FROG ISLAND DESIGN REPORT

DRAFT

Niagara Power Project (FERC No. 2216)

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NEW YORK POWER AUTHORITY

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ACRONYM LIST

ac	-	acres
ASOS	-	Automated Surface Observation System
cfs	-	cubic feet per second
CGIP	-	Chippewa Grass Island Pool
cms	-	cubic meters per second
Ct	-	Coefficient of Transmission
El.	-	elevation, in feet, per U.S. Lake Surface 1935 (USLS 35) vertical datum
ESC	-	Ecological Standing Committee
FERC	-	Federal Energy Regulatory Commission
ft	-	feet
ft/s	-	feet per second
GPS	-	global positioning system
HIP	-	Habitat Improvement Project
lb/ft	-	pounds per linear foot
lbs/ft^2	-	pounds per square foot
mph	-	miles per hour
NOAA	-	National Oceanic and Atmospheric Administration
NWL	-	normal water level
NYPA	-	New York Power Authority
NYSDOT	-	New York State Department of Transportation
NYSOPRHP	-	New York State Office of Parks, Restoration, and Historic Preservation
SAV	-	submerged aquatic vegetation
USACE	-	U.S. Army Corps of Engineers
USGS	-	U.S. Geological Survey
USLS 35	-	U.S. Lake Surface 1935 vertical datum, in feet (USLS 35 = IGLD 1985 + 1.20 feet)
WSEL	-	Water Surface Elevation

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EXECUTIVE SUMMARY

The New York Power Authority (NYPA) is designing a habitat improvement project in the Upper Niagara River as a result of the relicensing of the Niagara Power Project. The Frog Island Habitat Improvement Project (HIP) is a shallow, roughly 5-acre area that is currently devoid of vegetation. Located in the shallows between Motor and Strawberry Islands, this HIP involves the creation of emergent wetland and submerged aquatic vegetation (SAV) habitat in a portion of the river that at one time supported wetlands.

This report has been prepared to summarize existing knowledge of the Frog Island area, which will help establish reference conditions from which to base subsequent designs upon, and to present engineering analyses, approaches, and data for the development of the Frog Island Habitat Improvement Project. The design of Frog Island is still in the early stages and additional information obtained in the future, or different design approaches/goals, may affect the information contained in this document. All elevations in this report are in the U.S. Lake Surface Datum 1935 (USLS 35) vertical datum.

History of Frog Island

Human activities in this part of the river have alternated between periods of extensive dredge spoil disposal (1815-1910) and gravel mining (1912-1953) activities, which have quite substantially altered the shape, size, and number of islands in this complex. Historical maps prior to 1870 do not indicate a feature at the location of Frog Island, although mapping standards and accuracy at that time may have precluded documenting small islands or wetland areas in the middle of the river. Frog Island reached its largest size around 1938, with an area of approximately 4 acres. By 1951, the island's area was greatly reduced, and by 1985, it is no longer visible in aerial photographs. Much of Frog Island's more recent reduction in size appears to be directly related to the changing Lake Erie water levels and corresponding Niagara River flows. In 1986, U.S. Army Corps of Engineers (USACE) data indicates that both water levels and average flows had reached their historical peak. As a result of sustained high flows, wave action, and overtopping, potentially including ice action at different levels, Frog Island likely experienced significant erosion.

Review of Existing Habitats

A review of 12 nearby established habitats was conducted to help formulate design criteria that could be used as guidelines to create new habitat. This includes effects due to water levels, ice loading, wave action, wind, water quality, sunlight, etc. Several key trends were identified, including 1.) established emergent wetland habitat is only located in well protected areas and low energy environments, 2.) SAV may establish in higher energy areas, but needs to be protected from ice scour, and wave action (*i.e.* sufficient depth), and 3.) areas of shorter fetch / greater protection are able to support healthy SAV and emergent habitats.

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Design Requirements and Objectives

A number of specific objectives for the Frog Island HIP were identified through a series of collaborative discussions with the Ecological Standing Committee (ESC) and its members and these have been used to shape the design and approaches to the HIP. In summary, these objectives are to:

- Create a HIP that meets NYPA's responsibilities under the FERC license for the Niagara Power Project and Settlement Agreement
- Be cost effective, maximizing total area improved with the available funds
- Balance the need for long-term structural integrity (i.e., a robust design), natural variability in habitat (i.e., seasonal changes and/or gradual transition over time), and aesthetics
- Create both submergent habitat (approx. 2-6 ft deep) and deep emergent wetland habitat (approx. 2 ft deep)
- Enhance habitat diversity, minimize adverse affects on nearby habitats or sensitive species, and minimize the establishment of non-native, invasive vegetation and woody vegetation

Engineering Design

The Frog Island area is subjected to a number of wind, wave, ice, and water level forces that need to be considered in any design scenario.

A local wind analysis shows that the highest average and peak hourly winds come from the southwest (225 degrees); however, high winds typically occur in a slightly broader range at an angle of 220 to 250 degrees relative to the Frog Island area. These directions correspond to the broadest fetch for the Frog Island area, a distance of approximately 1.25 miles, and could influence the formation of wind-driven waves. Additionally, estimates based on local wind records indicate that the highest typical and peak wind speeds one could expect to see over a 50-year period are 50 mph and 60 mph, respectively. Wind speeds over a 1-year period were only slightly lower, at 43 mph for typical speeds and at 54 mph for peak gusts.

