upper river, permanent water level gages were available in close proximity to the sites (i.e., at the entrance to Tonawanda Creek and at LaSalle near Buckhorn Island). However, for detailed erosion areas on the lower river, an average of the water levels from temporary gages was required in order to determine an estimate of the water level at the sites. Similarly, detailed erosion areas on selected tributaries required an average water level to be determined from several temporary gages.

Copyright © 2005 New York Power Authority

The data collected in the field was used to better define the erosion conditions. This permits a better qualitative assessment of erosion and the influence of water level fluctuations.

4.2.3 Sedimentation Areas

The potential sedimentation areas located during the first field study were incorporated into GIS, and superimposed over aerial photographs of the Niagara River. This enabled an increased understanding of shoreline orientation with respect to exposure to waves and currents. In addition, the plan view of the area permitted an overview of shoreline structures that could promote sedimentation (i.e., jetties, wharfs, headlands, dredged sections of the river, etc.). Based on extensive experience with locating and documenting sedimentation areas on other projects, it was possible to employ this method to provide a preliminary assessment of sedimentation areas.

Using this data, and a review of existing bathymetric data for the Tonawanda Channel upstream of the Twin Intakes, a Geophysical survey was designed for the 2003 field study. The objectives of the survey are outlined in Section 4.1.5.

Baird retained the services of a marine geotechnical expert, Geophysics GPR International Inc. to complete the survey of the Tonawanda Channel. Using the strength of the backscatter from the side scan sonar, Geophysics GPR International was able to determine the surficial characteristics of the riverbed. The soft sediments, such as silt and clay absorb the side scan sonar signal and transmit a weaker signal giving lighter tones. A strong signal indicates a harder surface, such as sand, gravel or exposures of bedrock. Submerged aquatic vegetation (SAV) provides a very "noisy" signal, which was very common along the north shore of Grand Island (i.e. downstream of Tonawanda Island). In total, 33 miles of tracklines were collected on the upper Niagara River, recording both the surficial substrate and river depths. The final product is a geo-referenced digital image of the river bottom. In locations where the surficial mapping of the riverbed was in close proximity with the habitat transect mapping (Stantec et al. 2005), there was good agreement between the two datasets. For example, areas classified as 'submerged aquatic vegetation' in the geotechnical survey correspond to zones of 'moderate/dense/abundant aquatic beds' in the habitat transects. There was no overlap between the two datasets in the deeper zones of the river, such as the navigation channel.

Copyright © 2005 New York Power Authority

Additional details of the geophysical survey can be found in the report from Geophysics GPR in Appendix B.

The data collected to identify sediment sources and depositional areas is summarized in a qualitative Sediment Budget for the Niagara River in Section 6.0. Potential sediment sources and sinks are identified, and qualitative comments on their relative importance are provided. In addition, where possible, comments on the potential influence of the U.S./Canadian power generation on the Sediment Budget variable are provided.

4.2.4 Gorge Assessment

Attempts were made to assess the gorge area of the Niagara River from the Falls, to just upstream of the Robert Moses Niagara Power Plant tailrace and the upper river from the NYPA Project Intakes to the Falls. However, due to safety concerns, an assessment by foot was not possible. In its place, a video of the gorge area (taken by helicopter in April/May 2002) was reviewed to provide a preliminary assessment of the area.

Copyright © 2005 New York Power Authority

TABLE 4.1.3.1-1
CLASSIFICATION SCHEME FOR HISTORICAL RECESSION RATES

Estimated Historical Recession Rate (ft/year)	Erosion Classification	Erosion Severity Rating
0	stable	0
0 to 1	low	1
1 to 2	moderate	2
2 to 4	high	3
4 to 6	very high	4
> 6	severe	5

Copyright © 2004 New York Power Authority

FIGURE 4.1.2-1

"GOOD" STEEL SHEET PILE WALL

Copyright © 2005 New York Power Authority

FIGURE 4.1.2-2

"FAIR" STEEL SHEET PILE WALL

Copyright © 2005 New York Power Authority

FIGURE 4.1.2-3

"POOR" (OR FAILED) TIMBER CRIB

Copyright © 2005 New York Power Authority

FIGURE 4.1.7-1

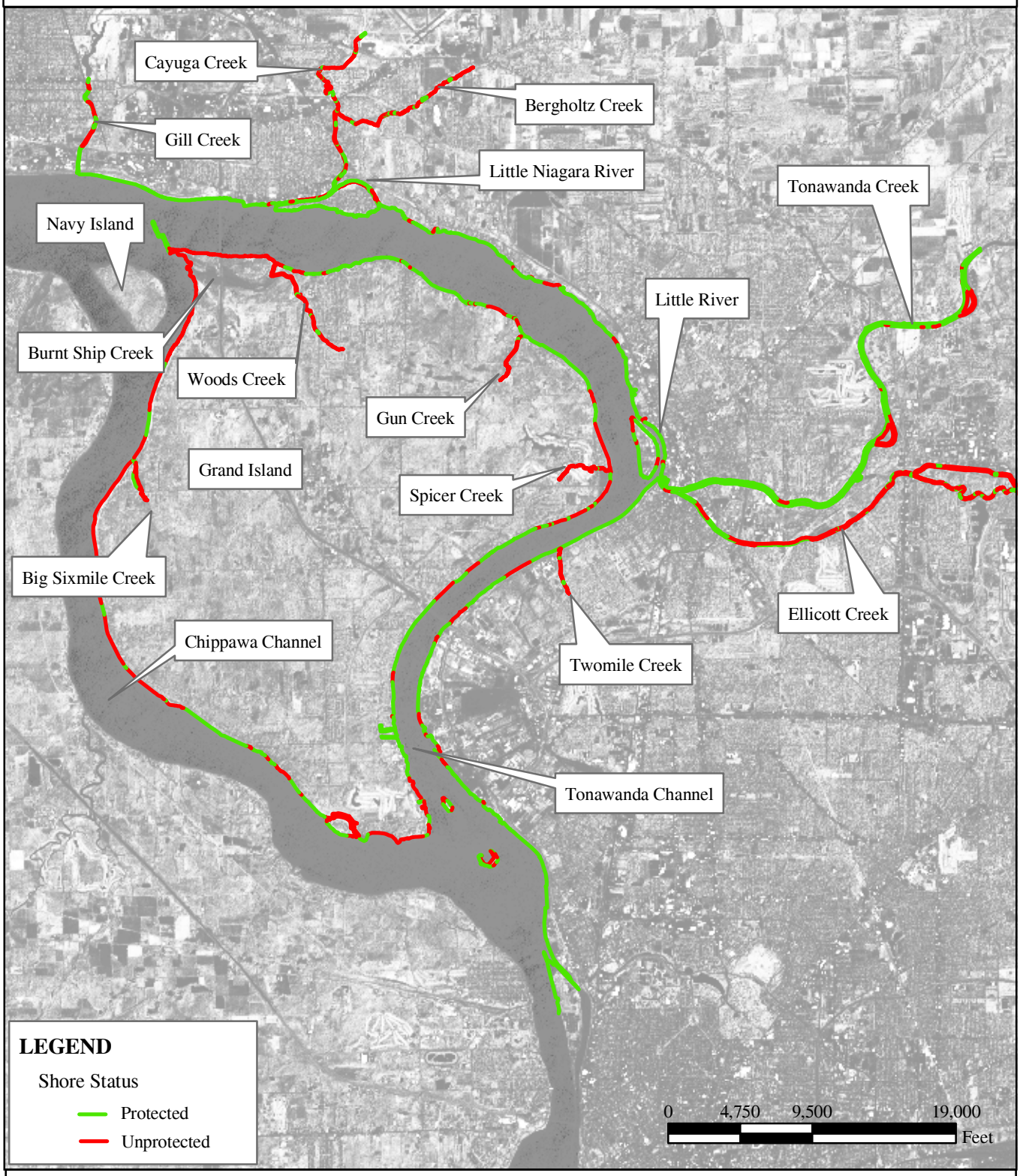
JETBOAT TRAVELING DOWNSTREAM ALONG THE CANADIAN SHORELINE

Copyright © 2005 New York Power Authority

NIAGARA POWER PROJECT (FERC NO. 2216)

Determine the Effects of Project Operations on Shoreline Erosion

Sedimentation on the Niagara River (including tributaries)



New York Power Authority

AREAS OF SHORE PROTECTION FOR THE UPPER NIAGARA RIVER AND TRIBUTARIES

NIAGARA POWER PROJECT

Figure 4.2.1-1

Copyright © 2004 New York Power Authority

Non-Internet Public (NIP) information has been removed from the following page(s).

This material is contained in:
Volume 2
Section: Shoreline Erosion and Sedimentation Assessment Study Upstream and Downstream of the Power Project

FIGURE 4.2.1-2

AREAS OF SHORE PROTECTION FOR THE LOWER NIAGARA RIVER AND TRIBUTARIES

[NIP – General Location Maps]

Copyright © 2005 New York Power Authority

5.0 ASSESSMENT OF EROSION

This section presents an initial overview of the key issues associated with erosion in the Study Area. It draws from the background description of the erosion processes for river shorelines in cohesive sediments provided in Section 3.0. It is to be noted that the material presented here is based on a qualitative understanding of site conditions (including soils, topography, and bathymetry) and driving forces of erosion (waves, currents, ice, natural and artificial fluctuations in water levels, and weathering processes). It is also to be noted that observations of erosion, in most cases, represent a single snapshot of a dynamic process that varies in time and space.

At several sites in the upper and lower river, as well as selected tributaries, additional field data was collected. At these locations, the additional field observations and data collection included: bathymetric and topographic profiles, recording of the spatial extent of erosion using GPS, observations of the geology above and below the river water level, characterization of land use, the presence of submerged aquatic vegetation and terrestrial cover, and geo-referenced ground-level digital photographs of the site conditions.

This section provides a discussion on the assessment of erosion within the Study Area. The type of erosion can be divided into two main groups, related to the local geology. Both are defined as "cohesive shores" (see Section 3.0). Group One includes erosion in glacial till and clay sediment on the upper and lower river, and Group Two is confined to sites on the lower river that feature actively eroding shale bluffs.

5.1 Upper Niagara River

The fraction of the shoreline or river bank within the Study Area that has been identified as eroding amounts to 3% of the shoreline length for the upper river. Erosion scarps are micro erosion features found along many of the low creek banks. POIs represent reaches that have eroded in the past, show signs of erosion potential, or feature protection structures that are deteriorating. Figure 5.1-1 shows

Copyright © 2005 New York Power Authority

the erosion and scarp areas, and the POIs for the upper river and tributaries. This discussion focuses on areas that have been identified as actively eroding.

The lack of more widespread river bank erosion is partly due to the extent of shoreline protection structures, particularly on the upper river. Approximately 63% of the shoreline of the upper river is protected, as shown in Figures 4.2.1-1. The shoreline protection features are discussed in more detail in Section 5.6.

As mentioned previously, the type of erosion can be divided into two main groups, related to the local geology. For Group One (erosion in glacial till and clay sediment) on the upper river, erosion is generally occurring on relatively low banks (heights less than 6 feet, usually in the 2- to 4-foot range) with little vegetation. The two most prominent examples are at the north end of Buckhorn Island (itself at the north end of Grand Island) and on the east side of Grand Island opposite Tonawanda Island. These are by far the two longest continuous reaches of erosion within the upper river Study Area (3,200 and 2,700 feet, respectively). Figure 5.1-2 is a photo of the erosion on Buckhorn Island and Figure 5.1-3 provides an example of the erosion along the Grand Island shore opposite Tonawanda Island. Both these erosion reaches feature relatively low banks generally devoid of vegetation, with many fallen trees. Another common and distinctive feature of these two areas is a wide, shallow, nearshore shelf. These two areas were chosen for more in-depth erosion surveys, as presented in Section 5.1.1.

The remaining Group One areas on the upper river fall into two subcategories: (1) erosion areas along the main river channels, primarily along the mainland side of the Tonawanda Channel between the South Grand Island Bridge and Tonawanda Island; and (2) erosion along the various tributaries. With the exception of a 2,000-foot-long section along the Tonawanda Channel, all the sites are generally less than 150 feet long. The sites along the Tonawanda Channel feature a steep nearshore slope in the range of 5:1 to 10:1. The erosion along this reach is confined to a scarp above the water line (see Figure 5.1-4).

To the best of our knowledge, published erosion measurements based on aerial photographs are not available for the Study Area. Baird & Associates (1994), reported on erosion rates along the north side of Navy Island, on the Canadian side of the river just west of Buckhorn/Grand Island. The rates ranged from a few centimeters to 0.5 meters/year (0.1 to 1.6 feet/year) for two erosion areas studied.

Copyright © 2005 New York Power Authority

Based on the recession rate classification scheme outlined in Table 4.1.3.1-1, erosion would be classified as low to moderate and have a severity rating of 1 to 2 (with 5 being the highest possible rating).

In addition to the air photo analysis, the Baird & Associates (1994) study of erosion on Navy Island also consisted of developing a wave climate, nearshore profile surveys, probing to establish surface and subsurface conditions, and numerical modeling (using an earlier version of the in-house COSMOS model) of waves, currents, and cohesive sediment erosion across two profiles representative of the two erosion areas. The Navy Island study produced the following conclusions that may be applicable to many of the Group One erosion sites in the Study Area:

- The nearshore profile consists of a thin and patchy veneer of sand and gravel (greatest thickness at the shoreline) over a gray, consolidated lacustrine clay. Clearly, this falls into the category of a cohesive shore;

- The two Navy Island erosion sites featured a relatively wide shelf of 50 to 150 m (160 to 500 ft) and shallow depths less than 1 m below mean water level (3.3 ft) shelf inside of a steep drop-off to deeper water;

- The numerical model runs showed that decreasing the range and/or frequency of high water levels would decrease the erosion rate where wide, shallow shelves front erosion zones. (It is important to note that significant improvements have been made to the numerical modeling approaches for cohesive shore erosion since the Navy Island study in 1994 thereby making it difficult to directly apply the 1994 results to the sites within this study);

- The two sites on Navy Island that were eroding coincided with: (a) adjacent land areas cleared of vegetation; and (b) absence of rooted aquatic vegetation immediately offshore of the eroding areas. It was postulated that the cleared areas result in sediment-laden runoff (i.e., high turbidity conditions) that inhibits growth of rooted aquatic macrophytes. In turn, the absence of macrophytes reduces the degree of wave attenuation and results in an environment that neither promotes deposition nor provides structure for roots to bind the lakebed sediment.

Copyright © 2005 New York Power Authority

Baird & Associates has extensive experience in evaluating the role of fluctuating water levels on erosion rates in the Great Lakes, and in the St. Lawrence and Niagara Rivers (Nairn and Baird 1992, Baird 1994, Baird 2001, Baird 2002a, Baird 2002b, Baird 2003b, and Baird 2003c). Based on this experience, Baird & Associates makes the following qualitative observations on the potential for water level fluctuations to influence erosion in the Niagara River Study Area.

1. The background bank recession rate is accelerated when the mean water level is increased because less wave energy is dissipated on the profile or shelf and more energy reaches the shoreline. Conversely, bank recession decreases when the mean water level is lowered over a long period (several decades) until the nearshore profile reaches a new equilibrium form at the lower level due to downcutting. The influence of U.S./Canadian power generation on the mean water level could be to reduce or increase erosion rates. This influence could persist for many decades.

2. At locations where there is a shallow nearshore shelf, erosion is accelerated when either the maximum water level or frequency of high water levels are increased (and decelerated when either are decreased). In other words, even if the mean is not altered changes to the nature of the water level fluctuations can influence erosion rates. The two Grand Island sites on the upper river may fall into this category. This influence could persist for many decades. The influence of U.S./Canadian power generation on water level fluctuations could be to reduce or increase erosion rates.

3. At locations with steep eroding bank faces and steep nearshore slopes (10:1 or steeper), changes to the range of water level fluctuations or the mean water level have less impact than shelf profiles. However, long-term erosion rates will still increase with higher water levels and decrease with lower levels. This may be the case for some of the lower and upper river erosion areas.

Copyright © 2005 New York Power Authority

5.1.1 Detailed Erosion Areas

Based on the results of the first study, two areas on the upper river were chosen for a more detailed assessment of erosion during the second field study. The two areas chosen were, 1) the Grand Island erosion site, located opposite of Tonawanda Island along the Tonawanda Channel, and 2) the north shore of Buckhorn Island near the North Grand Island Bridge (see Figure 5.1-1).

5.1.1.1 Grand Island (near Tonawanda Island)

Three topography and bathymetry profiles were collected in this area. The profiles were approximately 1,400 feet long and extended into water depths of 25 feet.

Figure 5.1.1.1-1 provides a conceptual sketch of a typical profile in this area. The sketch includes the water level on the day of the survey plus three statistical levels based on the hourly 1991 to 2002 gage data provided in URS et al. 2005b. For example, for 50% of the recorded river levels were above 565.8 ft, which is located on the bank face. In other words, over half the time the small beach at the toe of the bank is submerged and waves propagating onshore are capable of eroding the bank. These water level statistics, plus the topographic mapping for the area, highlight the low nature of the riverbanks and surrounding topography in this reach of the river. The occurrence of water levels and waves at and above the 50% exceedance level (565.8 ft) will result in bank erosion and this process is responsible for the large number of mature, dead trees observed along the shore.

The bank and river bed have been cut in lacustrine clay and feature a low to moderate erosion rate (severity rating of 1 to 2). The nearshore features a wide, shallow shelf extending approximately 300 feet into the river. The lack of vegetation on the river bed indicates the shelf is actively eroding and exposed to considerable wave energy. As shown in Figure 5.1.1.1-1, at approximately 300 feet on the X-axis, the profile elevation drops 15 feet over a very short distance. This rapid change in slope appears to be due to dredging, other human influences, or possibly a lower stage of the river. The Federal Navigation Channel can also be observed between 1,000 and 1,200 feet in the X-axis.

Copyright © 2005 New York Power Authority

It is interesting to note the correlation between the absence of submerged aquatic vegetation (SAV) coincident with a key area of erosion. The same observation was made at the Navy Island erosion sites studied by Baird in 1994 where the absence of SAV was thought to result in increased wave energy reaching the shore. In the Navy Island investigation it was postulated that the absence of SAV may be related to the high turbidity of runoff. This Grand Island erosion site is located immediately downstream of the mouth of Spicer Creek and possibly the absence of SAV is related to sediment loadings reducing the water clarity offshore of the erosion site (leading to suppression of SAV growth). Another possibility is that sediment eroded from the Niagara River shore is contributing to turbidity in the nearshore that suppresses the growth of SAV.

The deep river profile at Grand Island will allow large waves to propagate into the shore, uninfluenced by the river bathymetry, until the shallow shelf at approximately 300 feet. Based on our previous experience with similar profiles, the shelf is likely capable of dissipating the majority of the incoming wave energy at low river stages. However, with river levels at or above the 50% exceedance level, the shelf will not be effective at dissipating energy and waves will propagate over the beach and attack the bank, leading to erosion. The shelf would be more effective at dissipating wave energy if colonized with submerged aquatic vegetation.

5.1.1.2 Buckhorn Island

A conceptual sketch of a typical erosion profile at Buckhorn Island is provided in Figure 5.1.1.2-1. Similar to the Grand Island location, the top of bank features dense vegetation (e.g. hardwood forest). However, in contrast to the Grand Island site, the top of bank is well above the water level with an exceedance of 5% based on the 1991 and 2002 gage data (as provided by URS et al 2005b).

The bank face features a mature soil horizon, followed by a sandy lens (possibly related to a fluvial deposit from a de-glacial period), and lacustrine clay. The slope is actively eroding and the recession rate is classified as low to moderate (severity ranking of 1 to 2, refer to Table 4.1.3.1-1). The beach features only a thin veneer of sand and small pebbles above the clay. The fluvial deposit may be the source for the veneer of sand on the beach.

Copyright © 2005 New York Power Authority

The nearshore also features a well-developed platform or shelf, similar to the conditions at the Grand Island site. Sporadic clusters of SAV were observed. As illustrated in Figure 5.1.1.2-1, at 250 feet on the X-axis, the profile features a rapid decrease in elevation of almost 15 feet. This change in profile slope may be related to dredging for the Federal Navigation Channel. These deep conditions, only 250 feet from shore, will allow large waves to propagate into the bank, especially during storm events from the east. At the extreme low water levels, such as the 95% exceedance level, the shelf is likely very effective at dissipating wave energy and protecting the bank from erosion. However, at average and high water levels, waves will propagate across the shelf and attack the bank, leading to toe erosion and slope failures. The thin beach deposit will not offer any erosion protection during a storm at high river levels (i.e. 5% exceedance water level).

Once again, it is interesting to note the correlation between the general absence of submerged aquatic vegetation (SAV) at a key area of erosion. This agrees with observations at the Navy Island site (studied by Baird in 1994) and the other Grand Island site (discussed above) where the absence of SAV may result in increased wave energy reaching the shore. In the Navy Island investigation it was postulated that the absence of SAV may be related to the high turbidity of runoff. This second Grand Island erosion site is located immediately downstream of the mouth of Woods Creek and possibly the absence of SAV is related to sediment loadings which reduce the water clarity (and/or water quality) offshore of the erosion site (leading to suppression of SAV growth).

5.2 Lower Niagara River

The fraction of the shoreline within the Study Area that has been identified as eroding amounts to 14% of the shoreline length for the lower river. POIs represent reaches that have eroded in the past or that show signs of erosion potential, or feature shoreline protection structures that are deteriorating. Figure 5.2-1 shows the erosion areas and the POIs for the lower river. The following discussion focuses on areas that have been identified as actively eroding.

The lack of more widespread erosion is partly due to the extent of shoreline protection structures. Approximately 37% of the shoreline of the lower river is protected, as shown in Figure 4.2.1-2. The shoreline protection features are discussed in more detail in Section 5.6.

Copyright © 2005 New York Power Authority

As discussed in Section 5.1, the type of erosion can be divided into two main groups, related to the local geology. Both are defined as "cohesive shores" (see Section 3.0). Group One includes erosion in glacial till and clay sediment on the upper and lower river, and Group Two is confined to sites on the lower river that feature actively eroding shale bluffs.

On the lower river several Group One erosion sites feature exposed red clay faces. It is possible this clay deposit is partially consolidated talus eroded from the old Queenston Shale bluffs. The longest reach of this type is approximately 3,000 feet long and is located just south of Lewiston. Figures 5.2-2 and 5.2-3 present an example of this type of erosion. The erosion banks are 10 to 20 feet high, intermittent along the shore, and the shoreline itself appears to be armored by more resistant limestone or dolomite fallen from higher on the bluff (Figure 5.2-3). A review of NOAA Navigation Chart 14816 shows the nearshore slopes to be steep in this area, at about 5:1. These sites will be susceptible to bank erosion when the river stage exceeds the elevation of the existing limestone and dolomite at the waterline.

Group Two is confined to sites on the lower river that feature actively eroding shale bluffs. The primary example of erosion in Queenston Shale is found north of Lewiston. This 3,400-foot-long reach features relatively high exposed shale bluffs (Figure 5.2-4). A very small beach lies at the toe of the bluff, and the nearshore slope is again steep, at 5:1 (steep nearshore slopes exist along most of the lower Niagara River). The great height of the exposed erosion faces is due to the fact that this material is dynamically stable at a very steep slope, too steep for topsoil to maintain. The term "dynamically stable" indicates that the slope is retreating very slowly. In some places along the lower Niagara the gorge face (presumably consisting originally of exposed Queenston Shale) is now covered with soil and vegetation. In eroding areas, the exposed face above high-water level is sustained by weathering, including wet-dry and freeze-thaw processes. Additional survey data was collected in this area, as discussed in Section 5.2.1.

5.2.1 Detailed Erosion Area

A detailed erosion area was selected north of Lewiston to collect data on the eroding Queenston Shale river banks. A total of three bathymetric profiles were collected to provide accurate information on the riverbed geometry. Topographic information was collected and combined with the hydrographic data

Copyright © 2005 New York Power Authority

to produce profiles of the erosion area. Figure 5.2.1-1 provides a conceptual sketch of the typical profile in this area.

The detailed bathymetric data indicates that the riverbed features a steep nearshore profile (as discussed in Section 5.2), and a concave profile shape. From 600 to 900 feet on the X-axis in Figure 5.2.1-1, the river bed slope is 20:1 (H:V, Horizontal to Vertical). From the 25 foot depth contour to the waterline, the river bed slope increases to 5:1 (H:V). Based on this riverbed profile, wind-generated waves (if present) could propagate from deep water to the shoreline with little or no energy dissipation, regardless of water level. This profile condition is opposite to the detailed erosion areas on the Upper River, which featured a wide, shallow shelf, as discussed in Section 5.1.1.

The nearshore features small zones of submerged aquatic vegetation and a private boat dock, which were common along this reach of the river. A view of the shoreline looking downstream is presented in Figure 5.2.1-2. A thin shingle beach is present above the shale but does not provide erosion protection. The shingle material is actually eroded portions of the upper slope that have been rounded by waves and currents.

At the back of the beach, a talus deposit accumulates at the base of the shale bank and covers the horizontal bands of the Queenston Shale. This deposit, which is partially consolidated, is depicted graphically in Figure 5.2.1-1. The talus can also be seen in Figure 5.2.1-3, particularly at the base of the slope on the upstream side of the photograph. Above the talus, the horizontal bands of Queenston Shale can be clearly seen in Figure 5.2.1-3. The shale is capped with glacial till. The boundary between the shale and till is not clearly visible in the offshore photograph. However, the change from an exposed shale face to dense vegetation provides visual information on the location of this transition.

Although the river bank features a very steep slope ratio of 1:0.5 (H:V), it appears to be receding very slowly and the erosion rate is classified as low (severity of 1). In some locations, the talus is stable and sufficiently thick to support scrub vegetation and, occasionally trees. It is unclear why some sections of the river banks are stable, while others are eroding. One probable factor is land use at the waterline and on the tablelands. Recreational pressures at the waterline and on the slope will ensure that the talus is unstable and that vegetation does not fully develop. Another possible explanation is the slope of the

Copyright © 2005 New York Power Authority

nearshore and the degree of protection provided by the beach. For example, the Queenston Shale bank in Figure 5.2.1-4 is densely vegetated by willows, sumacs, and small deciduous trees. This location does not feature any boat docks and the waters edge appears to be armored with boulders (both natural and placed).

During low water levels (see minimum water level in Figure 5.2.1-1), river currents will erode the steep portions of the river bed from 900 to 1,000 feet on the X-axis if the critical shear stress exceeds the resisting properties of the shale. During high water levels, such as the maximum water level of 249.41 ft in Figure 5.2.1-1, currents may erode the beach material, talus deposit, and the toe of the bank. Currents may also destabilize vegetation and root systems, leading to erosion and slope failures at high river levels.

5.3 Tributaries - Upper River

A visual reconnaissance survey was undertaken in the main tributaries within the Study Area. It is important to note that creeks and tributaries, which transport runoff and sediment from the watershed to the Niagara River, are by definition, erosion features. That is, concentrated hydraulic flow and the associated erosion processes created the creeks and continues to modify their morphology today. Without active erosion in some point during their history, creeks would not exist.

It should also be recalled from the discussion of Section 5.1.1 that the turbidity -associated with the discharge from these creeks may influence the ability for submerged aquatic vegetation to thrive along the shore of the Niagara River. In two key erosion areas within the study boundaries of the Upper River and one on Navy Island the absence of SAV has been linked to erosion areas. It is certain that the absence of SAV results in greater wave energy reaching the shore, leading to more erosion. Therefore, the discharge from creeks may influence erosion rates, in addition to sedimentation within the main river.

For the purpose of this investigation, the morphology of the creeks has been characterized into the following categories: 1) actively eroding, 2) minor erosion, often in the form of a small scarp along the creek bank, 3) stable due to natural processes, such as vegetation, and 4) artificially stabilized or protected. This classification identifies the current morphology of the creeks, as observed in the fall of 2003. Historically, all reaches of the creek eroded at some time.

Copyright © 2005 New York Power Authority

The tributaries along the upper river that were visited included; Gill Creek, Cayuga Creek, Bergholtz Creek, Ellicott Creek, Twomile Creek, Big Six Creek, Burnt Ship Creek, Woods Creek, Gun Creek, Spicer Creek, and the Tonawanda Creek. With the exception of the Tonawanda Creek (for reasons described in Section 5.3.4), the upstream limit of the tributaries was determined based on the location where Niagara River water level fluctuations cease to have an influence. This limit was based on several factors including; (a) limits supplied by NYPA for selected tributaries (based on results of URS et al. 2005a), and (b) GIS analysis of local topographic information relative to water levels on the river. Figure 4.2.1-1 shows the locations of the tributaries.

The following sections provide a brief discussion of results from the reconnaissance study on the tributaries.

5.3.1 Gill Creek

Gill Creek is located between Niagara Falls and the intake for the Project. The upstream limit of the Study Area was determined by the presence of a dam across the creek (i.e., water level fluctuations on the river will not influence the creek beyond the dam). Figure 5.3.1-1 shows the limits of the Study Area for Gill Creek.

The south end of Gill Creek is highly industrialized with various shore protection structures located along this section. The northern two thirds of Gill Creek is predominantly residential, institutional, and parkland.

At the time of the study (October 2003), the flow through Gill Creek was negligible and water levels were very low. This resulted in large pools of stagnant water, algae plumes, and exposure of the armored banks at the mouth of the creek. The unprotected banks along Gill Creek consist of lacustrine clay. In most locations the banks and tablelands are stable and extensively vegetated.

Approximately 55% of Gill Creek is protected within the Study Area. The creek banks are protected with dumped armor stone, steel sheet pile, and concrete bridge abutments. The status of the

Copyright © 2005 New York Power Authority

protection structures is generally good. Some of the bridges may require maintenance in the future, however, this requirement is not water level related.

Approximately 1% of Gill Creek is considered to be actively eroding. Many of the unprotected areas of Gill Creek have a 6-inch to 1-foot high scarp along the creek banks. There were no POIs. Refer to Figure 5.3.1-2 for the spatial extents of the eroding banks and scarp areas. The scarp feature is common throughout the Study Area. It is interpreted as a natural response to the creek hydrology and indicative of a very slow long-term bank erosion rate. At higher water levels, the scarping would not be visible (refer to Section 5.3). At the time of the survey, approximately 25% of the shoreline showed signs of scarping.

5.3.2 Cayuga Creek

Cayuga Creek is located north of Cayuga Island, and the Study Area extends just south of Porter Road (State Rd 182). The upstream limit of the Study Area for Cayuga Creek was determined based upon information supplied by NYPA from URS et al. 2005a. Figure 5.3.2-1 shows the limits of the Study Area for Cayuga Creek.

Land-use surrounding Cayuga Creek includes residential, commercial, as well as parkland. Cayuga Creek becomes much narrower immediately north of the confluence with Bergholtz Creek at the Cayuga Road Bridge. North of this confluence, the banks of Cayuga Creek consist of lacustrine clay and are well vegetated with grass, shrubs, and trees. There are numerous flow impediments along this section of the creek caused by log jams and the collection of other debris/garbage. These debris jams may artificially raise the level of flooding on adjacent lands along Cayuga Creek during the spring freshet and large rainfall events.

Cayuga Creek is predominantly unprotected. Only 17% of the shoreline is protected, with the majority of the structures existing downstream of the confluence of Cayuga and Bergholtz Creeks. Refer to Figures 5.3.2-1. The bank protection features include dumped shot rock, timber cribs, stone, and concrete bridge abutments.

Copyright © 2005 New York Power Authority

Only 1% of the river banks along Cayuga Creek are actively eroding and less than 5% feature a small erosion scarp, as seen in Figure 5.3.2-2. The bank erosion is found predominantly at significant bends or turns in the creek morphology, which suggests the erosion is associated with high velocity flows during the spring freshet and large rainstorms. The banks were not eroding during the low flow conditions observed in the fall of 2003.

5.3.3 Bergholtz Creek

Bergholtz Creek intersects Cayuga Creek at the Cayuga Road Bridge. The upstream limit of the Study Area for Bergholtz Creek was Cayuga Ext. Drive Bridge. This limit was determined based upon information supplied by NYPA from URS et al. 2005a. Figure 5.3.2-1 shows the limits of the Study Area for Bergholtz Creek.

Land-use surrounding Bergholtz Creek, upstream of William Drive Bridge, is predominantly commercial, industrial and agriculture. Closer to the confluence with Cayuga Creek, the land-use is typically residential.

The banks of Bergholtz Creek have formed in lacustrine clay and are presently vegetated with grass, shrubs and trees. The upstream extent of the creek is very narrow as it traverses through farmland. Cattails and tall grass are common in this area. Further downstream, the creek widens, and the average creek bank is approximately 6-8 feet high.

While the upstream extent of the creek does not have many protection structures (with the exception of bridge abutments), the downstream extent of Bergholtz Creek has pockets of localized protection at individual residences. Approximately 10% of the creek is protected by structures, including dumped concrete, rip rap, stacked stone, timber crib, and concrete walls. The condition of the protection structures varies from poor to good.

Localized erosion is present along 6.5% of Bergholtz Creek within the Study Area. Also, approximately 6.0% of the creek has a 6-inch to 1-foot high scarp along the water line. The extent of the

Copyright © 2005 New York Power Authority

eroding banks and scarp areas are presented on Figure 5.3.2-2 in plan view. At higher water levels, the scarping would not be visible (refer to Section 5.3).

5.3.4 Tonawanda Creek

Tonawanda Creek is located to the east of the Tonawanda Channel on the Niagara River. It is part of the New York State Barge Canal system, and connects to the Erie Canal. It is reported that flows are reversed during the navigation season, as there is a gate in Lockport with a lower elevation than the Niagara River. As a result, the upstream extent of Tonawanda Creek (where water level fluctuations from the Niagara River cease to have influence) is difficult, if not impossible, to determine. Figure 5.3.4-1 shows the limits of the Study Area on Tonawanda Creek chosen for this study.

Land-use surrounding Tonawanda Creek consists of residential, commercial and parkland. The banks of the creek have formed in weak lacustrine clay. Most of the banks are vegetated with grass, shrubs and trees.

Generally, the creek banks along the length of Tonawanda Creek within the Study Area are protected at the water line by dumped stone. Additional localized protection structures along Tonawanda Creek include; steel sheet pile, timber crib, stacked blocks, and concrete walls. Approximately 83% of Tonawanda Creek is protected by some form of structure or dumped stone. Generally, the protection is in fair to good condition. However, there are areas that are in fair to poor condition.

Approximately 3% of the length of the creek within the Study Area is eroding, as seen in Figure 5.3.4-2. Erosion along Tonawanda Creek generally occurs on islands and other areas where no development and consequently no protection exists. Erosion in this area is mostly due to the frequent boat wakes. Scarping is present for approximately 1% of the creek length within the Study Area (refer to Figure 5.3.4.2). Several POIs were also documented.

Copyright © 2005 New York Power Authority

5.3.5 Ellicott Creek

Ellicott Creek is located to the south of Tonawanda Creek. The creek is wide, canal-like, and initially runs parallel to Tonawanda Creek. The upstream limit of the Study Area was located where the creek narrows at the PFOHL Park. Figure 5.3.4-1 shows the limits of the Study Area for Ellicott Creek.

Land-use around Ellicott Creek includes residential, commercial and industrial. The creek banks consist of lacustrine clay and are well vegetated with grass and shrubs. Approximately 20% of Ellicott Creek is protected within the Study Area. The following structures were observed; timber cribs, tires, dumped concrete / stone, and bridge protection. The status of the protection structures ranges from poor (failing) to good.

Since the creek banks have been cut in weak lacustrine clay, they are susceptible to erosion. Field measurements indicated approximately 5% of Ellicott Creek is eroding within the Study Area, as seen in Figure 5.3.4.2. Scarping along the bank (6-inch to 1-foot high micro erosion feature) is present for approximately 55% of the creek length within the Study Area. POIs were identified at the mouth of the creek, near the confluence of Tonawanda Creek.

5.3.6 Twomile Creek

Twomile Creek is located on the mainland near Tonawanda northeast of South Grand Island Bridge. The creek mouth is located further south than any other tributary reviewed during this study (i.e., furthest from the Project Intakes). The upstream limit of the Study Area was determined to be just south of Fletcher Street Bridge. Figure 5.3.6-1 shows the limits of the Study Area for Twomile Creek.

Generally, Twomile Creek has steep banks from 2 to 6 feet high. The creek banks have formed in lacustrine clay. The slopes are heavily vegetated with grass, shrubs, and trees. Land-use surrounding Twomile Creek is primarily parkland, with some residential and commercial.

Copyright © 2005 New York Power Authority

Natural vegetation and shrubs provides protection to the majority of Twomile Creek. However, protection structures exist along approximately 4% of the creek banks within the Study Area. Bridge abutments also offer localized protection along the creek.

Approximately 12% of Twomile Creek is eroding within the Study Area. Refer to Figure 5.3.6-2. Erosion areas are predominantly found at significant bends in the creek, and adjacent to bridge abutments. These features suggest that erosion along Twomile Creek appears to be predominantly caused by high velocity flows (i.e., during spring run-off). Scarping (6-inch to 1-foot high) is present for approximately 43% of the creek length within the Study Area. The spatial extents of the erosion areas are presented in Figure 5.3.6-2. No POIs were observed.

5.3.7 Big Sixmile Creek

Big Sixmile Creek is located on the west side of Grand Island. South of the Whitehaven Road Bridge abutment at the mouth of the river, the creek is very wide and may have been dredged to accommodate an existing 134 slip marina. However, the entire creek, including the existing marina basin, is considered part of the Study Area. The upstream limit of the creek was located 1,000 feet south of bridge abutment. Figure 5.3.7-1 shows the limits of the Study Area for Big Sixmile Creek and the existing marina.

Upstream of the marina basin, the creek is approximately 4 to 10 feet wide and during the field work in October 2003 the water depth was rarely more than 1.5 feet deep. Several small rapids are present along the length of the creek within the Study Area where the topography featured a major change in slope. With the exception of the marina grounds, land-use along Big Sixmile Creek is predominantly residential and parkland.

The banks of the creek are typical for the Upper River tributaries and the native sediment is lacustrine clay. The river banks range from 1 to 5 feet high and are covered in thick vegetation. There are no protection structures along Big Sixmile Creek, with the exception of the bridge abutments.

Copyright © 2005 New York Power Authority

When the entire marina basin is included, approximately 7% of the Big Sixmile Creek is actively eroding within the Study Area (refer to Figure 5.3.7-2). The majority of this erosion is located along the navigation channel used by the boaters to access the Niagara River and may be associated with boat wake. If the river banks immediately north of the boat slips are ignored (i.e. the navigation channel to the Chippewa Channel), less than 1% of the creek is actively eroding. The eroding banks in these narrow reaches of the creek suggest that erosion is caused by high velocity flows (i.e., during spring run-off), not the normal daily conditions. Approximately 1% of the creek banks show signs of a 6-inch to 1-foot high scarp, as seen in Figure 5.3.7-2. No POIs were observed in the field.

5.3.8 Burnt Ship Creek

Burnt Ship Creek is located at the northwest end of Grand Island and separates Grand Island from Buckhorn Island (see Figure 4.2.1.1). Currently, the outlet of Burnt Ship Creek is closed due to sedimentation at the mouth. It is possible that the outlet of Burnt Ship Creek was closed and/or is kept closed due to the general shoreline orientation, which protrudes into the river from the northwest end of Buckhorn Island. The shoreline orientation blocks and/or diverts the downriver transport of sediment along the west shore of Grand Island. Due to the closed outlet, water level fluctuations on the Niagara River do not currently influence the creek.

A preliminary review of the site was undertaken by kayak and by foot. This area is an active marsh that is heavily vegetated with cattails. Land-use surrounding the area consists of parkland (Buckhorn State Park). Given the dense marsh vegetation, it was not possible to observe the native geology. However, the presence of the marsh vegetation suggests lacustrine clay with modern deposits of unconsolidated sediment.

The water depth (at the time of the study) was approximately 6 inches to 1 foot deep. Due to the low-lying nature of the area (i.e., banks are non-existent), and the closed outlet, there is no erosion present.

Copyright © 2005 New York Power Authority

5.3.9 Woods Creek

Woods Creek is located on the north shore of Grand Island to the east of North Grand Island Bridge. Figure 5.3.9-1 shows the limits of the Study Area for Woods Creek.

The mouth of the creek is approximately 45 ft wide. Land-use surrounding the downstream portion of Woods Creek is generally parkland (Buckhorn State Park). Upstream of the park the creek becomes much narrower and the land-use is predominantly residential with a natural treed buffer between the creek banks and the development.

The creek banks along Woods Creek are typically 1 to 6 feet high and have evolved in lacustrine clay. They are covered with vegetation (grass, cattails, shrubs, and trees).

Localized protection structures exist along Woods Creek, including bridge abutments. Approximately 3% of Woods Creek is protected within the Study Area. Refer to Figure 5.3.9-1.

Only 1% of Woods Creek is eroding within the Study Area, as indicated on Figure 5.3.9-2. In addition, approximately 15.5% of the upstream area of Woods Creek (in the residential section) has a 6 inch to 1-foot high scarp at the water level. No POIs on were identified on the creek. However, two sites were located to the east (upstream) of the mouth.

5.3.10 Gun Creek

The mouth of Gun Creek is located along the northeast shore of Grand Island. The upstream limit of the Study Area for Gun Creek was determined based upon information supplied by NYPA from URS et al. 2005a. Figure 5.3.10-1 shows the limits of the Study Area for Gun Creek.

The creek is typically 12 to 15 feet wide and, at the time of the study, water depths were approximately 1 to 2 feet deep. The banks along the creek were generally quite steep and range from 1 to 10 feet in height.

Copyright © 2005 New York Power Authority

Land-use surrounding Gun Creek consists of residential near the downstream portions, and parkland / natural areas along the upstream portions.

Protection structures along Gun Creek are predominantly located near the downstream end of the creek. Refer to Figure 5.3.10-1. Approximately 11.5% of Gun Creek is protected within the Study Area with a variety of structures, including: stone, timber crib, concrete and steel sheet pile. The status of the protection is fair to poor.

Erosion areas along Gun Creek are predominantly in locations where the creek banks are very steep. Approximately 26% of Gun Creek is eroding within the Study Area. In addition, a 6-inch to 1-foot high scarp is apparent along 10% of Gun Creek. The field mapping of the erosion areas and scarping is presented in Figure 5.3.10-2. No POIs were identified on Gun Creek.

5.3.11 Spicer Creek

Spicer Creek is located on the east side of Grand Island, immediately north of the Holiday Inn. The upstream limit of the Study Area for Spicer Creek was determined based upon information supplied by NYPA from URS et al. 2005a. Figure 5.3.11-1 shows the limits of the Study Area for Spicer Creek.

The creek is heavily vegetated with some wetland areas. The upstream area Spicer Creek is quite narrow and shallow and meanders through the River Oaks Golf Course. There is a significant change in elevation along the length of the creek. Land-use surrounding the downstream area of Spicer Creek is split between commercial on the south side of the creek, and a cemetery on the north side. Upstream land-use consists of a golf course and residential development.

The creek banks in the downstream area of Spicer Creek have been cut in lacustrine clay and covered with vegetation (grass, shrubs, and trees). The clay was also observed for the upstream area along the golf course. Protection on the creek is limited to structures to prevent erosion in the immediate vicinity of culverts. These structures represent about 2% of the creek length, as documented in Figure

Copyright © 2005 New York Power Authority

5.3.11-1. The remainder of the creek does not have hard protection and is naturally stabilized with vegetation.

Approximately 10% of Spicer Creek is eroding within the Study Area. Refer to Figure 5.3.11-2 for the spatial extents of the eroding banks. Erosion areas are predominantly found at significant bends in the creek and immediately downstream of culverts. The creek banks in the erosion areas are generally high and steep. The nature and location of the erosion areas suggest that erosion along Spicer Creek is predominantly caused by high velocity flows (i.e., during spring run-off).

In the vicinity of the golf course and residential area there is a 6-inch to 1 foot high scarp along the toe of the creek bank. In total, 26% of the creek banks show signs of scarping. No POIs were identified. Refer to Figure 5.3.11-2.

5.3.11.1 Detailed Erosion Area

Of the many tributaries feeding the Upper Niagara River, Spicer Creek was selected as a detailed erosion area. A typical profile of the creek is shown in Figure 5.3.11.1-1. The profile is located between the marina basin to the south of the creek and the cemetery to the north. Refer to Figure 5.3.11-1.

As seen in the conceptual sketch, the river banks have been cut and are eroding through the weak lacustrine clay that is common throughout the study area above the falls. The banks are steep and void of any vegetation. During the field visit in the fall of 2003 there was almost no flow in the creek and water levels appeared very low. These conditions on Spicer Creek, combined with observations from many of the other tributaries along the Upper River support the hypothesis that bank erosion only occurs during the spring freshet and severe rainfall events when the creek level is elevated. The resulting flow velocities will generate bed shear stress levels that erode the river bottom and banks. Under the flow velocities observed in the fall of 2003, it is very unlikely the normal dry conditions could lead to erosion on the creek bed or banks.

Copyright © 2005 New York Power Authority

Water clarity was very poor during the field observations in the fall of 2003. Also, a high concentration of decaying organic matter was observed on the creek bed. Submerged aquatic vegetation was absent from the study area and this factor likely contributes to ongoing river downcutting during high flow conditions. Together, the downcutting and bank erosion maintain the steep sided river banks and vegetation is not able to stabilize the slope.

The upstream land use, which is dominated by the manicured greens for the golf course and paved impervious surfaces for the residential development, may accelerate the delivery of water to the creek during rainfall events and contribute to the high velocity flows that can cause erosion.

The combination of our field observations and site data recorded in Figure 5.3.11.1-1 suggest the long-term bank erosion rate in the creek is low and has a severity rating of 1.

5.4 Tributaries – Lower River

5.4.1 Fish Creek

Fish Creek is located to the north of Lewiston Reservoir. The creek terminates at the edge of the gorge along the lower Niagara River. Since the creek mouth is hundreds of feet above the river, water level fluctuations from the lower river will not have an impact on erosion processes along the creek. Any erosion will be due to flows associated with the creek watershed and local land-use practices. Figure 4.2.1-2 shows the location of Fish Creek.

Land-use surrounding Fish Creek is residential and parkland. It also features a golf course.

It was not possible to navigate the creek with a kayak. Therefore, the river banks were accessed at strategic locations by foot. The creek banks appear to consist of lacustrine clay and glacial till deposits. The creek meandered through dense forest and segments of the Niagara Falls Country Club. Some protection structures exist near bridge abutments as well as through the golf course, where the creek has been stabilized with a concrete channel.

Copyright © 2005 New York Power Authority

No erosion was observed at the select locations visited during the study. However, if erosion does exist, now or in the future, it is most certainly not related to water level fluctuations from the Niagara River.

5.5 Gorge Area

Attempts were made to assess the gorge area of the Niagara River from the Falls, to just upstream of the Robert Moses Niagara Power Plant tailrace and the upper river from the NYPA Project Intakes to the Falls. However, due to safety concerns, an assessment by foot along the waterline was not possible. In its place, a video of the gorge area (taken by helicopter in April/May 2002) was reviewed to provide an assessment of the area.

5.5.1 Assessment of Video

It is important to note that the Niagara Gorge, by definition, is an erosion feature. The very presence of the gorge is due to erosion of the riverbed, and associated slope failures, which are triggered by downcutting of the river at the base of the slope, physical and chemical weathering, and slope drainage. However, under the current physical conditions and flows in the Niagara River, these processes are very slow due to the resisting properties of the shale bedrock. The impact of physical and chemical weathering on the landscape are continuous but difficult to observe or measure year to year. Failures can also occur on the upper slopes of the gorge, well beyond the range of river level fluctuations.

The analysis of the video concentrated on the lower slopes of the gorge (river banks), as the upper slopes were outside the zone of influence for water level fluctuations. Based on the video, two locations of active erosion were identified:

1. River banks opposite the Whirlpool, particularly the downstream banks, and

Copyright © 2005 New York Power Authority

2. Between the Lower Rail and Rainbow bridges. A concrete building is located at mid-slope in this area. It appears that the building was constructed on fill or weak sedimentary rock. The toe of the bank appears to be eroding.

For the remainder of the river banks, the shoreline appeared stable in the video. In many cases, the waters edge was naturally armored with rocks and blocks dislodged from the upper portion of the gorge.

5.5.2 Jetboat Wake

Concern has been raised over the possibility of river bank erosion due to the wake from jetboats that operate between Lewiston and the Whirlpool on the lower river and gorge area. As part of this study, a preliminary visual assessment of the jetboat wake was undertaken at two locations. It should be noted that the peak season for jetboat operations is from May thru October. The observations made during this study occurred in October (towards the end of the season) and, the frequency of the jetboat excursions may be reduced during this time of the year. Figure 4.1.7-1 shows a typical jetboat and its wake as it travels downstream along the Canadian shoreline.

Two jetboats were observed as they traveled downstream along the Canadian shoreline. Based on the observations, it was found that the wake from the boats was not substantial at the shoreline for the selected locations. The jetboats were, typically, following a route close to the Canadian shoreline. Therefore, the effects of the wake on the American side of the river were minimized due to the distance traveled by the wake and the associated decay in the wake height. In addition, the river currents in the gorge may dampen the jetboat wake height before it reaches the American shoreline.

To make more definitive comments on the influence of the jetboat wakes would required additional observations and data collection.

Copyright © 2005 New York Power Authority

5.6 Summary of Shore Protection in the Study Area

The extent of shore protection in the Study Area was presented in Figures 4.2.1-1 and 4.2.1-2 for the upper and lower reaches of the river, respectively (including tributaries). As part of the field survey, the condition of each structure was also evaluated. In general, shore protection within the Study Area is in fair to good condition. As noted in Section 4.1.2, this is not an evaluation of whether the protection is well designed or constructed, only its state of deterioration. An evaluation of the level of performance of the individual protection structures (from a design perspective) was beyond the scope of this investigation. Furthermore, since there was a very wide range of protection types along the shore, it was not possible to classify all, property by property.

Some conclusions can nevertheless be drawn. Most importantly, the widespread extent of protection may suggest that the shoreline, particularly on the upper river, is prone to erosion. This is compatible with our assessment that all shores in the Study Area are classified as cohesive shores, which by definition are always eroding at some location across the profile. The sedimentary rock shores of the lower Niagara generally feature much lower erosion rates than the glacial till/lacustrine clay shores of the upper river but nevertheless this would appear to be an actively eroding gorge. Another observation regarding shore protection was that damaged or deteriorated shore protection at the riparian level was often the result of poor engineering design. In particular, the protection was in several cases inadequately designed (or constructed) to accommodate fluctuating water levels. Some design deficiencies in this respect included:

- Structures with gaps and absence of insufficient filtering making them prone to loss of soil;
- Insufficient crest elevation; and
- Lack of toe protection.

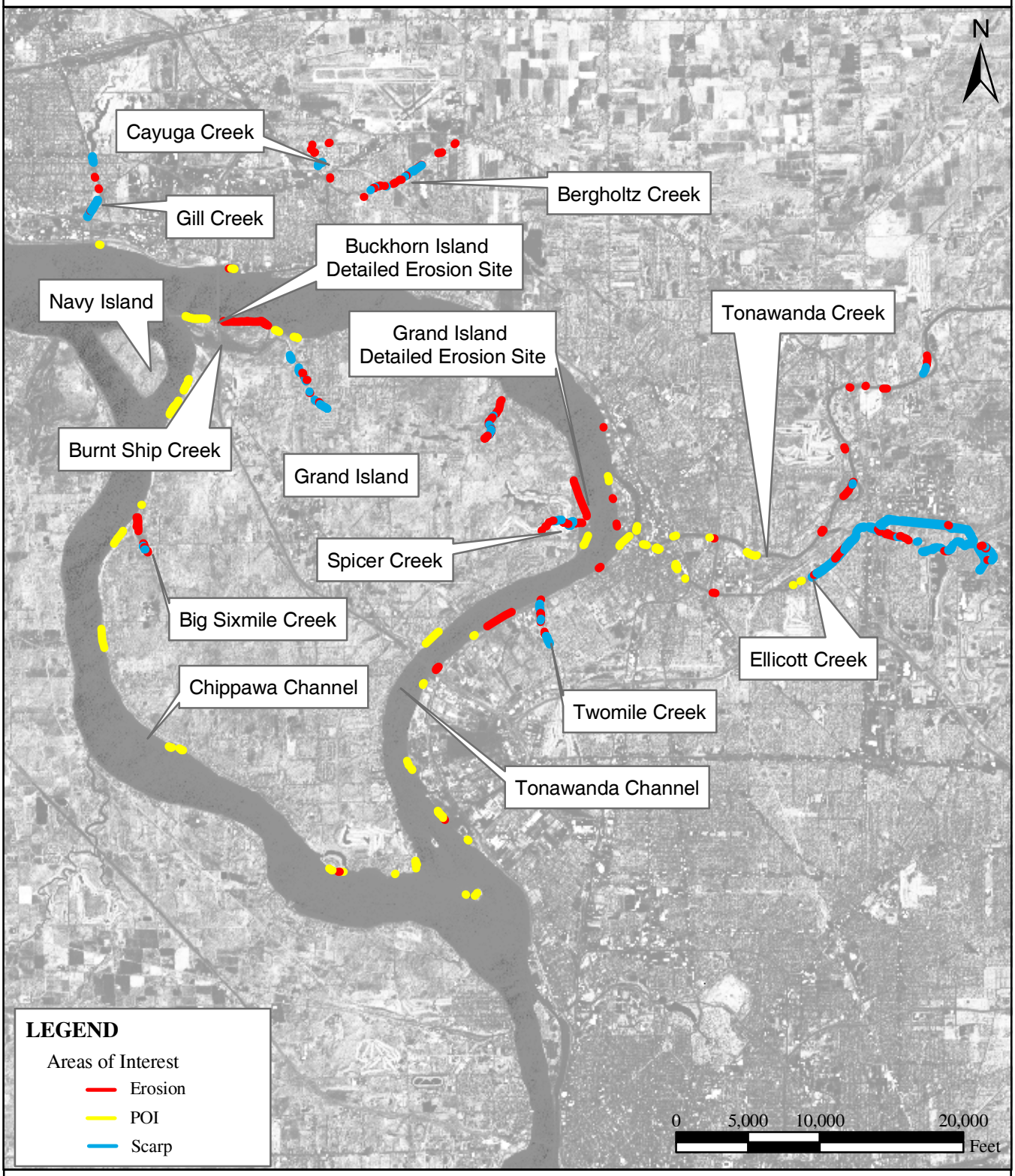
Shoreline protection should be designed to address the water level fluctuation regime that exists at a given location.

Copyright © 2005 New York Power Authority

NIAGARA POWER PROJECT (FERC NO. 2216)

Determine the Effects of Project Operations on Shoreline Erosion

Sedimentation on the Niagara River (including tributaries)



New York Power Authority

EROSION AREAS AND POI's
FOR THE UPPER NIAGARA RIVER
AND TRIBUTARIES

NIAGARA POWER PROJECT

Figure 5.1-1

Copyright © 2004 New York Power Authority

FIGURE 5.1-2

EROSION ALONG BUCKHORN ISLAND ON THE UPPER NIAGARA RIVER

Copyright © 2005 New York Power Authority

FIGURE 5.1-3

EROSION ALONG GRAND ISLAND OPPOSITE TONAWANDA ISLAND ON THE UPPER NIAGARA RIVER

Copyright © 2005 New York Power Authority

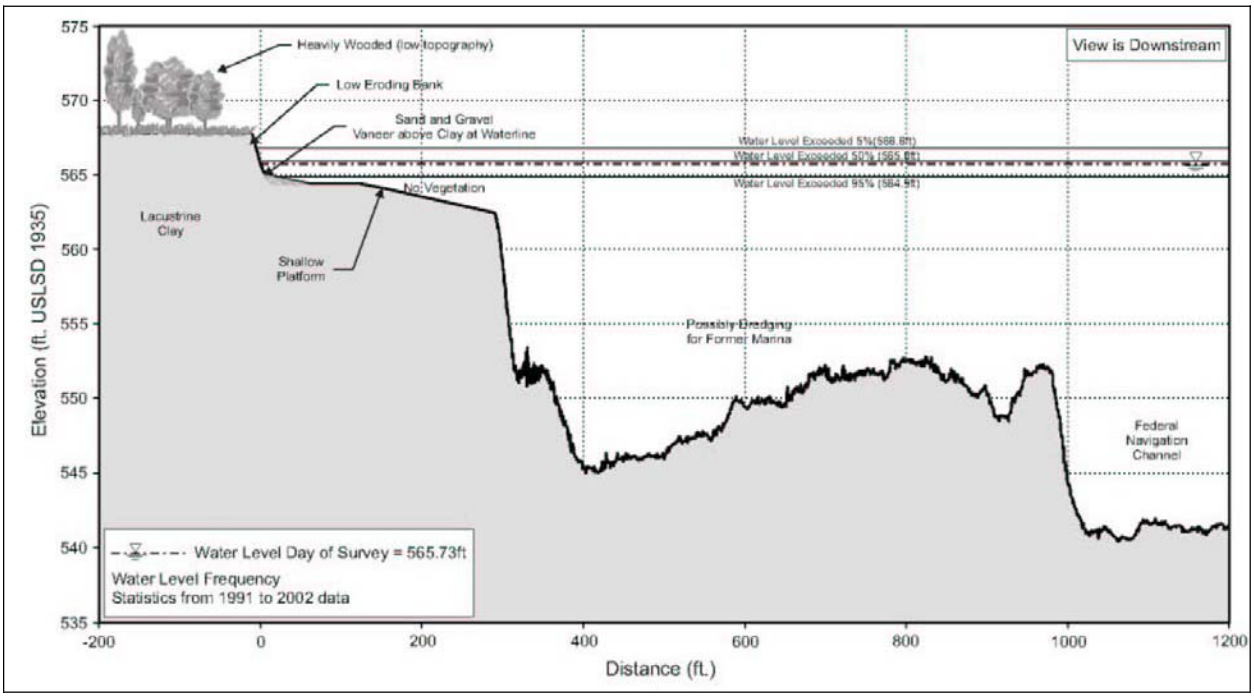
FIGURE 5.1-4

EROSION ALONG THE MAINLAND SIDE OF TONAWANDA CHANNEL ON THE UPPER NIAGARA RIVER

Copyright © 2005 New York Power Authority

FIGURE 5.1.1.1-1

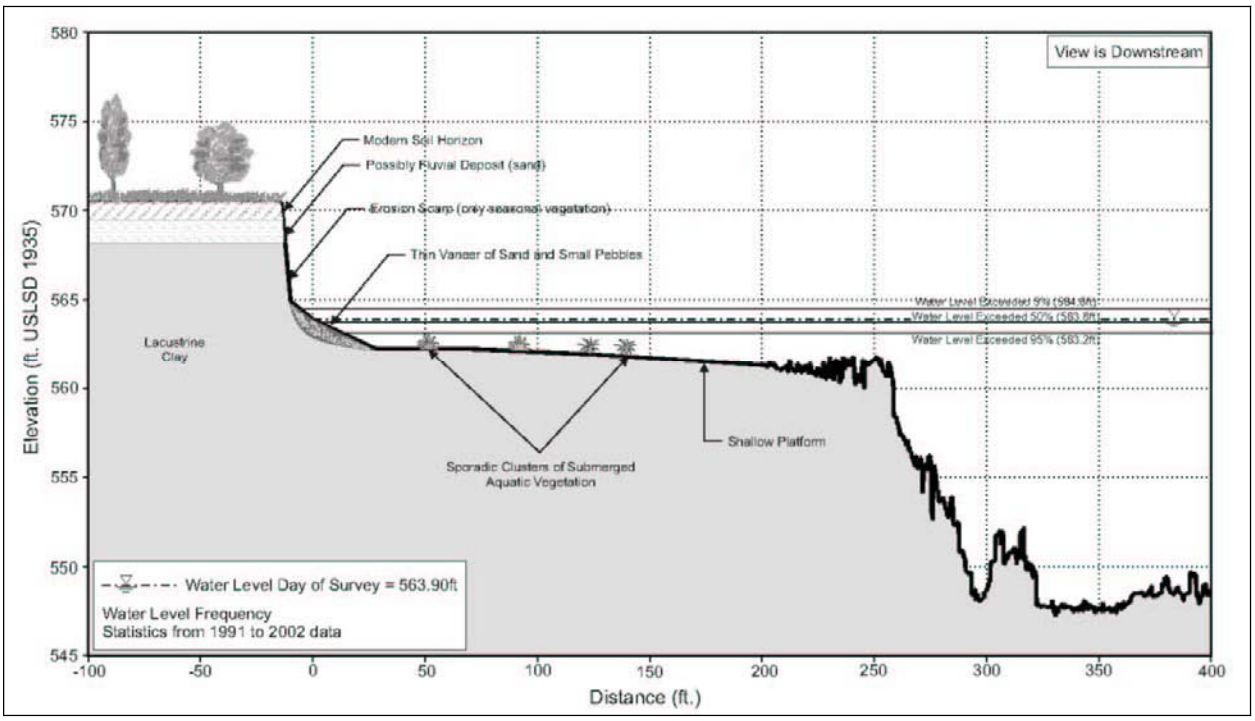
GRAND ISLAND EROSION AREA (OPPOSITE TONAWANDA ISLAND) – CONCEPTUAL SKETCH OF TYPICAL PROFILE



Copyright © 2005 New York Power Authority

FIGURE 5.1.1.2-1

BUCKHORN ISLAND EROSION AREA – CONCEPTUAL SKETCH OF TYPICAL PROFILE



Copyright © 2005 New York Power Authority

Non-Internet Public (NIP) information has been removed from the following page(s).

This material is contained in:
Volume 2
Section: Shoreline Erosion and Sedimentation Assessment Study Upstream and Downstream of the Power Project

FIGURE 5.2-1

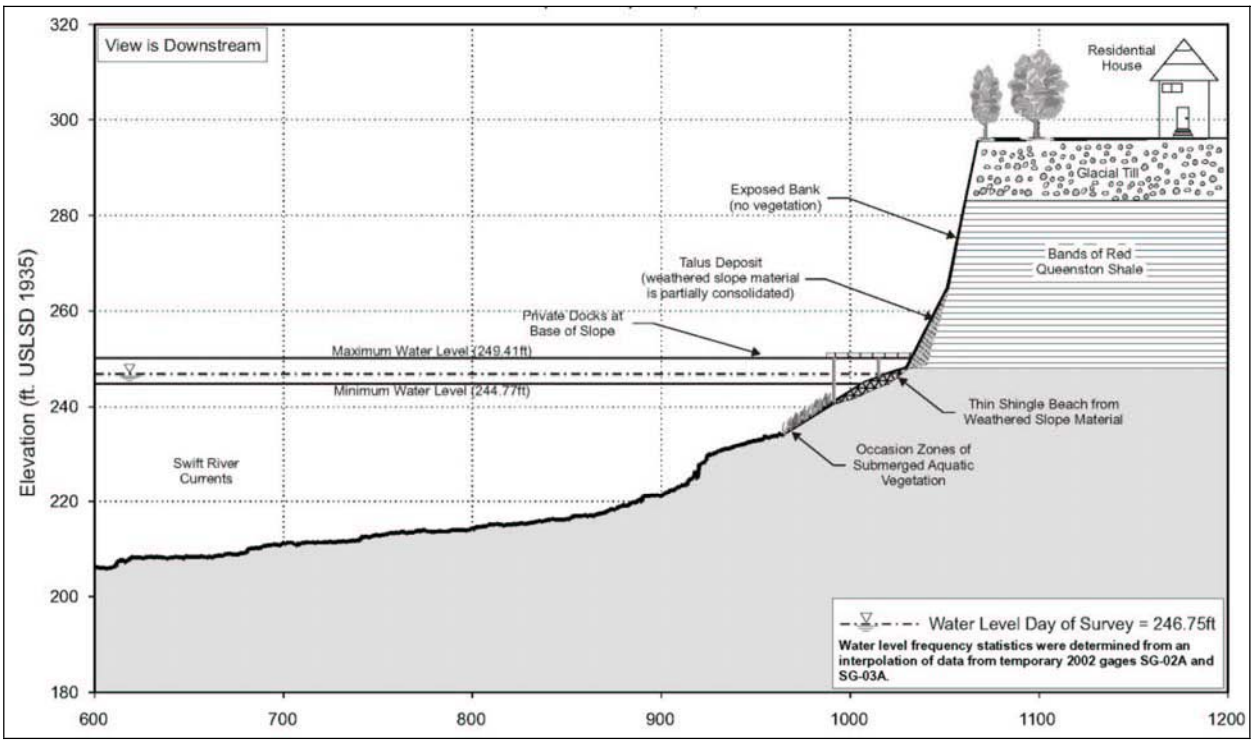
EROSION AREAS AND POIs ON THE LOWER NIAGARA RIVER

[NIP – General Location Maps]

Copyright © 2005 New York Power Authority

FIGURE 5.2.1-1

LOWER NIAGARA RIVER EROSION AREA – CONCEPTUAL SKETCH OF TYPICAL PROFILE



Copyright © 2005 New York Power Authority

FIGURE 5.2.1-2

LOWER NIAGARA RIVER EROSION AREA – LOOKING DOWNSTEAM

Copyright © 2005 New York Power Authority

FIGURE 5.2.1-3

LOWER NIAGARA RIVER EROSION AREA – LOOKING UPSTREAM

Copyright © 2005 New York Power Authority

FIGURE 5.2.1-4

LOWER NIAGARA RIVER EROSION AREA – EXISTING CONDITIONS

Copyright © 2005 New York Power Authority

FIGURE 5.2-2

EROSION ALONG CLAY TALUS ALONG THE LOWER NIAGARA RIVER SOUTH OF LEWISTON (1)

Copyright © 2005 New York Power Authority

FIGURE 5.2-3

EROSION INTO CLAY TALUS ALONG THE LOWER NIAGARA RIVER SOUTH OF LEWISTON (2)

Copyright © 2005 New York Power Authority

FIGURE 5.2-4

EROSION OF QUEENSTON SHALE BLUFFS ALONG THE LOWER NIAGARA RIVER NORTH OF LEWISTON

Copyright © 2005 New York Power Authority

NIAGARA POWER PROJECT (FERC NO. 2216)

Determine the Effects of Project Operations on Shoreline Erosion

Sedimentation on the Niagara River (including tributaries)

New York Power Authority

LIMIT OF SURVEY ON GILL CREEK

NIAGARA POWER PROJECT

Figure 5.3.1-1

Copyright © 2004 New York Power Authority

NIAGARA POWER PROJECT (FERC NO. 2216)

Determine the Effects of Project Operations on Shoreline Erosion

Sedimentation on the Niagara River (including tributaries)

New York Power Authority

LIMIT EROSION AND SCARPING ON GILL CREEK

Figure 5.3.1-2

NIAGARA POWER PROJECT

Copyright © 2004 New York Power Authority

Non-Internet Public (NIP) information has been removed from the following page(s).

This material is contained in:
Volume 2
Section: Shoreline Erosion and Sedimentation Assessment Study Upstream and Downstream of the Power Project

FIGURE 5.3.2-1

LIMITS OF STUDY AREA FOR CAYUGA AND BERGHOLTZ CREEKS

[NIP – General Location Maps]

Copyright © 2005 New York Power Authority

Non-Internet Public (NIP) information has been removed from the following page(s).

This material is contained in:
Volume 2
Section: Shoreline Erosion and Sedimentation Assessment Study Upstream and Downstream of the Power Project

FIGURE 5.3.2-2

LIMITS OF EROSION AND SCARPING ON CAYUGA AND BERGHOLTZ CREEKS

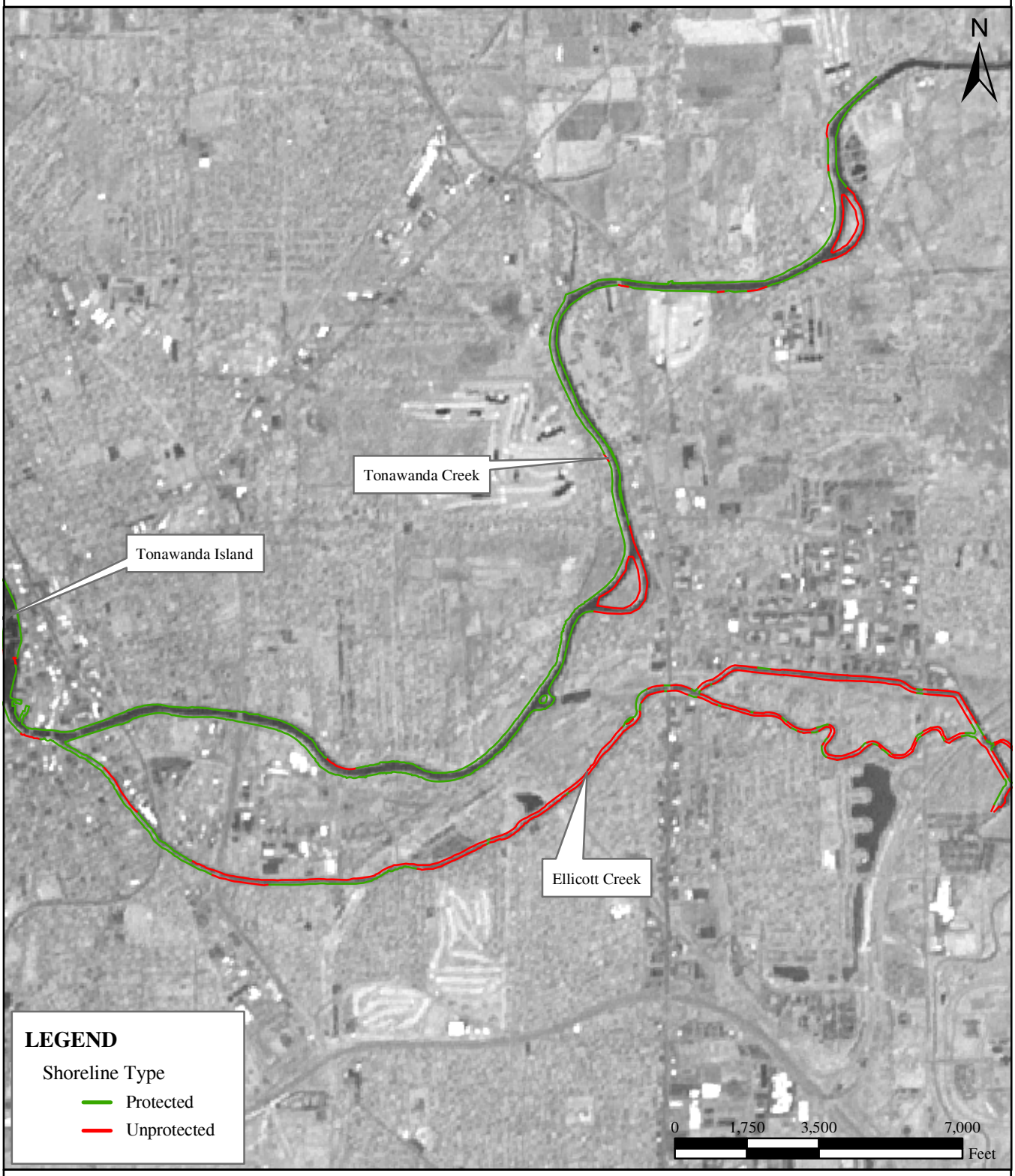
[NIP – General Location Maps]

Copyright © 2005 New York Power Authority

NIAGARA POWER PROJECT (FERC NO. 2216)

Determine the Effects of Project Operations on Shoreline Erosion

Sedimentation on the Niagara River (including tributaries)



New York Power Authority

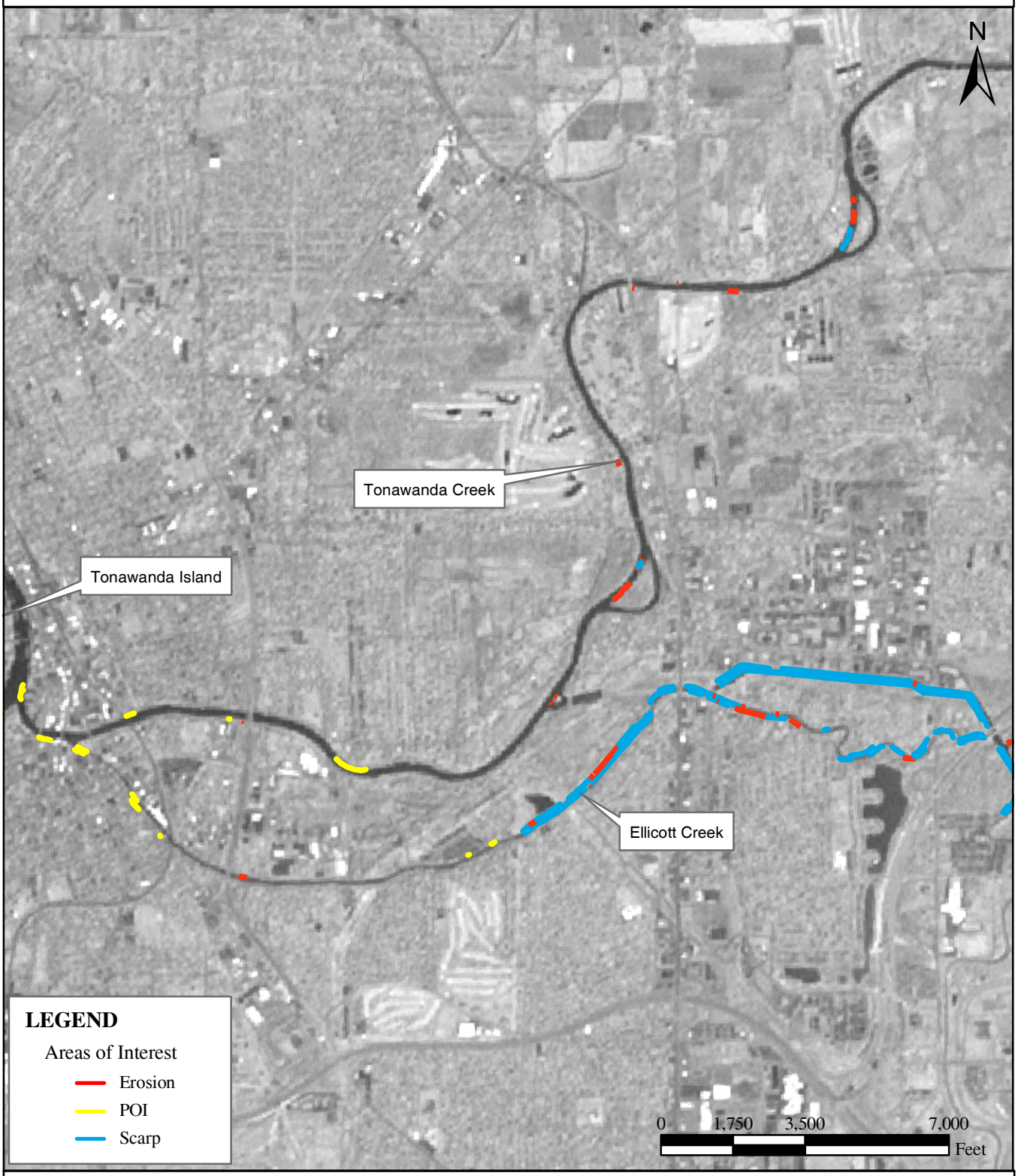
LIMIT OF SURVEY ON TONAWANDA AND ELLICOTT CREEKS

NIAGARA POWER PROJECT

Figure 5.3.4-1

Copyright © 2004 New York Power Authority

NIAGARA POWER PROJECT (FERC NO. 2216)
Determine the Effects of Project Operations on Shoreline Erosion
Sedimentation on the Niagara River (including tributaries)



New York Power Authority

LIMIT OF EROSION AND SCARPING ON TONAWANDA AND ELLICOTT CREEKS

NIAGARA POWER PROJECT

Figure 5.3.4-2

Copyright © 2004 New York Power Authority

NIAGARA POWER PROJECT (FERC NO. 2216)

Determine the Effects of Project Operations on Shoreline Erosion

Sedimentation on the Niagara River (including tributaries)

New York Power Authority

LIMIT OF SURVEY ON TWOMILE CREEK

NIAGARA POWER PROJECT

Figure 5.3.6-1

Copyright © 2004 New York Power Authority

NIAGARA POWER PROJECT (FERC NO. 2216)

Determine the Effects of Project Operations on Shoreline Erosion

Sedimentation on the Niagara River (including tributaries)

New York Power Authority

LIMIT OF EROSION AND SCARPING ON TWOMILE CREEK

NIAGARA POWER PROJECT

Figure 5.3.6-2

Copyright © 2004 New York Power Authority

NIAGARA POWER PROJECT (FERC NO. 2216)

Determine the Effects of Project Operations on Shoreline Erosion

Sedimentation on the Niagara River (including tributaries)

New York Power Authority

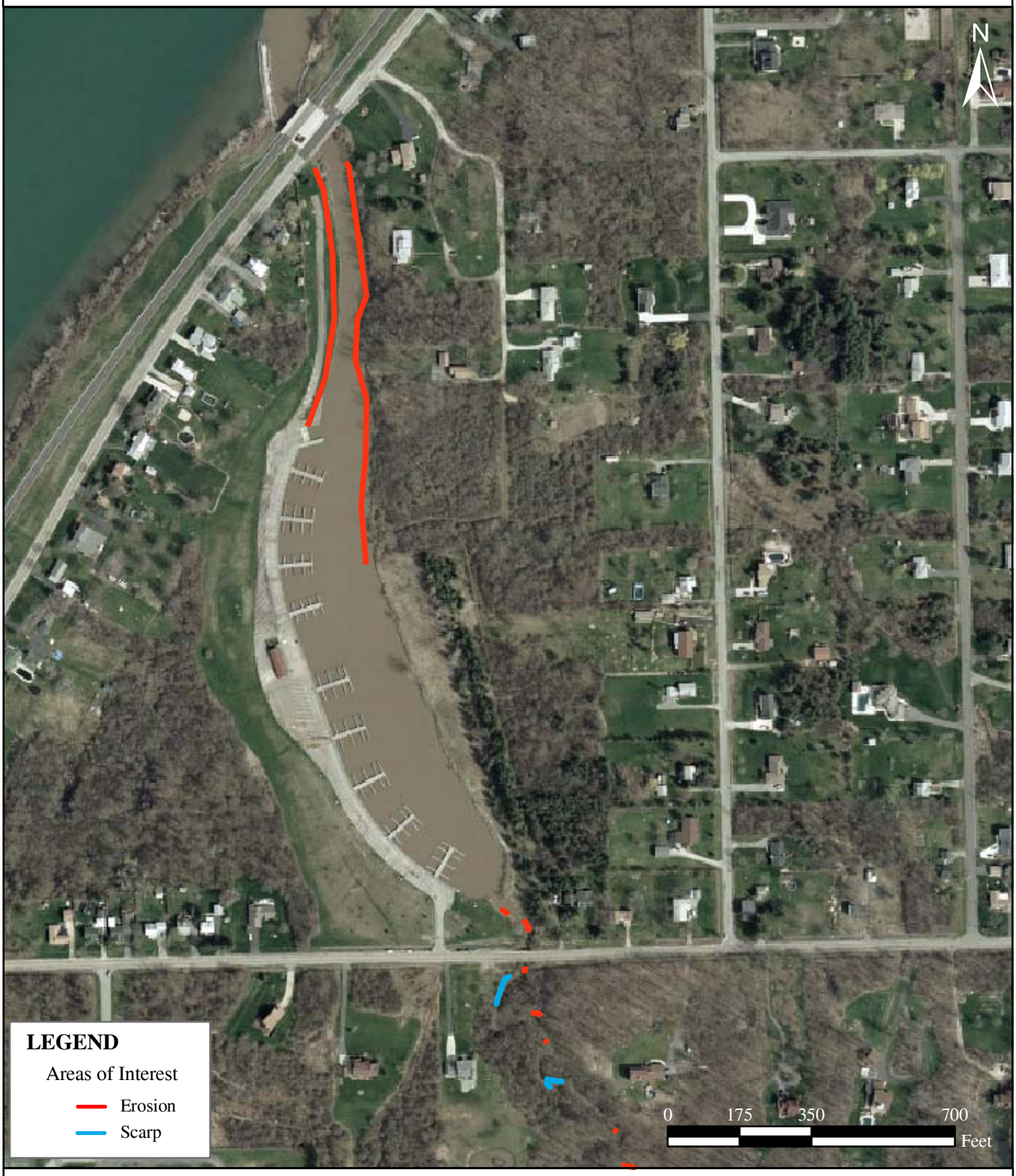
LIMIT OF SURVEY
ON BIG SIXMILE CREEK

NIAGARA POWER PROJECT

Figure 5.3.7-1

Copyright © 2004 New York Power Authority

NIAGARA POWER PROJECT (FERC NO. 2216)
Determine the Effects of Project Operations on Shoreline Erosion
Sedimentation on the Niagara River (including tributaries)



New York Power Authority

LIMIT OF EROSION AND SCARPING ON BIG SIXMILE CREEK

NIAGARA POWER PROJECT

Figure 5.3.7-2

Copyright © 2004 New York Power Authority

NIAGARA POWER PROJECT (FERC NO. 2216)

Determine the Effects of Project Operations on Shoreline Erosion

Sedimentation on the Niagara River (including tributaries)

New York Power Authority

LIMIT OF SURVEY ON WOODS CREEK

NIAGARA POWER PROJECT

Figure 5.3.9-1

Copyright © 2004 New York Power Authority

NIAGARA POWER PROJECT (FERC NO. 2216)

Determine the Effects of Project Operations on Shoreline Erosion

Sedimentation on the Niagara River (including tributaries)

New York Power Authority

LIMIT OF EROSION AND SCARPING ON WOODS CREEK

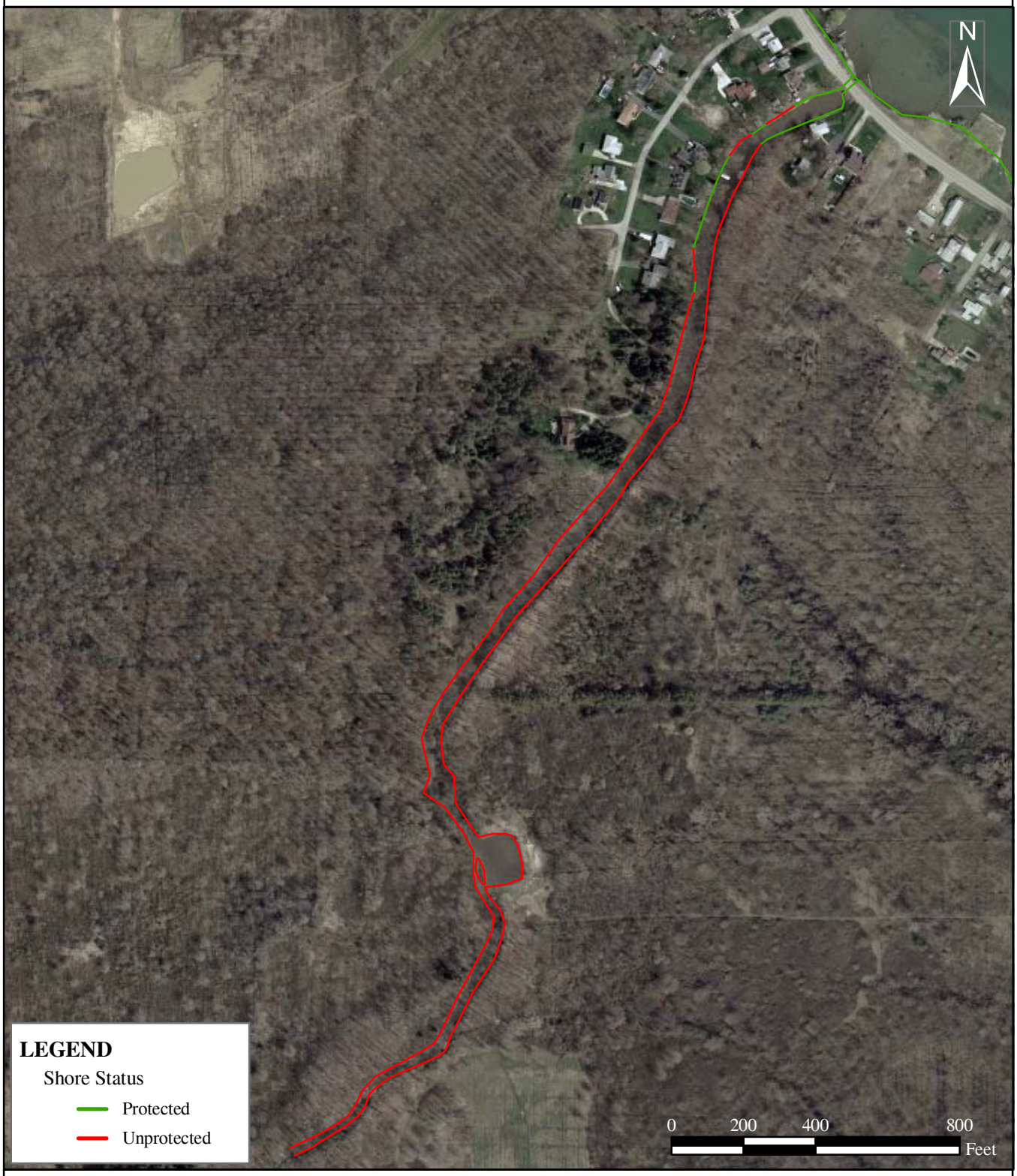
NIAGARA POWER PROJECT

Figure 5.3.9-2

NIAGARA POWER PROJECT (FERC NO. 2216)

Determine the Effects of Project Operations on Shoreline Erosion

Sedimentation on the Niagara River (including tributaries)



New York Power Authority

LIMIT OF SURVEY ON GUN CREEK

NIAGARA POWER PROJECT

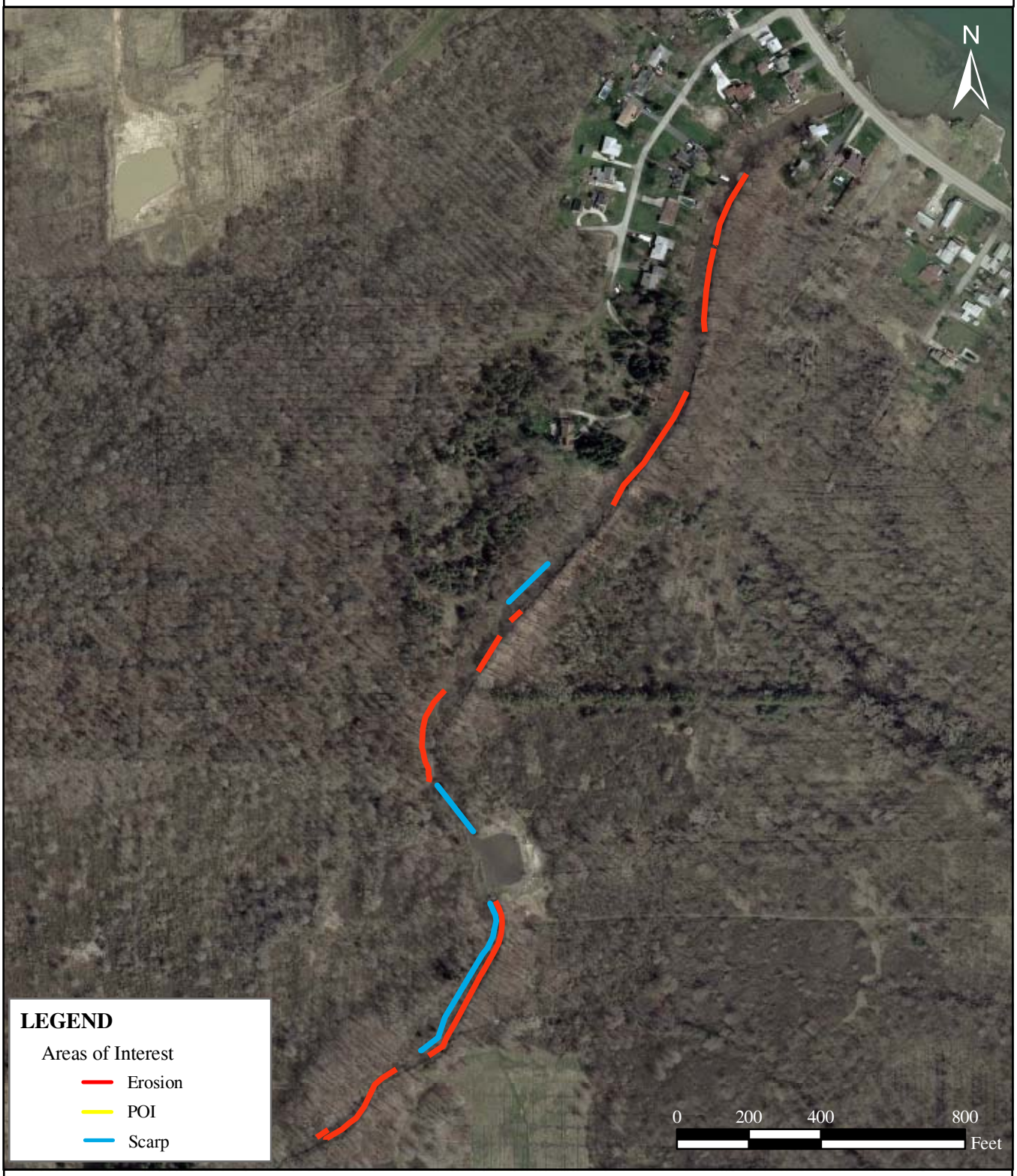
Figure 5.3.10-1

Copyright © 2004 New York Power Authority

NIAGARA POWER PROJECT (FERC NO. 2216)

Determine the Effects of Project Operations on Shoreline Erosion

Sedimentation on the Niagara River (including tributaries)



New York Power Authority

LIMIT OF EROSION AND SCARPING ON GUN CREEK

NIAGARA POWER PROJECT

Figure 5.3.10-2

Copyright © 2004 New York Power Authority

NIAGARA POWER PROJECT (FERC NO. 2216)

Determine the Effects of Project Operations on Shoreline Erosion

Sedimentation on the Niagara River (including tributaries)

New York Power Authority

LIMIT OF SURVEY ON SPICER CREEK

NIAGARA POWER PROJECT

Figure 5.3.11-1

Copyright © 2004 New York Power Authority

NIAGARA POWER PROJECT (FERC NO. 2216)
Determine the Effects of Project Operations on Shoreline Erosion
Sedimentation on the Niagara River (including tributaries)

New York Power Authority

LIMIT OF EROSION AND SCARPING ON SPICER CREEK

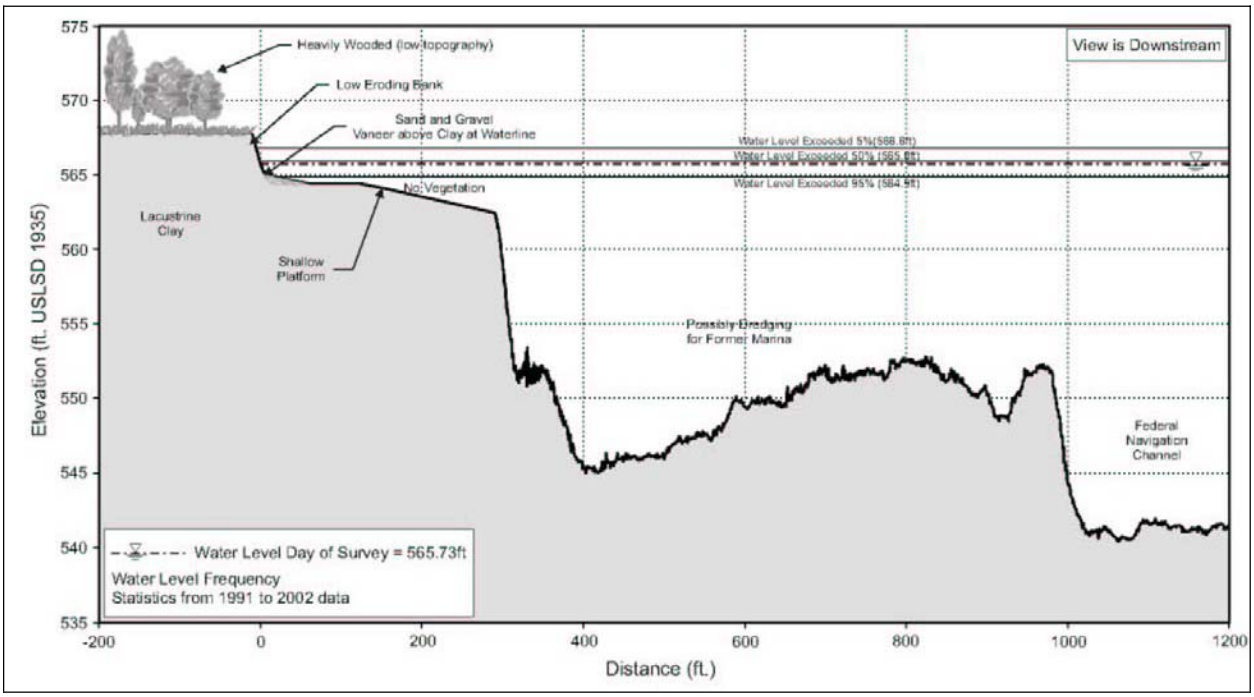
NIAGARA POWER PROJECT

Figure 5.3.11-2

Copyright © 2004 New York Power Authority

FIGURE 5.3.11.1-1

SPICER CREEK EROSION AREA – CONCEPTUAL SKETCH OF TYPICAL PROFILE



Copyright © 2005 New York Power Authority

6.0 ASSESSMENT OF SEDIMENTATION

Background on general sedimentation processes was provided in Section 3.5. Based on this information and the knowledge gained in the first study, a sedimentation study was designed to answer the following questions: 1) where does the sediment come from, 2) how and where is it transported, and 3) where does the sediment ultimately go (also known as sediment sinks). To answer these questions a conceptual Sediment Budget has been formulated for the Niagara River, extending from the headwaters of the river at Lake Erie, to the mouth at Lake Ontario. The study limits for the Sediment Budget also includes local canals, rivers, creeks and engineered diversions.

In theory, once all the sources (e.g. bank erosion), transport pathways (e.g. river currents) and sediment sinks (e.g. Lewiston Reservoir) are quantified, the Sediment Budget should balance. In other words, the sum of all sources is equal to the sum of all sinks, with the transport pathways providing the means for the sediment redistribution. The balanced or closed Sediment Budget then provides a valuable management tool to evaluate the relative contribution of different sediment sources, such as sediment supplied from watersheds and creeks versus bank erosion on the main river. Plus, knowledge of transport pathways provides valuable data for the design of remedial alternatives to reduce sediment supply and deposition in the future. And finally, as noted in Section 5.1.1 there may be an interaction between sediment loading (and related sedimentation areas) from creeks and erosion of the main river banks. For example, creeks that deliver turbid water to the main channel will have a negative impact on the health of submerged aquatic vegetation, which in turn acts as a natural dissipater of wave energy propagating towards the shore.

Quantifying all sinks and sources to close the Niagara River Sediment Budget is beyond the scope of this investigation. However, a qualitative summary of the sources, transport pathways and sinks will be provided based on our field investigations in both studies, and published data from other sources. Figure 6.0-1 summarizes the geographic extent of the conceptual Sediment Budget and the various sediment sources and sinks in a conceptual drawing. The following equation defines the parameters of the Sediment Budget:

Copyright © 2005 New York Power Authority

Sources = Sinks

$S_{LE} + S_{BE} + S_{RD} + S_{WCC} = SS_D + SS_{RB} + SS_{LR} + SS_{WR} + SS_{LO}$

SOURCES:

- S_{LE} Sediment from Lake Erie
- S_{BE} River bank erosion
- S_{RD} River bed downcutting
- S_{WCC} Sediment from watersheds, canals and creeks

SEDIMENT SINKS:

- SS_D Dredging (and disposal outside of the river system)
- SS_{RB} Deposition on the River bed (and floodplain)
- SS_{LR} Lewiston Reservoir
- SS_{WR} Welland River
- SS_{LO} Lake Ontario

A balanced Sediment Budget will assist in identifying potential source areas for new sediment supplies to the river, and pathways for the transport of this sediment to the various sinks, such as the

Copyright © 2005 New York Power Authority

Niagara Bar. A second benefit of a balanced Sediment Budget, and possibly more important for the re-licensing effort, is the ability to quantify the importance of one source over another, such as the contribution from river bank erosion versus inputs from Lake Erie. Also, the sediment budget would assist in understanding interactions between sedimentation from one source (such as loadings from creeks) and an associated response, such as areas void of SAV and thus susceptible to bank erosion. Finally, the Sediment Budget could support an evaluation of the influence of natural versus U.S./Canadian power generation induced fluctuations in water levels and the associated impacts on erosion and sedimentation.

6.1 Sediment Sources

The four primary sources of material for the conceptual Sediment Budget are: sediment from Lake Erie, riverbank erosion, river bed downcutting, and inputs from watersheds (tributaries). Each of these sources is discussed in further detail in the following sections.

6.1.1 Sediment from Lake Erie

Suspended sediment and bed load from the shores of Lake Erie have the potential to contribute a significant percentage of the total sediment supply to the Niagara River, especially during storm events when silt and clay from the lake bottom are re-suspended and available for transport by currents. Surge events on Lake Erie, which will increase the head between the Peace Bridge and the Chippawa-Grass Island Pool, may also play a significant role on the quantity of suspended sediment delivered to the Niagara River from Lake Erie. The largest surge events at Buffalo are driven by westerly and southwesterly winds on Lake Erie and these events will also generate large waves that in turn re-suspend sediment from the lake bed or erode the lake shoreline. Surge events also result in larger flow into the Niagara River; therefore, when flows into the river from the lake are at their maximum, there is also potential for high sediment load. The term S_{LE} is used in the Sediment Budget equation and Figure 6.0-1 to denote inputs from Lake Erie.

The Niagara Power Project has no influence on the volume of suspended sediment delivered to the Niagara River from Lake Erie. However, changes in the levels of the Chippawa-Grass Island Pool,

Copyright © 2005 New York Power Authority

which alter the hydrologic conditions in the river, may influence the transport of the Lake Erie sediment through the system.

6.1.2 Bank Erosion

Bank erosion was documented at two principal locations in the upper Niagara River: Grand Island opposite Tonawanda Island, and Buckhorn Island east of the North Grand Island Bridge (refer to Section 5.1.1). The conceptual sketches of these two sites (Figures 5.1.1.1-1 and 5.1.1.2-1, respectively), document two well developed shallow platforms or shelves, leading to a steep eroding bank. This shore platform and bank has evolved over hundreds of years and formed in the weak lacustrine clay. Since the lacustrine clay was formed at the base of an ancestral lake that covered the region during the last glacial retreat, the material is primarily silt and clay. Once the riverbed and bank sediments are eroded by waves, the silt and clay are quickly suspended and transported downstream by the river currents. Bank erosion at both locations has the potential to contribute new material to the budget and sediment sinks. It was noted in Section 5.1.1 that one possible cause for the erosion at these sites is the absence of submerged aquatic vegetation and that the absence of vegetation may be related to high sediment loading from the creek mouths upstream of these two sites.

Since both sites feature a well-developed, wide shelf, they are susceptible to accelerated erosion during periods high river levels plus wave action. During low river levels, the majority of the wave energy is dissipated on the shelf and the bank does not erode. Therefore, the erosion rate at these locations and the generation of new material to the Niagara River Sediment Budget will be influenced by U.S./Canadian power generation to some extent. Whether the U.S./Canadian power generation has increased or decreased the long-term bank recession rates within the study area is unknown.

6.1.3 River Downcutting

The Side Scan Sonar recorded during the geophysical survey provided valuable data on the river substrate of the Tonawanda Channel, and consequently, the potential contribution of river downcutting to the total sediment load in the Niagara River. A sample of the Side Scan data is provided in Figure 6.1.3-1 in the vicinity of the South Grand Island Bridge. As discussed in Section 4.2.3, and the complete

Copyright © 2005 New York Power Authority

Geophysical Report in Appendix B, the strength of the backscatter was used to characterize the surficial characteristics of the riverbed. The soft sediments, such as silt and clay, absorb the signal and transmit a weaker signal giving the lighter tones. A strong signal indicates a harder surface, such as sand, gravel or exposures of bedrock. Submerged aquatic vegetation (SAV) provides a very "noisy" signal, which was common along the north branch of the Tonawanda Channel.

Figure 6.1.3-2 displays the "sediment" GIS layer available from URS Corporation. It provides about 50% coverage for the two branches of the river around Grand Island. Substrate types identified include bedrock, coarse gravel, gravel and sand. The results from the 2003 side scan sonar tracklines are also plotted on the map and shaded as polygons. There are a few discrepancies between the two datasets where overlap occurs:

1. West of Tonawanda Island, the side scan data mapped the substrate in the Federal Navigation Channel as silty sand, possibly sand and gravel. The "sediment" GIS layer identified this region as bedrock.

2. The bedrock classification continues downstream of Tonawanda Island to Cayuga Island. The side scan results recorded extensive and dense beds of submerged aquatic vegetation (SAV). Since the SAV cannot grow and survive on a bedrock river bed, these two findings conflict. One possibly explanation is a layer of unconsolidated sediments (silts and clays) located above the bedrock, which would suggest this area is an important sink for sediment on the river.

The general interpretation for the riverbed from the South Grand Island Bridge to Tonawanda Island is a sand-gravel bed with isolated exposures of bedrock at depths greater than 20 feet. At some point along the riverbanks, the geology reverts to glacial till, capped with lacustrine clay at the shoreline. It is interesting to note that, from the riverbanks to the 12 foot contour, the nearshore is covered in dense SAV. This region may correspond to the transition from bedrock to glacial till and lacustrine clay, since macrophytes cannot survive on a bedrock riverbed. Alternatively, it may simply represent the water clarity limit for survival of macrophytes (usually taken as twice the Secchi depth).

Copyright © 2005 New York Power Authority

Bathymetric data was also collected during the geophysical survey. A cross-section (Profile 2) of the Tonawanda Channel downstream of the South Grand Island Bridge is plotted in Figure 6.1.3-3. The cross-section is considered typical for this section of the river. The banks are steep and the majority of the profile is over 20 feet deep, with maximum depths of 30 feet. Based on this data and our knowledge of the local geology, this section of the river is likely stable, with the morphology controlled by bedrock in certain locations. Contributions of fine sediments, such as silt and clay, are likely minimal from this section of the river.

North of Tonawanda Island and the Turning Basin for the Federal Navigation Channel, the river cross-section changes significantly, as seen in Figure 6.1.3-4. The cross-section (Profile 11) shows a much wider river (almost twice the width) compared to the cross-section at the South Grand Island Bridge. Conversely, depths are significantly reduced to approximately 10 feet below Chart Datum, on average (compared to 20 ft for Profile 2). The morphology of the riverbed is also highly irregular in Profile 11 when compared against Profile 2. The irregularities are interpreted as dense SAV.

With the exception of the Federal Navigation Channel, the side scan recorded very dense SAV coverage for the entire north branch of the Tonawanda Channel. Since SAV can only grow in sand sized sediment or finer (usually silt and clay), these regions may feature a dynamic or mobile bed above glacial till or bedrock that changes with different flow regimes of the river. In other words, depending on the currents, fine sediment will either accumulate on the bed or be mobilized and transported down river. The navigation channel, which is clearly seen in Figure 6.1.3-4, features a sand and gravel bottom with exposures of bedrock and occasional patches of SAV based on the interpretation of the side scan data. Channels within channels, such as the condition at Profile 11 (i.e. the navigation channel), usually feature higher flow velocities than the adjacent shallow areas along the shore. This may explain the presence of the coarser sediment at the bed of the navigation channel through this reach, as any fine material is transported in suspension or as bed load. Therefore, with the exception of the Federal Navigation Channel, this segment of the river is likely both a sediment sink and source, depending on the flow conditions.

Copyright © 2005 New York Power Authority

6.1.4 Watersheds, Canals and Creeks

Watersheds in the Great Lakes contribute significant quantities of sediment (plus nutrients and contaminants) to the lakes and connecting channels, such as the Niagara River. Sediment volumes from watersheds can range from 50 to 250 tons per square mile of watershed, per year. The site-specific rate is related to soil type, land use (agricultural versus forest, for example), land cover, and topography. For the many creeks and canals that drain into the Niagara River, there are three main source types:

1. non-point source land based erosion from agricultural fields, construction sites and urban runoff,

2. point sources from storm water outfalls, sewer outfalls and industrial/institutional discharges, and

3. riverbank erosion and riverbed downcutting.

Of the three primary source types, only riverbank erosion and downcutting is potentially linked to U.S./Canadian power generation. As discussed in Section 5.3, the field observations from the fall of 2003 suggested that the majority of bank erosion in the tributaries is associated with high flow rates, possibly linked to the spring freshet and large rainfall event. Much of the Niagara River watershed is located within the Lake Erie "snow belt" region and annual precipitation rates are in the range of 36 inches per year.

It is likely that contributions from non-point sources contribute the majority of new sediment from the watersheds. Since non-point sources are not influenced by water level fluctuations, U.S./Canadian power generation is not anticipated to have an influence on this variable. Similarly, since bank erosion appears to be related to extreme flows, not daily water level fluctuations, it is also unaffected by U.S./Canadian power generation. Nevertheless, as noted in Section 5.1.1 non-point sources from creeks (such as Spicer and Woods Creeks on Grand Island) may have important influences on bank erosion areas immediately downstream of these creek mouths.

Copyright © 2005 New York Power Authority

6.2 Transport Pathways for Sediment

Generally, the sediment transport direction and pathway for the Niagara River, or any other river, is downstream. For the present investigation, transport pathways include the upper and lower Niagara River, connecting channels, rivers and creeks

There are five primary sediment sinks for the Niagara River Sediment Budget; dredging, deposition on the riverbed and floodplain, the twin intakes and the Lewiston Reservoir, the Welland River and Canadian reservoir, and the Niagara Bar. These individual sediment sinks will be discussed based on the findings from the fieldwork and other sources.

6.2.1 Dredging

When sediment is dredged from the Niagara River and connecting channels it is permanently lost from the system (providing it is deposited outside of the active river). The Buffalo District USACE was contacted about dredging practices for the Niagara River to collect any available data that would assist with formulating the conceptual Sediment Budget.

The following summary points are relevant for the dredging variable in the Sediment Budget:

1. Maintenance dredging is completed in the Black Rock Channel, which provides deep draft access for ships delivering oil and gas to local refineries. The bulk of this sediment is delivered from local tributaries, such as Scajaquada Creek, that drain in to the Black Rock Channel. The removal of this sediment will not affect the Niagara River Sediment Budget,

2. There has been no dredging of the Federal Navigation Channel, from the mouth of the Black Rock Channel to the NYPA Twin Intakes in the last 25 years, and

Copyright © 2005 New York Power Authority

3. There is very little barge and ship traffic downstream of the Erie Canal at Tonawanda Island.

Based on these findings, it appears that dredging is not currently an important sink for the Sediment Budget.

6.2.2 River Bed Deposition

Deposition of sediment on the riverbed and associated floodplain represents a potential sink for the Niagara River Sediment Budget. The interpretation of the side scan sonar identified two potential sediment sinks; the Turning Basin for the Federal Navigation Channel located immediately downdrift of Tonawanda Island, and the Intake Bay downstream of the North Grand Island Bridge. Figure 6.3.2-1 presents an enlarged view of the side scan data for the Turning Basin. Along the shallow west banks of the river, the nearshore is dominated by submerged aquatic vegetation. The lines that run parallel to the Federal Channel record a mixture of sand and soft sediments, such as silt and clay. The deep water associated with the Turning Basin and the junction of the Little River with the main channel will result in a depositional environment under certain flow conditions.

The side scan results for the Intake Bay are presented in Figure 6.3.2-2. The red line locates the 18 foot depth contour and clearly marks the transition from the shallow river bed dominated by submerged aquatic vegetation to the deep bay. The substrate in the bay has been interpreted as a mixture of soft sediments, sand and exposed bedrock. The results suggest that the Intake Bay is a possible sink for river sediments, which can then be transferred to the reservoir via the Twin Intakes.

River bed sedimentation was also observed at the mouth of Burnt Ship Creek, as seen in Figure 6.3.2-3, and described in Section 5.3.8. The present shoreline configuration at the north-west tip of Buckhorn Island, which may be influenced by the presence of the dykes, creates a depositional environment for sediment traveling downstream along the west side of Grand Island. The photograph also suggests that the northern tip of Buckhorn Island is a depositional zone, which would affect the sediment budget calculations for the river bed variable.

Copyright © 2005 New York Power Authority

6.2.3 Lewiston Reservoir

Deposition is occurring in the Lewiston Reservoir, via the NYPA Twin Intakes. This deposition has been documented in the report entitle "Extent of Sedimentation and Quality of Sediment in the Lewiston Reservoir and Forebay (ESI 2005). This is a sink for the Sediment Budget.

6.2.4 Welland River

The Welland River, located opposite the Twin Intakes at Chippawa on the Canadian shores of the river, was engineered to flow backwards and provide water for the Canadian Power Plant. Any suspended sediment or bed load lost to the Welland River is a potential sink for the Niagara River Sediment Budget. No data is available on the actual volume. U.S. power generation likely has little influence on this sediment sink.

6.2.5 Lake Ontario

The final sink for the Sediment Budget is a physical feature known as the Niagara Bar, which is located at the mouth of the river on the bed of Lake Ontario. This large depositional feature, which is really a submerged river delta, is clearly seen in Figure 6.3.5-1. As river currents interact with Lake Ontario they decrease at the mouth and fine sediment carried in suspension is deposited on the lakebed in the delta. The delta (and the river flow) also impedes longshore currents from the east and west, leading to additional deposition of sand and gravel from the littoral zone of Lake Ontario.

Changes in the flow in the Lower Niagara River related to U.S./Canadian power generation and the scenic Falls flow may affect the rate of sediment transport in the river and ultimately the volume of deposition in the Niagara Bar. For example, during low flows on the Lower Niagara River, sediment will settle to the riverbed until velocities increase due to higher flows.

Copyright © 2005 New York Power Authority

6.3 Summary of Sediment Sources, Transport Pathways and Sediment Sinks

The four primary source terms for the sediment budget were presented in Section 6.1 and summarized graphically in Figure 6.0-1. Based on the fieldwork and desk studies completed for this investigation, all four variables have the potential to contribute material to the Niagara River Sediment Budget.

Five sediment sinks were introduced in Section. 6.2. All the variables, with the exception of dredging (which does not presently occur), have the potential to represent important sink terms for the Sediment Budget calculations.

6.4 Power Generation Impacts on the Sediment Budget

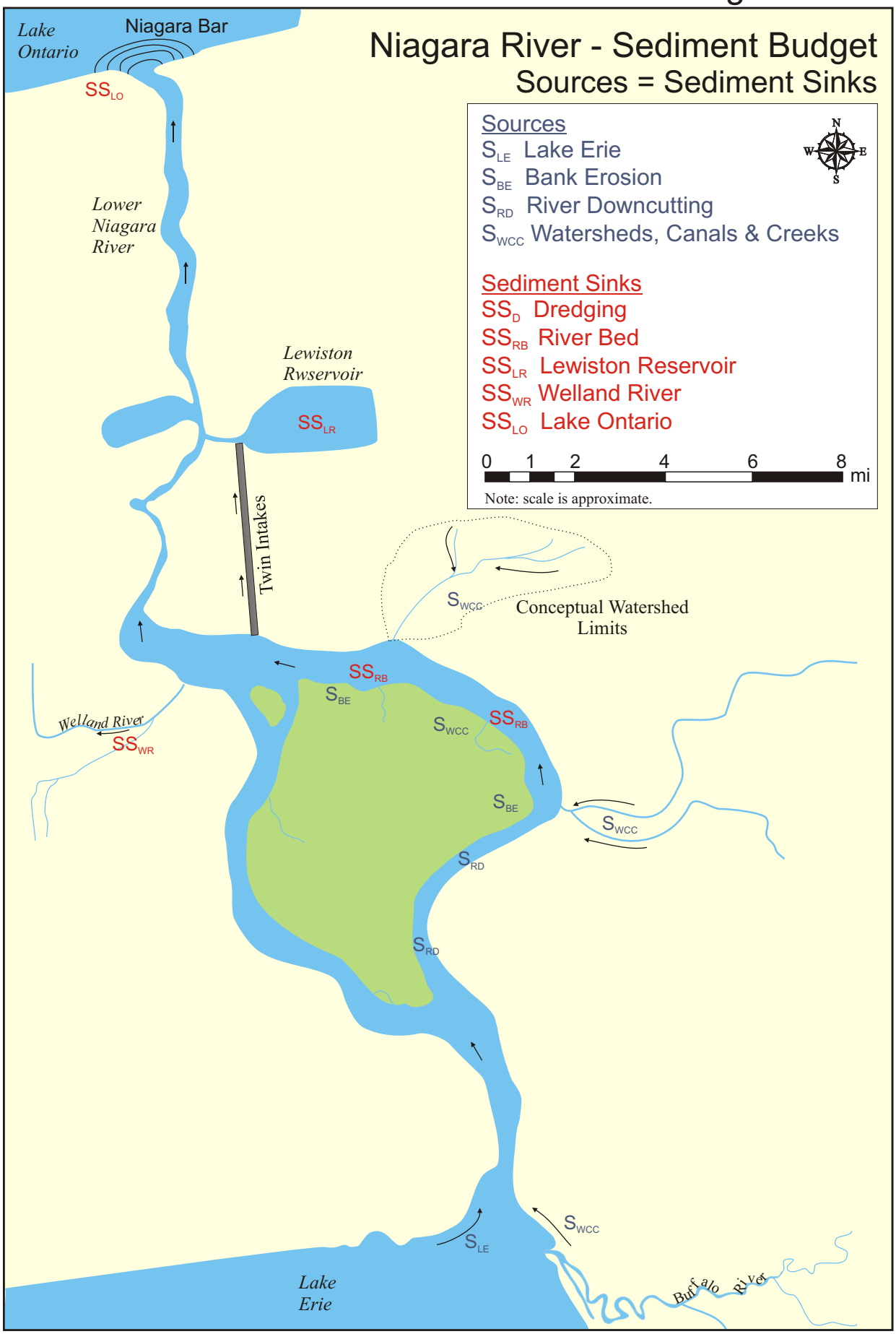
The objective of the conceptual sediment budget was to provide qualitative descriptions of the various sources and sinks. Therefore, it is beyond the scope of this study to present quantitative information on the impacts of U.S./Canadian power generation for the sediment sources, pathways and sinks. The daily and hourly fluctuations in the river hydrology and the associated impacts on water levels likely have some impact on the sources and sinks, such as bank recession and depositional patterns.

6.5 Future Sedimentation Rates in the Lewiston Reservoir

Although the results of the Sediment Budget are only conceptual, the identification of sediment sources and sinks is important to understanding the erosion and sedimentation processes on the Niagara River in a regional context. Based on our present knowledge of the sources, there is no indication that the rate of new material for the Sediment Budget will decrease. Without any change to the system (e.g. sediment loadings from creeks, protection of the eroding areas, or modifications to the intake bay and structures), it is likely that the sedimentation in the reservoir will continue at the historical rate.

Copyright © 2005 New York Power Authority

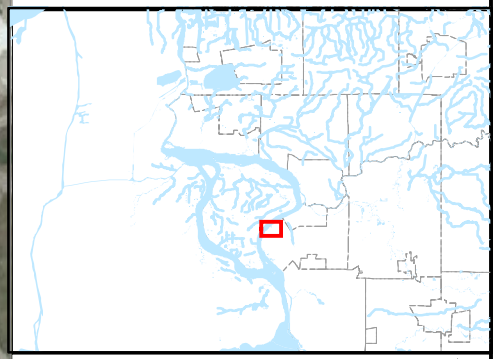
Figure 6.0-1


Niagara River - Sediment Budget
Sources = Sediment Sinks
Sources
S_{LE} Lake Erie
S_{BE} Bank Erosion
S_{RD} River Downcutting
S_{WCC} Watersheds, Canals & Creeks
Sediment Sinks
SS_D Dredging
SS_{RB} River Bed
SS_{LR} Lewiston Reservoir
SS_{WR} Welland River
SS_{LO} Lake Ontario
0 1 2 4 6 8 mi
Note: scale is approximate.
N
W
E
S
Lake Ontario
Niagara Bar
SS_{LO}
Lower Niagara River
Lewiston Rwservoir
SS_{LR}
Twin Intakes
S_{WCC}
Conceptual Watershed Limits
SS_{RB}
S_{BE}
Welland River
SS_{WR}
S_{WCC}
SS_{RB}
S_{BE}
S_{WCC}
S_{RD}
S_{RD}
S_{WCC}
S_{LE}
Lake Erie
Buffalo River

NIAGARA POWER PROJECT (FERC NO. 2216)
Determine the Effects of Project Operations on Shoreline Erosion\Sedimentation on the Niagara River (including tributaries)

Sample of Side-Scan Data
South Grand Island Bridge

Note:
Side Scan Sonar Collected
Oct. 16 & 17, 2003



N

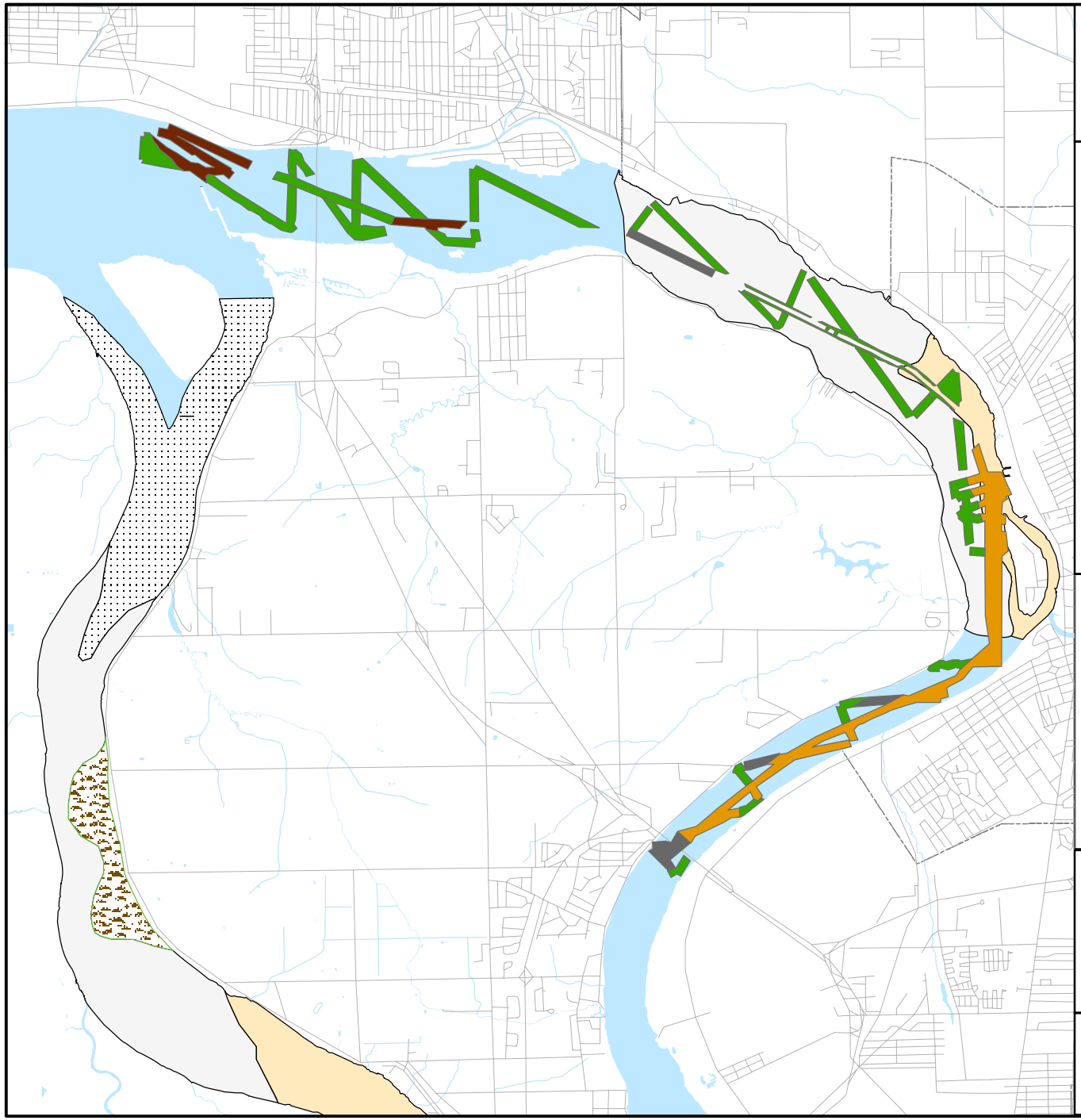
0 350 700 1,400 Feet

Figure 6.1.3-1

New York Power Authority

NIAGARA POWER PROJECT

Copyright © 2004 New York Power Authority



NIAGARA POWER PROJECT (FERC NO. 2216)
Determine the Effects of Project Operations on Shoreline Erosion\Sedimentation on the Niagara River (including tributaries)

Study Sediment Layer and 2003 Side-Scan Tracklines Upper Niagara River

LEGEND

2003 Side Scan Sonar

- Hard Bottom/Rocks
- Sand - Possible Rock
- Silty Sand (maybe sandy/gravel)
- Submerged Aquatic Vegetation

Published Data

- Bedrock
- Coarse Gravel
- Gravel
- Municipal Boundaries
- Water Bodies
- Roads

Note:
Summary of Side Scan Results
for Surficial Geology and "Sediment"

N

0 3,000 6,000 12,000 Feet

Figure 6.1.3-2

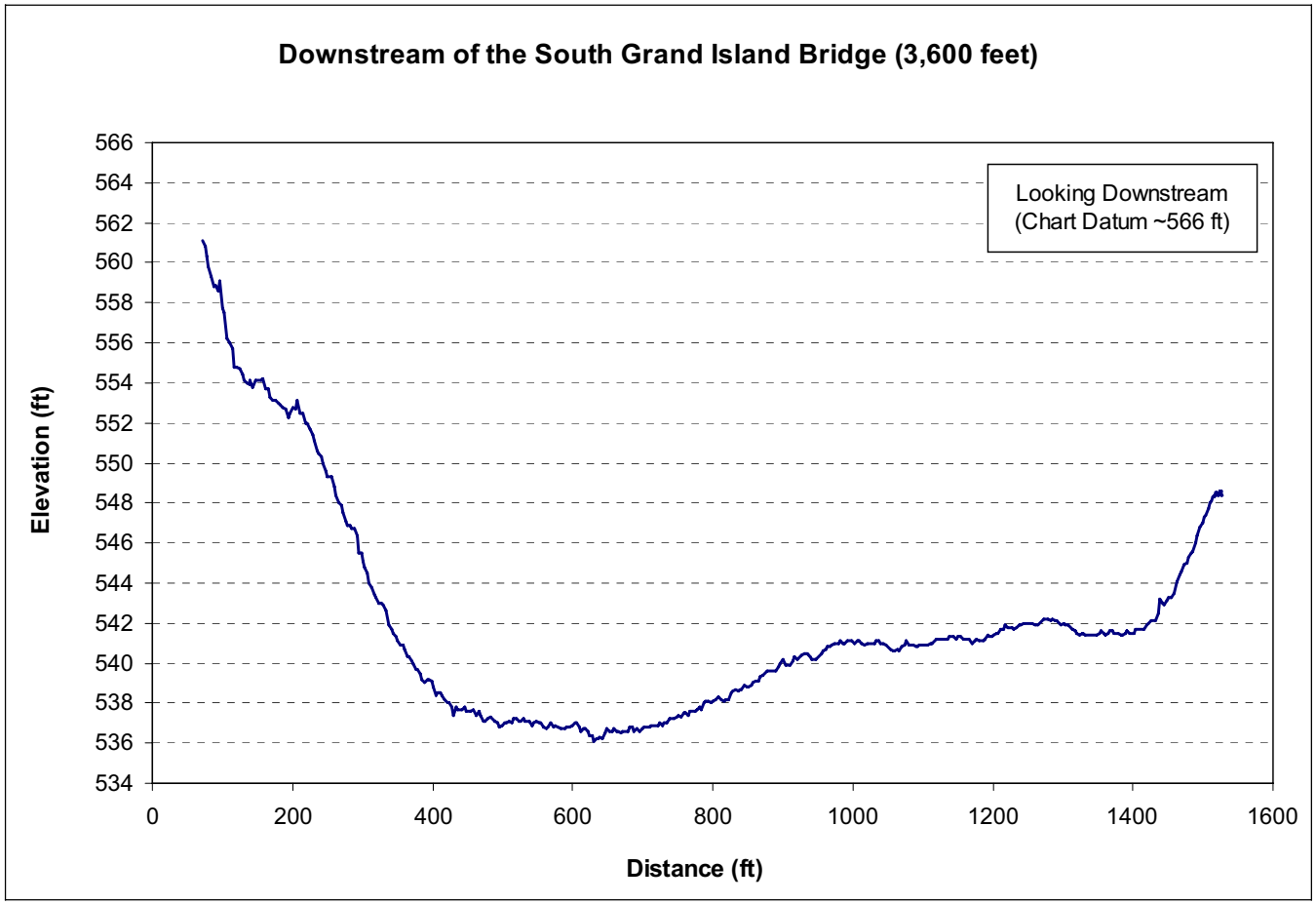
New York Power Authority

NIAGARA POWER PROJECT

Copyright © 2004 New York Power Authority

FIGURE 6.1.3-3

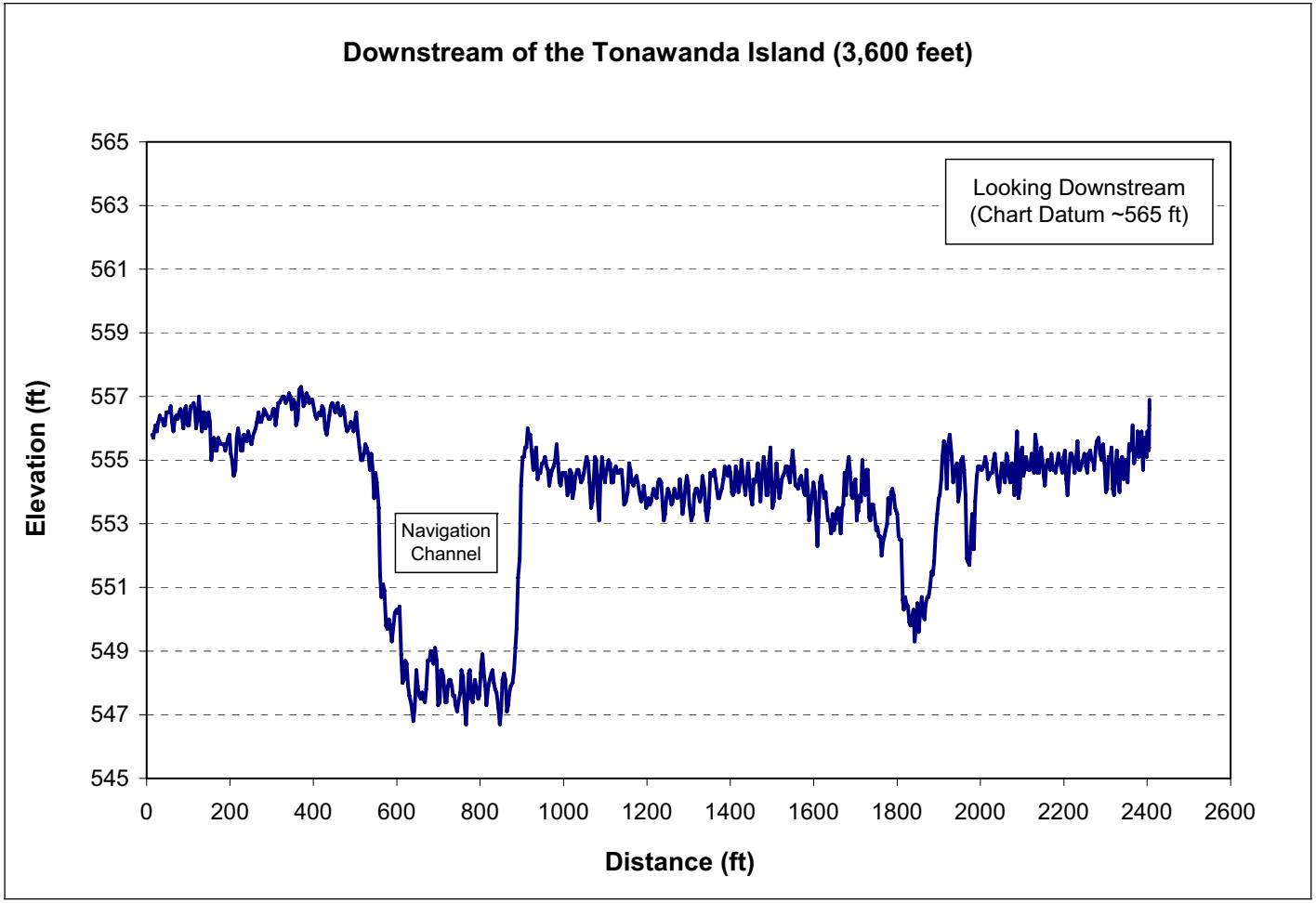
CROSS-SECTION OF THE TONAWANDA CHANNEL, PROFILE 2



Copyright © 2005 New York Power Authority

FIGURE 6.1.3-4

CROSS-SECTION OF THE TONAWANDA CHANNEL, PROFILE 11

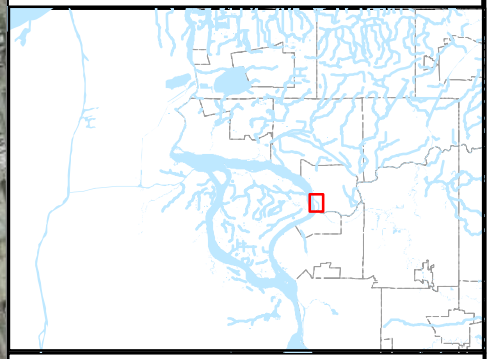


Copyright © 2005 New York Power Authority

NIAGARA POWER PROJECT (FERC NO. 2216)
Determine the Effects of Project Operations on Shoreline Erosion\Sedimentation on the Niagara River (including tributaries)

Side-Scan Image of Turning Basin Immediately Downdrift of Tonawanda Island

Note:
Side Scan Sonar Collected
Oct. 16 & 17, 2003



N

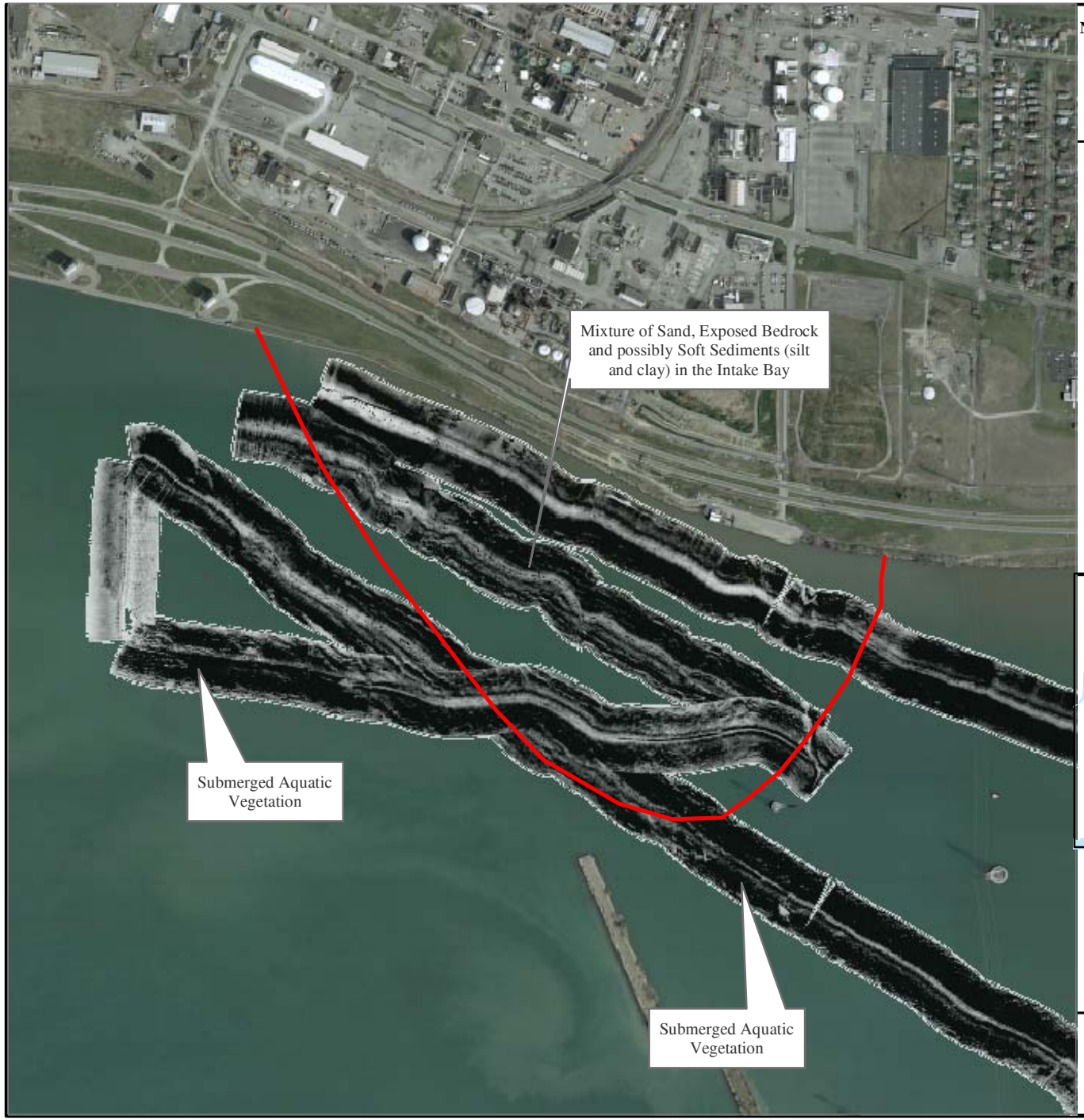
0 450 900 1,800 Feet

Figure 6.3.2-1

New York Power Authority

NIAGARA POWER PROJECT

Copyright © 2004 New York Power Authority



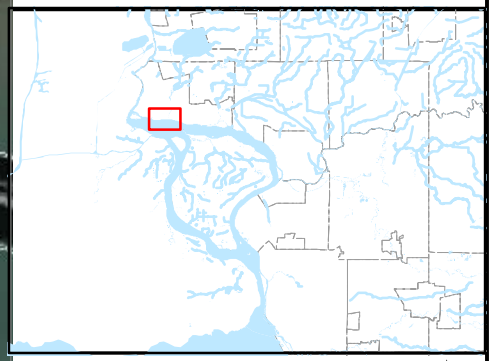
NIAGARA POWER PROJECT (FERC NO. 2216)
Determine the Effects of Project Operations on Shoreline Erosion\Sedimentation on the Niagara River (including tributaries)

Side-Scan Image of Intake Bay

LEGEND

Intake Bay

Note:
Side Scan Sonar Collected
Oct. 16 & 17, 2003



N

0 375 750 1,500 Feet

Figure 6.3.2-2

New York Power Authority

NIAGARA POWER PROJECT

Copyright © 2004 New York Power Authority

NIAGARA POWER PROJECT (FERC NO. 2216)
Determine the Effects of Project Operations on Shoreline Erosion
Sedimentation on the Niagara River (including tributaries)

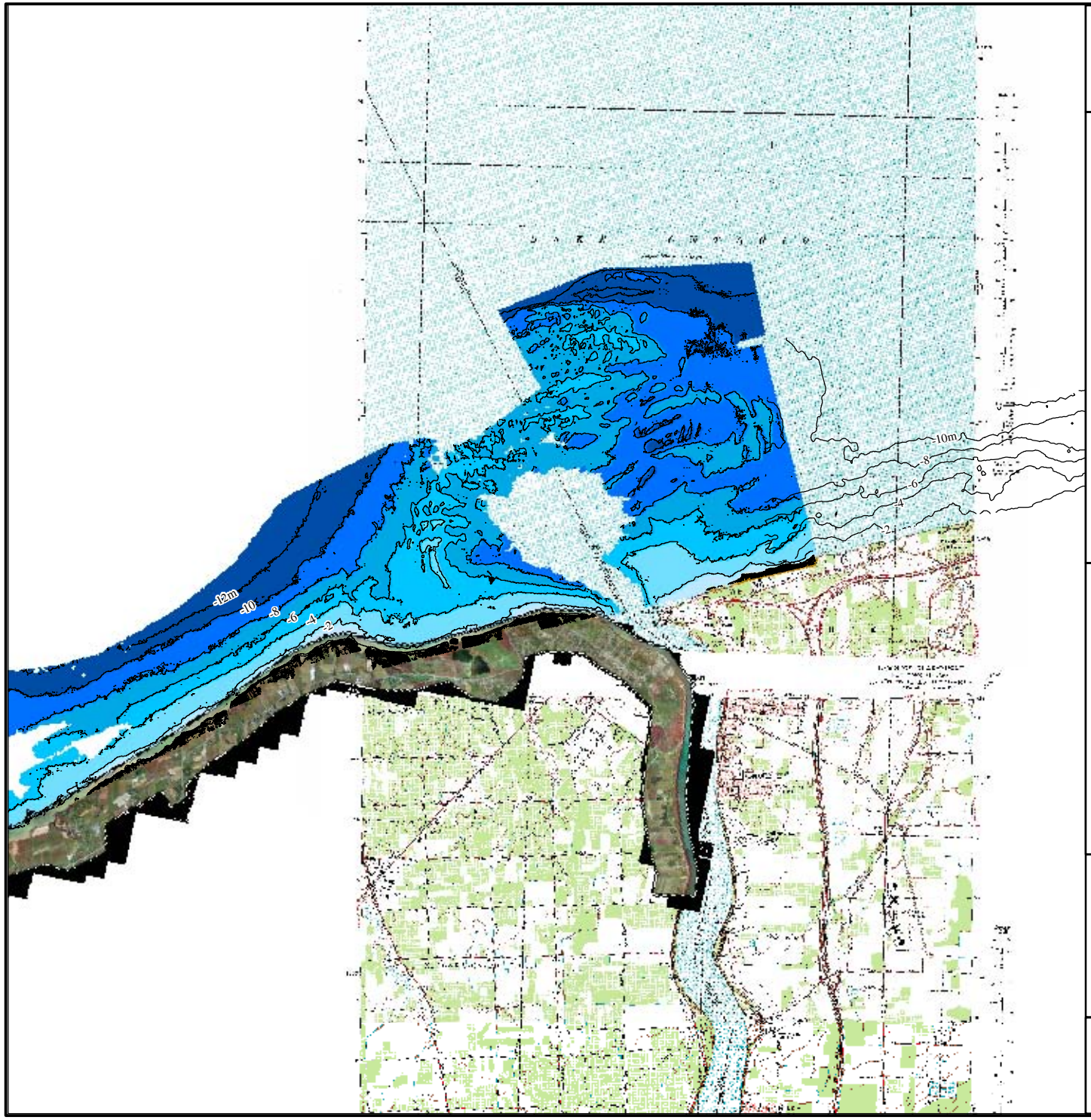
New York Power Authority

OBSERVED RIVER BED SEDIMENTATION AT THE NORTH-WEST TIP OF BUCKHORN ISLAND

NIAGARA POWER PROJECT

Figure 6.3.2-3

Copyright © 2004 New York Power Authority



LEGEND

2m Contours

DEM Classification

- Less than -10m
- -9.9 to -8.0
- -7.9 to -6.0
- -5.9 to -4.0
- -3.9 to -2.0
- -1.9 to 0
- 0 to 5.0
- Greater than 5m

(DEM = Digital Elevation Model)

Bathymetry Collected in 2001

N

Scale

0 2,750 5,500 11,000 Feet

New York Power Authority

NIAGARA POWER PROJECT

7.0 SUMMARY AND CONCLUSIONS

Sections 7.1 and 7.2 summarize our field observations and data collection on shoreline erosion, sedimentation, and shoreline protection structures on the upper and lower Niagara River and major tributaries.

7.1 Upper River

Only 3% of the upper river shoreline has been identified as actively eroding based on the field investigations associated with this U.S./Canadian power generation. Approximately 63% of the upper river shoreline within the Study Area is protected by some form of structure (i.e., steel sheet pile wall, rip rap, concrete block, etc.).

In most cases along the upper river, the eroding shore type is cohesive, consisting of low banks of lacustrine clay. Two of the three longest continuous erosion reaches, which are located on Grand Island, feature wide, shallow, nearshore shelves. The existence of a shelf with this cohesive shore type indicates that erosion will increase during periods of high water levels. One possible explanation for the two main erosion areas on Grand Island is linked to the absence of submerged aquatic vegetation (SAV) on the nearshore shelf that acts as an efficient natural dissipater of wave energy where it is present. The absence of SAV may in turn be related to locally high levels of turbidity associated with sediment loading from the two creeks (Spicer and Woods Creeks) that empty into the Niagara River just upstream of these sites. Some erosion areas along the Tonawanda Channel were observed to have a steep nearshore profile, a situation that is, however, more common along the lower river. Water level fluctuation implications for these steep profile conditions are summarized in Section 7.2. On the upper river, bank erosion is primarily driven by wind-generated waves on the main river and currents on the larger tributaries.

It was observed, that many of the shore protection structures that were deteriorating or not offering adequate protection did not appear to be adequately designed or constructed for the existing site conditions and range of water levels.

Copyright © 2005 New York Power Authority

Several long reaches of possible sedimentation zones were identified during the first Baird study. It is noted, however, that these evaluations were based only on observations of water depths, and on some consideration for possible river processes. A more refined definition of the sedimentation issues in the upper river was undertaken during the 2003 study. A sediment budget equation was developed for the primary sediment sources (i.e. suspended sediment from Lake Erie) and sinks, such as the bay for the Twin Intakes and the Niagara Bar at the mouth of the Niagara River. The conceptual framework developed for the Sediment Budget is a useful planning tool. For example, the results suggests that deposition rates along the river and in the reservoir will continue in the future at the historical rate.

7.1.1 Tributaries

As noted in Section 5.3, the tributaries by definition, are erosion features. That is, their very presence is due to erosion, which sustains their existence, and will continue to modify their morphology in the future.

Based on the field investigations within the Study Area, it was determined that a total of 4% of the creek banks are actively eroding. In addition, 16% of the total creek bank length is experiencing scarping, which is a common process in most creeks. Some form of structural protection exists in along approximately 40% of the total creek bank length within the Study Area. However, it should be noted that both Tonawanda Creek and Gill Creek heavily skew this protection total. Both of these creeks have protection along the majority of their lengths and they are two of the longest creeks draining into the Niagara River.

7.2 Lower River

Almost 14% of the lower river shoreline has been identified as actively eroding. Compared to the upper river, less of the lower river shoreline is protected (37% of the Study Area length). Erosion along the lower river is primarily driven by currents and wind-generated waves.

Copyright © 2005 New York Power Authority

The erosion areas on the lower river fall into two groups, based on the character of the cohesive shore: (1) Queenston Shale; and (2) partially consolidated red clay that appears to be a talus consisting of weathered Queenston Shale. In general, the nearshore slopes along the lower river are very steep, which tends to lower the sensitivity of this profile type to high water levels. These steep nearshore profile areas on both the upper and lower river, however, are still susceptible to erosion at high water levels.

The focus of detailed data collection for the sedimentation investigation in 2003 was the Upper Niagara River. Sediment source and sink terms were identified for the upper and lower river. A qualitative description of all variables in the Sediment Budget equation was provided.

Copyright © 2005 New York Power Authority

REFERENCES

Baird & Associates. 1997. Defensible Methods of Assessing Fish Habitat: a New Relationship between Macrophyte Coverage and Intensity of Wave Action. Canadian Manuscript Report of Fisheries and Aquatic Sciences, unpubl.

Baird & Associates. 1996b. Approach to the Physical Assessment of Developments Affecting Fish Habitat in the Great Lakes Nearshore Regions. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2352.

Baird & Associates. 1996a. Defensible Methods of Assessing Fish Habitat: Physical Habitat Assessment and Modeling of the Coastal Areas of the Lower Great Lakes. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2370.

Baird & Associates. 1994. Erosion Process Evaluation, Navy Island, Niagara River, prep. for Public Works Canada.

Baird & Associates. 2001. FEPS Development and Application to the LMPDS Prototype Counties, Final Report, Fiscal Year 2000, prep. for the U.S. Army Corps of Engineers.

Baird & Associates. 2002a. Lake Ontario and Upper St. Lawrence River Investigation, Phase I Final Report, prep. for the International Joint Commission.

Baird & Associates. 2002b. Effect of Operation of the International St. Lawrence Power Project on Shoreline Erosion below Moses Saunders Power Dam.

Baird & Associates. 2003a. Shoreline Erosion and Sedimentation Study Upstream and Downstream of the Power Project. Prep. for the New York Power Authority. Baird & Associates. 2003b. FEPS Modeling for the LMPDS, Final Report, Fiscal Years 2001/2002, prep. for the U.S. Army Corps

Copyright © 2005 New York Power Authority

of Engineers. Baird & Associates. 2003c. Demonstration of the FEPS at Elbow Harbour, Lake Diefenbaker, Saskatchewan.

Baird, W.F. 1973. Shore Erosion at Lanoraie, Quebec. Marine Engineering Design and Construction Branch. Department of Public Works, Ottawa.

Boyd, G.L. 1992. A Descriptive Model of Shoreline Development Showing Nearshore Control of Coastal Landform Change: Late Wisconsinan to Present, Lake Huron, Canada. Ph.D. thesis, Department of Geography, University of Waterloo, Ontario.

Davidson-Arnott, R.G.D. 1986. Rates of erosion of till in the nearshore zone. Earth Processes and Landforms 11:53-58.

Davidson-Arnott, R.G.D., and D.R.J. Langham. 2000. The effects of softening on nearshore erosion of a cohesive shoreline. Marine Geology. 166:145-62.

Environmental Standards, Inc. 2005. Extent of Sedimentation and Quality of Sediments in the Lewiston Reservoir and Forebay, prep. for the New York Power Authority.

Dean, R.G. 1977. Equilibrium Profiles, U.S. Atlantic and Gulf Coasts. Ocean Engineering Report, University of Delaware, no. 12.

Edil, T.B., and P.J. Bosscher. 1988. Lake shore erosion processes and control. In: Proceedings of the 19th Annual Conference of International Erosion Control Association, New Orleans.

Fuller, J.A. 2002. Bank recession and lakebed downcutting: response to changing water levels at Maumee Bay State Park, Ohio. J. Great Lakes Res. 28(3):352-61.

Copyright © 2005 New York Power Authority

Grabau, A.W. 1901. Guide to the Geology and Paleontology of Niagara Falls and Vicinity. In: New York State Museum Bulletin 45. Albany, NY: New York State Museum.

Hutchinson, J. 1986. Behavior of cohesive shores. In: Proceedings Symposium on Cohesive Shores, Keynote Paper, National Research Council Canada, Associate Committee on Shorelines.

International Joint Commission. 1993. Erosion Processes Task Group Report, International Great Lakes St. Lawrence River Water Level Reference Study.

Johnston, Richard H. 1964. Groundwater in the Niagara Falls Area, New York, with Emphasis on the Water-Bearing Characteristics of the Bedrock. Bulletin No. GW-53. Albany, NY: State of New York Conservation Dept., Water Resources Commission.

Kamphuis, J.W. 1987. Recession rate of glacial till bluffs. J. Waterway, Port, Coastal, Ocean Eng. 13(1):60-73.

Kamphuis, J.W. 1984. A Limited Desk Study on Shoreline Erosion Caused by Ship-Generated Waves. Public Works Canada, Ottawa.

Kindle, E.M. and F.B. Taylor. 1913. Geological Atlas of the United States, Niagara Folio. U.S. Geological Survey Folio 190.

Minns, C.K., J.D. Meisner, J.E. Moore, L.A. Greig, and R.G. Randall. 1995. Defensible Methods for Pre- and Post-Development Assessment of Fish Habitat in the Great Lakes. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2328.

Nairn, R.B., and H.N. Southgate. 1993. Deterministic profile modelling of nearshore processes, part II: sediment transport and beach profile development. Coastal Engineering Manual 19:57-96.

Copyright © 2005 New York Power Authority

Nairn, R.B., and W.F. Baird. 1992. Erosion Processes Evaluation Paper, International Great Lakes St. Lawrence River Water Level Reference Study.

New York Power Authority. 2002. First-Stage Consultation Report, vols. I and II, prep. by URS Corporation, Gomez and Sullivan Engineers, PC, E/PRO Engineering & Environmental Consulting, LLC, and Panamerican Consultants, Inc.

Ofuya, A.O. 1970. Shore Erosion: Ship and Wind Waves, St. Clair, Detroit and St. Lawrence Rivers. Marine Engineering Design Branch, Department of Public Works.

Ontario Ministry of Natural Resources. 1997. Technical Guides for Flooding, Erosion, and Dynamic Beaches in Support of Natural Hazards Policies 3.1 of the Provincial Policy Statement (1997) of the Planning Act.

Philpott, K.L. 1984. Comparison of cohesive coasts and beach coasts. In: Proceedings Coastal Engineering in Canada. ed. J.W. Kamphuis. Kingston, Ont.: Queen's University.

Riggs, S.R., W.J. Cleary, and S.W. Snyder. 1995. Influence of inherited geologic framework on barrier shoreface morphology and dynamics. Marine Geology 126(1/4):213-34.

Stantec Consulting Services, Inc., URS Corporation, Gomez and Sullivan Engineers, P.C., and E/PRO Engineering & Environmental Consulting, LLC. 2005. Effect of Water Level and Flow Fluctuations on Terrestrial and Aquatic Habitat, prep. for the New York Power Authority.

Sunamura. 1992. Geomorphology of Rocky Coasts. John Wiley and Sons.

URS Corporation, Gomez and Sullivan Engineers, P.C., and E/PRO Environmental & Engineering Consulting, LLC. 2005b. Niagara River Water Level and Flow Fluctuation Study, prep. for the New York Power Authority.

Copyright © 2005 New York Power Authority

URS Corporation, Gomez and Sullivan Engineers, P.C., and E/PRO Engineering & Environmental Consulting, LLC. 2005a. Upper Niagara River Tributary Backwater Study. Prep. for the New York Power Authority.

Copyright © 2005 New York Power Authority

APPENDICES

Copyright © 2005 New York Power Authority

APPENDIX A

GLOSSARY

Copyright © 2005 New York Power Authority

GLOSSARY

bank	a steep, almost vertical, cliffed section at the edge of a river or lake, generally less than 25 feet in elevation.
bioengineering	a term that refers to a broad range of techniques to reduce shoreline erosion and stabilize steep slopes with natural, non-structural techniques such as vegetation and slope re-grading.
bluff	a steep, almost vertical, cliffed section at the edge of a river or lake, generally greater than 25 feet in elevation.
cohesive (soil)	refers to sediments that were deposited during glacial periods and are generally heavily consolidated (compressed by glacial ice). When exposed to waves and currents in the nearshore zone and at the shoreline, the cohesive sediment is highly erodible. Once the fine particles from the cohesive material have been dispersed by wave action the sediment is not able to reconstitute its original properties; in other words, the erosion is irreversible.
consolidated (soil)	soil or sediment that is heavily compacted and has a high density (often related to glacial processes).
desiccation	the continuous cycle drying on an exposed bank face, which leads to weathering and erosion of the soil.
downcutting	the vertical erosion of the shoreline and nearshore zone by wave action and currents. Also called “downwasting”.
dynamic equilibrium	a profile or beach deposit that has reached a specific range (or envelope) of long term shapes in response to the local wave conditions and water level fluctuations.
equilibrium profile	a consistent profile morphology or shape for the lakebed and beach that develops when the system is in balance with erosion and deposition processes.

Copyright © 2005 New York Power Authority

falls and topples	mass movement of debris when soil separates into blocks and falls away from the parent slope due to undercutting of the slope and/or development of fissures (vertical cracks) in the soil.
headland	a large protrusion or promontory along the shoreline, often higher than the adjacent lands and associated with an abrupt change in the local geology, such as a bedrock outcrop, that erodes at differential rates than the neighboring shoreline.
lag deposit	a thick blanket of large cobbles and boulders that develops on the beach and in the nearshore zone when fine particles from the soil matrix are eroded or winnowed by wave action.
nearshore shelf	the shallow gently sloping portion of the lake or riverbed adjacent to the shoreline (generally from the shoreline to 5 feet of water depth).
nearshore zone	the shallow waters at the edge of a river or shoreline, extending to a depth of 10 feet.
perched water table	a saturated layer of soil that develops in a bank or soil horizon above the natural water table when an impermeable layer of soil blocks the downward migration of water.
profile	a side view or cross section (2 dimensional representation) of the land/river bed elevation and slope conditions, normally measured in a perpendicular direction to the general shoreline orientation.
rotational failure	the movement of a mass of soil downslope along a semi-circular concave face.
shoreline processes	the interaction of the driving physical forces at the interface of land and water, such as waves and currents, with the resisting forces (shoreline geology).
significant wave	average of the highest 1/3 of recorded wave heights.
slip plane	an internal bed or plane in a bank which facilitates the downslope movement of a mass of soil under wet or saturated conditions.
spreads and flows	the slumping or mass movement of debris down a slope that occurs for soils with high water content and/or high plasticity.
stratigraphy	the composition and depositional sequence of sediment and rock layers below the land and lakebed surface.

Copyright © 2005 New York Power Authority

sub-aerial	occurring on land or at the earth's surface (as opposed to under water or underground).
subaqueous	occurring below the surface of a water body.
tablelands	a plateau bounded by a steep bank, bluff or cliff.
talus	the collection of fallen disintegrated rock and soil material at the base of a slope.
till	non-sorted and non-stratified sediment of varying sizes (ranging from fine clays to large boulders) which is carried and deposited by glaciers.
toe	the major break in slope at the intersection of the back of the beach and the base of a natural bank, bluff or cliff face.
transgressive	a series of parallel or successive landforms (generally occurring on slopes) that develop over time in close proximity to each other.

Copyright © 2005 New York Power Authority

APPENDIX B

GEOPHYSICAL STUDY, SELECT AREA OF THE TONAWANDA CHANNEL

Copyright © 2005 New York Power Authority

MARINE SUBSURFACE INVESTIGATIONS
TONAWANDA SECTION – NIAGARA RIVER

Prepared for:

BAIRD & ASSOCIATES
627 Lyons Lane, suite 200
Oakville (Ontario)
L6J 5Z7

Prepared by:

GEOPHYSICS GPR INTERNATIONAL INC.
2545, rue Delorimier
Longueuil, (Quebec)
JP4 3P7

DECEMBER 2003 **T-03546**

Copyright © 2005 New York Power Authority

TABLE OF CONTENTS

1. INTRODUCTION ***1***

2. METHODOLOGY ***2***

2.1 Geodetic parameters & datums 2

2.2 Positioning 2

2.3 Geophysical Data Acquisition 3

2.3.1 Survey vessel 3

2.3.2 Bathymetry 3

2.3.3 Side-scan sonar 4

2.4 Data processing procedure 4

2.4.1 Bathymetric data processing 4

2.4.2 Side scan sonar data processing 5

3. RESULTS AND INTERPRETATION ***6***

3.1 Precision 6

3.1.1 Horizontal precision 6

3.1.2 Vertical precision 7

3.2 Bathymetry 7

3.3 Side-scan sonar 8

3.3.1 Underwater debris 10

4. SUMMARY ***13***

LIST OF TABLES

TABLE 1 – Example bathymetry profile data from the Excel file. 7

TABLE 2 – List of objects with significant height from riverbed 11

Copyright © 2005 New York Power Authority

LIST OF FIGURES

FIGURE 1 – Location map of the survey area ……..……...1
FIGURE 2 – Example bathymetric profile across the river ……..……...8
FIGURE 3 – Example raw side-scan record showing soft sediments ……...9
FIGURE 4 – Example raw side-scan record showing hard bottom ……..……10
FIGURE 5 – Example raw side-scan record showing aquatic vegetation ….……11
FIGURE 6 – Example raw side-scan record showing debris in shipping channel ….……...12

APPENDICES

APPENDIX A – Bathymetry sounding maps
APPENDIX B – Digital data files

Copyright © 2005 New York Power Authority

1. INTRODUCTION

Geophysics GPR International Inc. was commissioned by Baird & Associates in October 2003 to undertake subsurface surveys along the Tonawanda channel of the Niagara River, New York. The main aims of the survey were to provide data for use as part of an erosion and sedimentation study.

The data acquisition took place on the 16th and 17th October 2003. The instruments employed during the survey are as follows: a Differential Global Positioning System (DGPS) for positioning, a side-scan sonar system for riverbed characterization and a survey grade digital echo-sounder for bathymetry measurements.

The survey area was comprised of a series of lines crossing the river, as well as a line following the navigation channel in the center of the river. The line locations were provided by Baird. A general location map of the survey area can be seen in Figure 1.

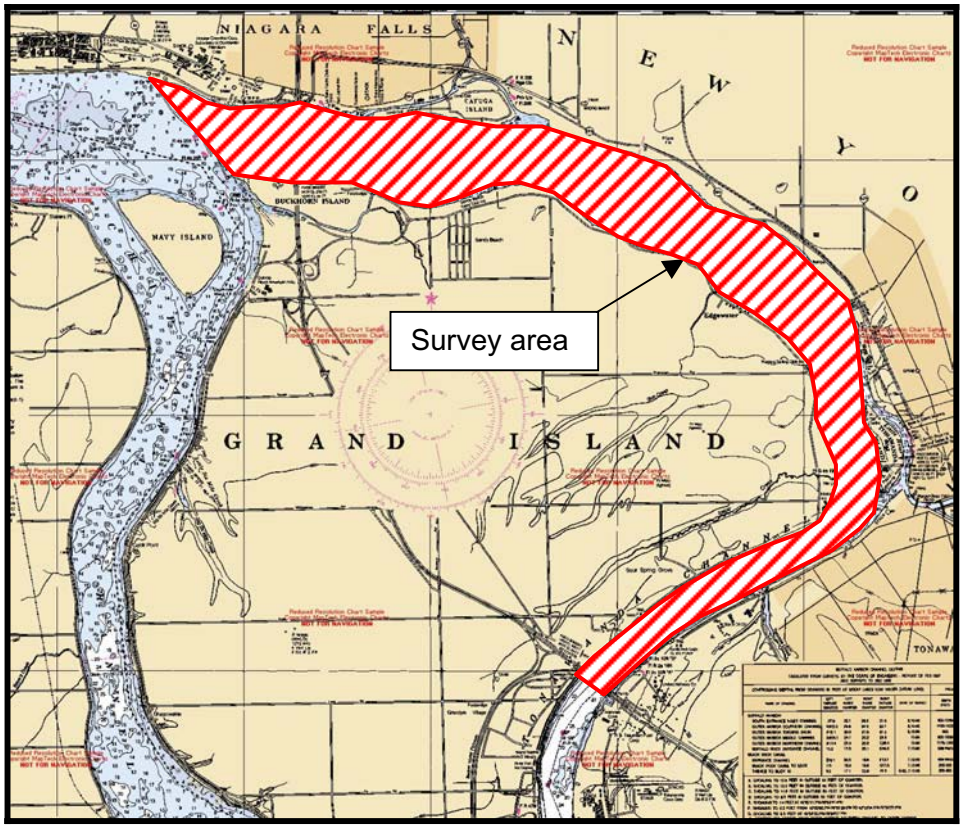


Figure 1 – General location map of the survey area

Copyright © 2005 New York Power Authority

2. METHODOLOGY

2.1 Geodetic parameters & datums

The navigation data was collected in Geodetic coordinates from the GPS system (Datum: WGS-84). These coordinates were converted in real time to the required grid coordinates, using the State-Plane (NAD-27) projection system (New York west). A standard datum transformation algorithm (NADCON) was used for the WGS-84 (GPS system) to NAD-27 shift.

The vertical datum reference for the survey was the US Great Lakes Survey from 1935 (USGLS-35).

The linear units of measure employed are US survey feet, unless specified otherwise.

2.2 Positioning

Dynamic positioning was carried out using a Trimble Series 4000 Differential Global Positioning System (DGPS). The reception of positional corrections from the US Coast Guard beacon enabled a horizontal accuracy of ± 6ft to be obtained. The reception of the correction signal was made by a Trimble Pro-beacon receiver linked to the GPS module on the survey vessel.

A laptop computer running the navigation software Hypack Max (from Coastal Oceanographics Inc.) was used on the survey vessel. The coordinates (Latitude/longitude) as measured by the DGPS system were read in real time and stored at the rate of one reading per second on the laptop's hard drive by Hypack Max. These coordinates were converted into Cartesian (X,Y) coordinates of the local grid used for surveying. The current vessel position relative to the local grid was displayed on the screen for use in positioning by the crew onboard. The side-scan system was fed with navigation data directly from the GPS system. This will be discussed in more detail for each instrument in Section 2.3. During acquisition, the data were geo-referenced (attached to the (X,Y) grid position in real time) and stored on hard-disk.

The various instrument offsets relative to the GPS antenna were noted in order to shift the coordinates to the sensor position.

Copyright © 2005 New York Power Authority

2.3 Geophysical Data Acquisition

The data acquisition took place on the 16th and 17th October 2003. During the surveying, 3 people were on board the survey vessel. The captain of the vessel was responsible for piloting the vessel as well as for its maintenance. The two geophysicists operated the various survey instruments on board.

2.3.1 Survey vessel

The marine data acquisition was carried out from a 26-foot aluminum work vessel, the "Dirt Water Kid", out of Fort Erie. The vessel was equipped with a single inboard diesel motor, capable of maintaining steerage and station keeping in shallow waters.

2.3.2 Bathymetry

Bathymetric measurements were carried out at all times during the course of the survey. The instrument used to acquire the data was a Reson Navisound 215 Digital echo-sounder attached to a standard beam transducer. The frequency used by the instrument was 200 kHz. The transducer was located at a position directly off the Starboard side of the vessel, 2 feet from the stern.

The fathometer provides asynchronous interfacing with data acquisition systems via a bi-directional RS-232 port. The instrument was linked to the navigation and data acquisition software Hypack Max via this port, allowing continuous logging and geo-referencing of the digital bathymetric data to the computer.

Calibration of the fathometer was carried out each day, using a standard bar-check technique.

Since the bathymetry and sonar surveys were carried out simultaneously, the vessel maneuverability was reduced (towfish considerations), and hence the track lines do deviate from the theoretical lines in places, particularly at the start and end of the lines. In addition, it was not always

Copyright © 2005 New York Power Authority

feasible to get in very close to the shoreline for the above reason.

2.3.3 Side-scan sonar

The side-scan sonar employs a sensor (towfish) towed behind the vessel underwater. The towfish emits an acoustic signal which is received and sent up the cable to a recorder on the vessel. The system used was a Klein 595, with digitization carried out real-time by a SonarWiz interface (from Chesapeake Technology Inc.). The acoustic frequency used by the side-scan unit was 500 kHz. The instrument ranges used were 37.5 and 50 meters on each side of the towfish, giving a total scan range of between 75 and 100 meters. This instrument scans only the subsurface (i.e. river bed) and does not penetrate it.

During data acquisition, the vessel speed was kept between 2 and 5 knots, while the towfish was kept at least 6 feet off the bottom where possible. The length of cable out was manually adjusted to obtain the required length.

The side-scan data was stored digitally by the SonarWiz system in the standard XTF binary format, which includes all relevant information regarding the survey, such as navigation, length of cable out, and other information required to process the files.

2.4 Data processing procedure

The data processing for the survey was carried out at the head-office of Geophysics GPR International Inc.

2.4.1 Bathymetric data processing

The raw bathymetric data files contain the local grid position, depth, time, and fix location stamp. The raw data files were exported from Hypack Max in ASCII format, ready for processing using proprietary software. Firstly, the depths were corrected for the draft and speed of sound if

Copyright © 2005 New York Power Authority

necessary.

Hourly water level information for the duration of the survey was provided by Baird for the relevant stations along the river, namely GN-Huntley, GN-Tonawanda, GN-Lasalle, and GN-Niagara river intake. The water level data are referenced to the USGLS-35 datum, in US survey feet. Water levels were seen to vary little over the survey period (less than 1 foot maximum).

For the purposes of the data processing, a model of the river water level could be created, based on the information from all the stations mentioned above. A program was written to calculate the water level at each minute and each location along the river, with respect to the USGLS-35 datum. This water level model could then be used to reduce the depth soundings to elevation relative to USGLS-35. The use of four water level stations in the data reduction should produce a relatively realistic set of transects with respect to datum, however, extensive surveying of the water levels along the river at intervals of 1km would be required in order to model the river profile accurately.

The processed files were merged into data files in ASCII format containing the reduced (XYZ) data points. The data was then checked and edited. The bathymetry lines that were run perpendicular to the river were used to create a series of vertical cross sections of the riverbed. Since the track lines were not exactly along the theoretical axes, there is some distortion in the profiles. A program was written to project the elevation values onto the axes and hence a projected chainage value could be associated with each elevation. The true vessel track data was kept with the projected data in an Excel file. Where the offset from the axes is too great (over 100 ft) no projected chainages are calculated.

2.4.2 Side scan sonar data processing

The raw side-scan sonar data consisted of a digital file in the standard XTF format. The software SonarWeb from Chesapeake Technology was used to process the XTF file into mosaic form.

Copyright © 2005 New York Power Authority

Before SonarWeb could be used, some pre-processing of the side-scan data was necessary, this included mainly smoothing the navigation associated with the sonar data, and correcting for the fact that the amount of cable out changed quite slowly with time. This was done using GPR's proprietary software, written especially for this purpose.

The XTF files could then be imported into the SonarWeb project. The survey zone was split into eight separate projects, due to file size limitations. The purpose of creating these projects was to produce final sonar mosaics at high resolution for display and analysis.

The main task was to track the return from the riverbed (bottom-track) along all the side-scan data. Bottom-tracking allowed the water column to be accurately measured and removed, to provide slant range corrected data. Once all the files in a project were accurately bottom-tracked, the mosaic could be generated using a set resolution and color scheme. The mosaics were produced at a resolution of 0,5 feet.

The corrected mosaics could then be exported in geotiff format. The geotiffs can subsequently be imported into a GIS package for analysis. These mosaics were also used to perform the surficial interpretation.

3. RESULTS AND INTERPRETATION

3.1 Precision

3.1.1 Horizontal precision

The intrinsic GPS positioning precision is +/-6 ft. The estimated error in the towfish position (layback plus lateral offset) was at least +/- 6 ft. The length of cable out was known, and the layback was calculated automatically by the processing software using a NOAA concatenation formula. The concatenation factor was assumed to be constant, although in reality it will vary according to many factors. In addition, unpredictable yawing of the towfish will introduce errors in the projected beam positions, which could become significant at the outer sections of the swath.

Copyright © 2005 New York Power Authority

3.1.2 Vertical precision

The river bottom elevation precision is estimated to be in the order of +/- 1 ft. This takes into account the precision of the echo-sounder, the vessel draft error, the heave effect of waves. This error estimate assumes that there is no error in the water level correction (see Section 2.4.1 for more details on reduction to datum).

3.2 Bathymetry

The main product of the bathymetry is an ASCII XYZ file containing the position, depth, elevation and water level for each sounding (see Appendix B for a sample). Two file were produced, one for each day of surveying. On average, there is one sounding per three feet of linear distance covered. The second product was an Excel file containing a total of 15 profiles across the river (see Table 1 for format of the file).

EASTING X (ft)	NORTHING Y (ft)	PROJECTED chainage (ft)	ELEVATION USGLS-35 (ft)	OFFSET FROM AXIS ft	VESSEL TRACK chainage (ft)
416918.2	1104359.8	2.2	551.9	-17.86	2.20
416922.1	1104359.3	6.1	551.9	-18.30	6.13
416926.2	1104358.9	10.2	552.0	-18.63	10.25
416929.3	1104358.6	13.3	551.9	-18.87	13.37
416932.3	1104358.3	16.3	551.9	-19.12	16.38
416935.8	1104358.1	19.8	551.7	-19.26	19.89
416938.8	1104357.9	22.8	551.9	-19.41	22.89
416941.9	1104357.7	25.9	552.4	-19.56	26.00
416945.1	1104357.7	29.1	552.1	-19.50	29.20
416948.3	1104357.6	32.3	552.2	-19.55	32.40
416951.5	1104357.6	35.5	552.0	-19.49	35.60
416954.8	1104357.6	38.8	552.1	-19.44	38.90
416958.3	1104357.7	42.3	552.4	-19.28	42.40
416961.5	1104357.9	45.5	552.0	-19.02	45.61
416964.7	1104358.1	48.7	552.0	-18.77	48.82
416968.4	1104358.2	52.4	552.1	-18.60	52.52
416971.5	1104358.3	55.5	551.7	-18.45	55.62

Table 1 – Example profile data from the Excel file

The profiles are plotted with respect to a chainage system based on the start and ends of the theoretical lines. Both projected chainage and vessel track (actual) chainage are provided. An example profile is shown in Figure 2.

Copyright © 2005 New York Power Authority

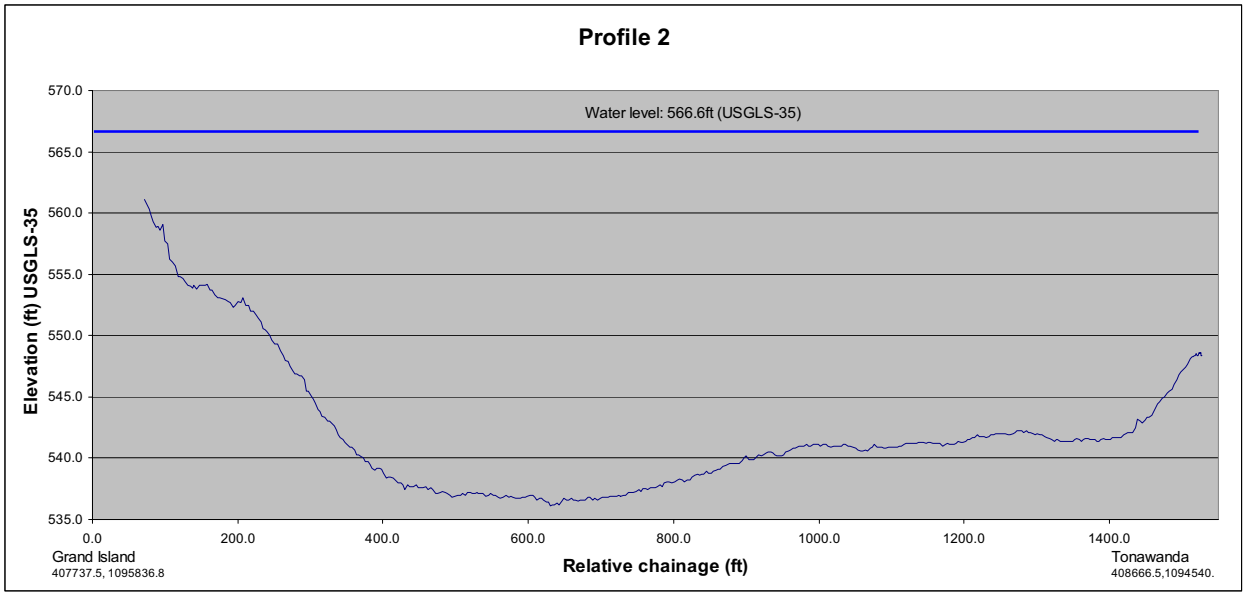


Figure 2 – Example riverbed profile

In addition the elevation soundings were plotted on a plan view showing the shoreline of the river, in order to provide a general overview of the results. The resulting two maps were produced at a scale of 1:2,000 (1" = 166.66 ft.). Due to the scale of the drawings, only points spaced at around 100 ft intervals could be plotted to ensure legibility. These maps are intended as a general overview only (see Appendix A for an image of the drawings).

The bathymetry lines in the southern half of the survey area show a clean, relatively flat profile, indicating a sandy / silty bottom, except near the shores. In the northern half, however, the profile is irregular, probably indicating the presence of aquatic vegetation on the riverbed.

3.3 Side-scan sonar

The side-scan backscatter strength can be used as a general means for carrying out a surficial interpretation of the riverbed. Weaker backscatter strength indicates softer sediments (silt and clay) that absorb the signal, strong backscatter indicates a harder surface such as sand or rock outcrop. The shallow water environment in the northern part of the area meant that the mosaics from this area are noisier and hence difficult to interpret due to the geometry of the system.

Copyright © 2005 New York Power Authority

The surficial composition of the riverbed along the navigation channel and in the deeper sections is interpreted as being mostly of sand. A patchy texture was detected in the channel from coordinates (411246E, 1113134N) continuing to the northwest. This could possibly be caused by partially exposed flat bedrock in the channel. In the northern half of the survey area, significant quantities of what is interpreted as aquatic vegetation are seen. This is confirmed by the bathymetry data. The side-scan mosaics were used to delineate the different surficial components, and the results are provided as an Arc-View shape file and database, or as a CAD DXF file, both of which are geo-referenced vector products. Examples from the raw side-scan records showing the different types of river bottom encountered can be seen in Figures 3 – 5.

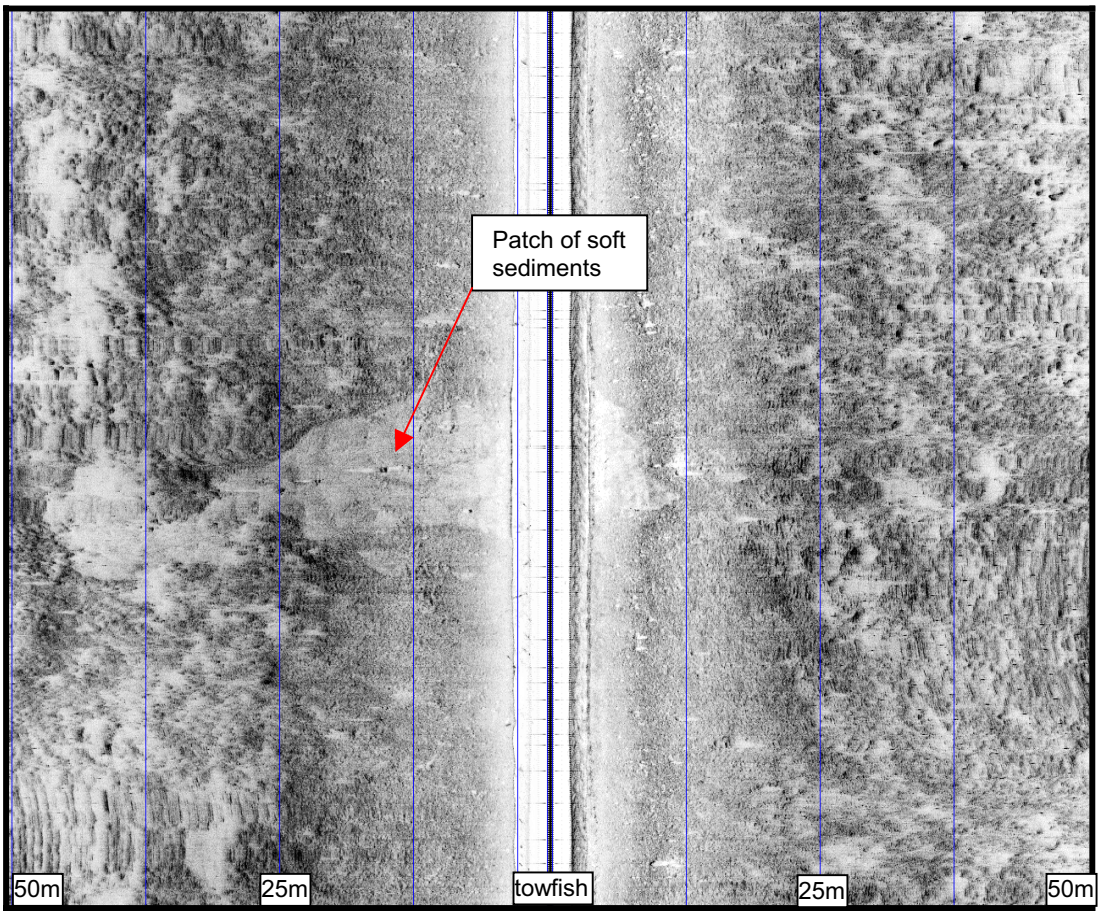


Figure 3 – Example side-scan record from the shipping channel (soft sediments)

Copyright © 2005 New York Power Authority

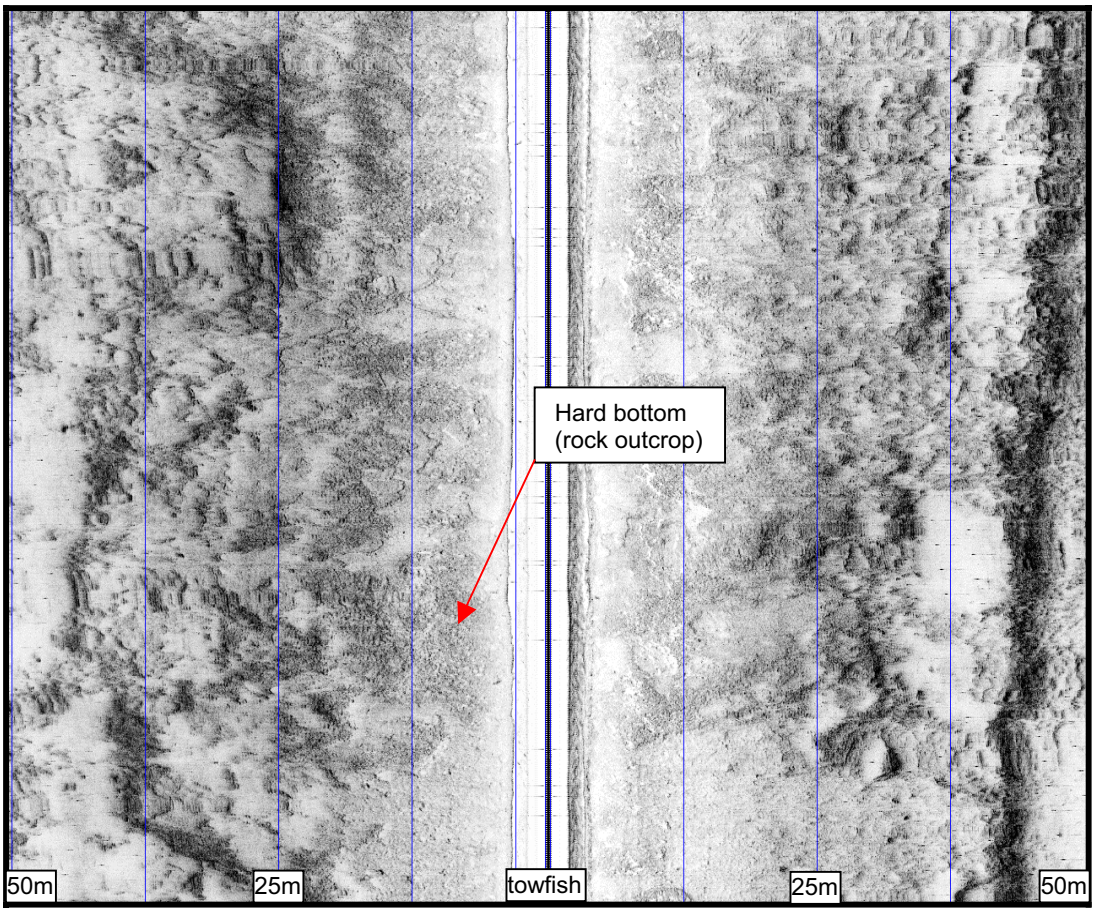


Figure 4 – Example side-scan record from the shipping channel (hard bottom)

It should be noted that this interpretation remains subjective without ground truthing information regarding the true nature of the riverbed (from grab sampling / borehole data, etc.).

3.3.1 Underwater debris

A significant quantity of objects assumed to be man-made debris were identified from the side-scan mosaics. These objects are easily identified since they are often out of place in the regional context, and they cast linear acoustic shadows. Debris was found as discrete items or concentrated in areas. Most of the debris is to be found near piers or wharves and in the shipping channel. These items are classified and can be examined by looking at the shape files or the CAD file.

The exact nature of these objects is not known, but the objects of linear nature are probably logs or trees carried by the river. Several objects

Copyright © 2005 New York Power Authority

were identified in the shipping channel or turning basin that have a significant height from the riverbed (see Table 2).

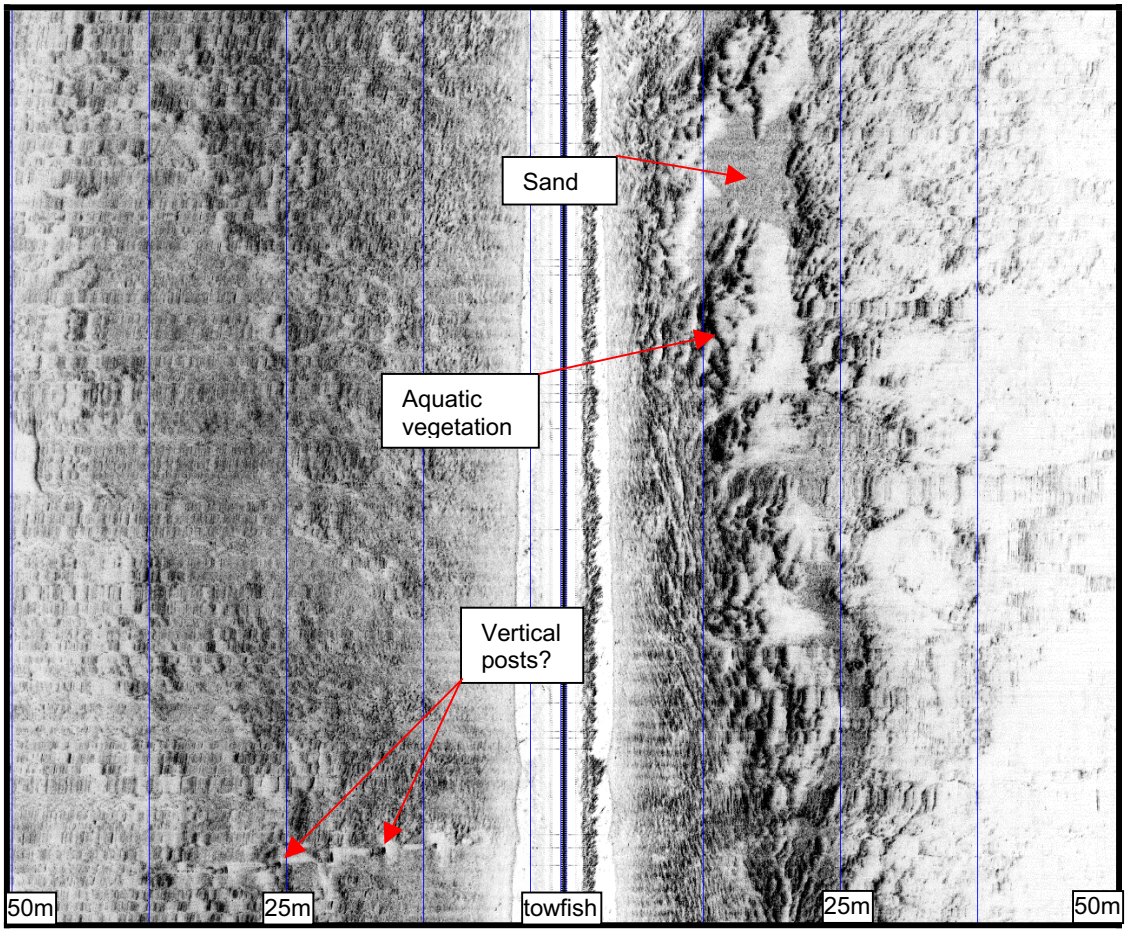


Figure 5 – Example side-scan record from the northern section of the river (weeds)

An example from the raw side-scan data showing some items of debris is shown in Figure 6.

No.	Object height (ft)	Easting (ft)	Northing (ft)
1	8	385620	1120623
2	5	398641	1117089
3	4	390322	1118790

Table 2 – Coordinates of debris with significant height off the riverbed

Copyright © 2005 New York Power Authority

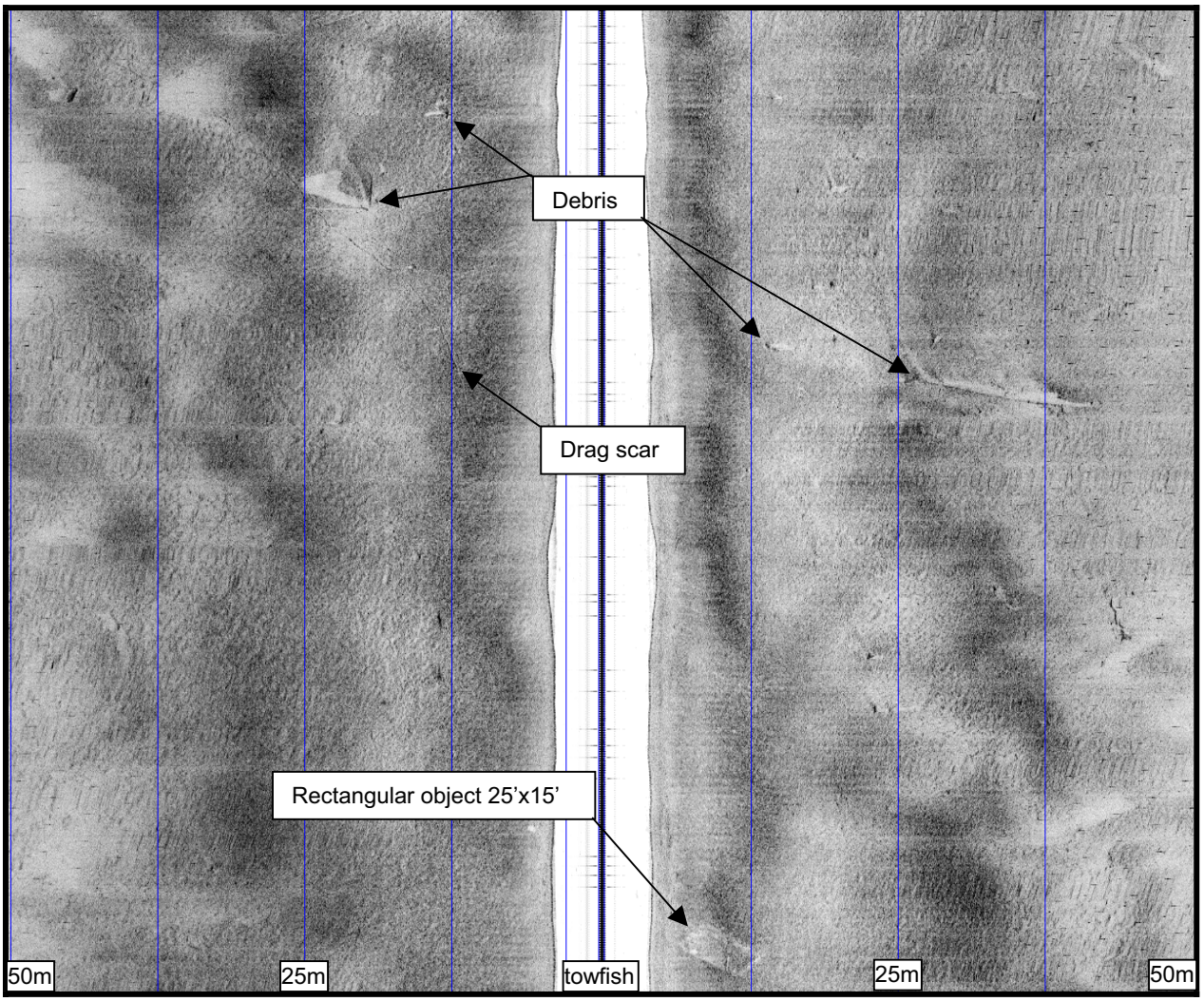


Figure 6 – Example side-scan record showing debris is the shipping channel

Copyright © 2005 New York Power Authority

4. SUMMARY

Bathymetry and side-scan surveys were conducted in the Tonawanda section of the Niagara River for use as part of a larger study of the evolution of the river over time. The surveys were conducted on the 16th and 17th October 2003. Data processing and interpretation was carried out by GPR at the head office.

The side-scan sonar survey was carried in conjunction with the bathymetric survey. All data were acquired and geo-referenced with the aid of a DGPS system capable of receiving differential corrections from a US Coast Guard beacon. The data were stored on the hard disk of a laptop computer by means of the navigation software Hypack Max, from Coastal Oceanographics Inc. A SonarWiz digitizing system was used to record the side-scan data onto computer hard drive in XTF format.

The results of these surveys enabled high resolution sonar mosaics to be produced showing information on the riverbed along the theoretical lines provided by the client. These mosaics were used to produce a surficial interpretation of the riverbed. The bathymetry along the theoretical lines was also provided. The results of the study are provided in digital form, either as geo-referenced raster images (geotiff) for the mosaics, or as ASCII XYZ & Excel data for the bathymetry (see Appendix B for samples). In addition the bathymetry soundings were plotted on two A0 size drawings for general reference (see Appendix A for an image of the drawings).

Based on side-scan sonar backscatter characterization, the navigation channel is interpreted as having a surficial composition mostly of sand, with some possible rock outcrops in the area north of Tonawanda Island. In the northern half of the area, in the shallower waters, significant quantities of what is interpreted as aquatic vegetation were identified. A significant number of objects interpreted to be man-made debris were identified from the sonar mosaics, including three objects of significant height in the shipping channel.

Copyright © 2005 New York Power Authority

This report was written by Gary Moody, geophysicist and approved by Réjean Paul, P. Eng. geophysicist.

_____
Gary Moody, M.Sc. Geoph.
Project manager

_____
Réjean Paul, P. Eng. Geoph.
President

Copyright © 2005 New York Power Authority

APPENDIX A

PLAN VIEW MAPS

Copyright © 2005 New York Power Authority

APPENDIX B

DIGITAL DATA FILES

Copyright © 2005 New York Power Authority

x(ft)	y(ft)	elev.	depth	water level (all units in feet)
405355.7	1091620.5	543.48	22.40	565.88
405353.6	1091617.8	543.68	22.20	565.88
405351.3	1091614.8	543.78	22.10	565.88
405349.2	1091612.6	543.78	22.10	565.88
405346.8	1091610.2	543.88	22.00	565.88
405344.5	1091608.2	543.98	21.90	565.88
405341.9	1091606.4	544.08	21.80	565.88
405338.8	1091604.8	544.08	21.80	565.88
405335.9	1091603.5	543.98	21.90	565.88
405332.8	1091602.6	543.88	22.00	565.88
405329.7	1091602.0	543.78	22.10	565.88
405326.5	1091601.7	543.68	22.20	565.88
405323.2	1091601.7	543.38	22.50	565.88
405319.4	1091601.9	543.08	22.80	565.88
405316.2	1091602.3	542.88	23.00	565.88
405313.2	1091603.0	542.38	23.50	565.88
405310.1	1091603.8	541.98	23.90	565.88
405306.9	1091604.7	541.78	24.10	565.88
405303.7	1091605.8	541.38	24.50	565.88
405300.5	1091607.1	540.78	25.10	565.88
405297.3	1091608.5	540.18	25.70	565.88
405294.1	1091609.9	539.78	26.10	565.88
405290.6	1091611.5	539.49	26.40	565.89
405287.4	1091613.1	538.79	27.10	565.89
405284.5	1091614.6	538.49	27.40	565.89
405281.9	1091616.1	538.09	27.80	565.89
405279.3	1091617.6	537.89	28.00	565.89
405276.7	1091619.1	537.79	28.10	565.89
405274.0	1091620.7	537.69	28.20	565.89
405270.9	1091622.7	537.19	28.70	565.89
405268.2	1091624.7	536.89	29.00	565.89
405265.4	1091626.9	536.59	29.30	565.89
405263.0	1091628.8	536.49	29.40	565.89
405260.5	1091630.9	536.59	29.30	565.89
405257.8	1091633.8	536.69	29.20	565.89
405255.7	1091636.0	536.89	29.00	565.89
405253.2	1091638.8	537.29	28.60	565.89
405251.1	1091641.0	537.59	28.30	565.89
405250.2	1091642.2	537.59	28.30	565.89
405247.8	1091645.1	537.79	28.10	565.89
405245.8	1091647.5	537.19	28.70	565.89
405243.8	1091649.9	537.79	28.10	565.89
405241.8	1091652.4	537.99	27.90	565.89
405239.8	1091654.9	537.09	28.80	565.89
405237.9	1091657.4	537.09	28.80	565.89
405236.1	1091659.8	537.19	28.70	565.89
405234.3	1091662.4	537.09	28.80	565.89
405232.1	1091665.5	537.39	28.50	565.89
405230.3	1091668.3	537.69	28.20	565.89
405228.4	1091671.1	538.39	27.50	565.89
405226.7	1091673.9	539.09	26.80	565.89
405224.9	1091676.7	540.09	25.80	565.89
405223.2	1091679.5	541.39	24.50	565.89
405221.5	1091682.3	542.18	23.70	565.88

Copyright © 2005 New York Power Authority

x(ft)	y(ft)	elev.	depth	water level (all units in feet)
404594.4	1092038.4	541.61	24.30	565.91
404596.0	1092041.5	541.91	24.00	565.91
404599.4	1092048.4	541.91	24.00	565.91
404601.0	1092051.6	541.61	24.30	565.91
404602.6	1092054.8	541.31	24.60	565.91
404604.0	1092057.7	541.21	24.70	565.91
404605.4	1092060.4	540.71	25.20	565.91
404606.8	1092063.1	540.81	25.10	565.91
404608.9	1092067.2	540.91	25.00	565.91
404610.4	1092070.0	540.41	25.50	565.91
404611.8	1092072.8	540.61	25.30	565.91
404613.3	1092075.6	541.21	24.70	565.91
404614.9	1092078.3	541.51	24.40	565.91
404616.4	1092081.0	541.81	24.10	565.91
404618.0	1092083.8	541.61	24.30	565.91
404620.1	1092087.2	541.11	24.80	565.91
404621.9	1092090.1	540.61	25.30	565.91
404624.6	1092094.1	540.41	25.50	565.91
404627.1	1092097.5	540.81	25.10	565.91
404629.5	1092100.8	540.81	25.10	565.91
404632.0	1092104.2	540.51	25.40	565.91
404634.4	1092107.5	540.71	25.20	565.91
404636.6	1092110.5	540.41	25.50	565.91
404638.9	1092113.6	540.51	25.40	565.91
404641.2	1092116.7	540.61	25.30	565.91
404643.0	1092119.1	540.61	25.30	565.91
404644.9	1092121.5	540.41	25.50	565.91
404646.7	1092124.0	540.31	25.60	565.91
404648.6	1092126.4	540.41	25.50	565.91
404650.6	1092128.8	540.41	25.50	565.91
404652.5	1092131.3	540.61	25.30	565.91
404654.4	1092133.7	540.61	25.30	565.91
404657.1	1092136.8	540.41	25.50	565.91
404659.8	1092139.9	540.21	25.70	565.91
404662.5	1092143.0	540.51	25.40	565.91
404665.3	1092146.2	540.61	25.30	565.91
404668.0	1092149.3	540.71	25.20	565.91
404670.2	1092151.7	540.91	25.00	565.91
404672.6	1092154.4	541.51	24.40	565.91
404674.7	1092156.8	542.01	23.90	565.91
404676.8	1092159.0	542.11	23.80	565.91
404679.5	1092161.9	541.71	24.20	565.91
404681.6	1092164.1	541.51	24.40	565.91
404684.2	1092166.6	541.21	24.70	565.91
404687.4	1092169.4	541.51	24.40	565.91
404690.5	1092172.2	541.91	24.00	565.91
404693.7	1092175.0	542.31	23.60	565.91
404696.8	1092177.8	542.11	23.80	565.91
404699.5	1092180.2	542.11	23.80	565.91
404701.8	1092182.2	541.91	24.00	565.91
404704.9	1092184.8	541.91	24.00	565.91
404708.0	1092187.4	542.01	23.90	565.91
404711.1	1092189.9	542.01	23.90	565.91
404713.5	1092191.7	542.01	23.90	565.91

Copyright © 2005 New York Power Authority