A wave condition analysis indicates that dominant wave-approach fetch to the Frog Island area is 1.25-miles wide and consists of deeper water extending from the Canadian shore that gets shallower as the waves approach the Frog Island area. Using the wind, fetch, and depth data, a series of wave-height sensitivity analyses indicate that mean wave heights, measured from trough to crest, reach up to 2.6 ft under peak wind gust speeds of 60 mph. Since this is a total wave height, actual distance above a still water elevation is half the height, which would equate to 1.3 ft above the water surface elevation and does not include wave runup height.

Using this information, evaluation of wave runup and transmission across breakwaters, was used to help define the dimensions needed for two different breakwater options, a low-crested approach that is wider but less prominent and a high-crested approach that was narrower and more robust. The analysis indicates that low-crested breakwaters would need a reef breadth

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of approximately 30 feet, with a crest at approximately El. 567.0 ft in order to protect leeward areas from waves and ice loading over a range of water levels. This type of low-crested breakwater would need to be located on the western side of the HIP to limit wave energy generated by the long fetch. Additional protection against ice loading on the head of the island could be addressed with larger boulders. For the high-crested breakwater, wave runup heights of approximately 3.0 to 4.5 feet were estimated, which would require a breakwater crest elevation of El. 569.5 ft to El. 571.0 ft to prevent overtopping at normal pool.

Based on previous water level analysis (NYPA, 2005), normal water level (50% exceedence) is El. 566.5 ft, but there are minor daily, seasonal, and also long-term fluctuations. Storm surges have resulted in an historic high water level of El. 570.3 ft, representing a 4-foot increase over normal water surface elevations at the proposed Frog Island. Historical water levels and flows in the river were noted in the mid-1930s and mid-1960s, with the highest flows observed from approximately 1970 to the mid-1980s. Current water levels are somewhat lower, and are close to the long-term average level. Water levels have changed over time, and future changes would likely affect the design of the new Frog Island HIP. To accommodate changes in water levels, the designs should not rely solely upon specific, contemporary, elevations in anticipation of static water levels. Rather, designs should utilize features that would allow vegetation to respond over time to changes in water levels.

Computer modeling was used to help identify and evaluate potential hydraulic affects associated with the proposed instream habitat modifications. Analysis was performed using preliminary designs for the Frog Island HIP and was coordinated with Dr. Hung Tao Shen of Clarkson University, Potsdam, NY, using his 2-dimensional DynaRICE model. The results of nine scenarios, for both the existing and proposed conditions, indicate that there is little to no impact on the open water levels due to the construction of the Frog Island HIP. The model was also used to predict the potential for ice jamming in the river, as well as the effect of ice loading on the HIP. The model indicated that the construction of the HIP at the Frog Island site is not likely to increase the probability that an ice jam would form in this part of the Niagara River. The Ice model results also show that ice thickness under high-wind conditions may reach 2-3 feet at the upstream head and southeastern edge of the proposed Frog Island, which would result in ice loading forces of 47 pounds per linear foot for compressive force during peak storm events, and 75 pounds per square foot of shear stress. The potential for ice runup was evaluated, and under these conditions, there is less than half the force needed to push ice over a breakwater at normal water levels; to have ice overtopping would require a minimum of approximately 100-200 lb/ft of force on a sloped embankment.

Soil borings and shallow test pits indicate that the soil profile at the project location is generally described as silty sand, or sandy silt with trace gravel, with very little organic and clay materials. Placement of foundation and breakwater materials, as well as the redistribution of sediment to create habitat features, has the potential to compress and displace water from within the underling riverine substrate material. Considering that substrate in the “bare spot” location may have been compressed by previously placed fill material (subsequently removed during gravel mining activities), no more than 1-foot of settlement is expected with the HIP, largely during construction, and will be accounted for in the design. Rock filled marine mattress

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systems may be used to establish the breakwater foundations, with larger stones placed on top of these mats.

In order to create and maintain the desired deep emergent and SAV habitat, the outside edges of the improvement area will need to be protected with breakwaters. The structures need to be designed to help prevent wave action and reduce ice damage and scour, yet allow water to flow through to the interior habitat to enable the dynamic exchange of water and nutrients. The western side of the HIP would be subjected to the greatest forces from wind and wave conditions while the head of the island would be subjected to the greatest ice loading forces. Regardless of either high or low-crest approach, the breakwaters (both inside and outside faces) will need to be layered with armor stone to protect the smaller-diameter stone making up the core of the breakwater. This stone armor needs to have a mean diameter of 15-18 inches to protect against both wave and ice action.

Surveys of wetlands were completed at a number of locations along the Upper Niagara River in 2007 to help identify reference wetland conditions for the HIPs. These surveys were then used to develop recommended elevation ranges and planting zones for vegetation community types at Frog, Motor, and Strawberry Islands (NYPA. 2009). Recommended elevation ranges were developed for wet meadow (≥ El. 566.2 ft), shallow emergent (El. 565.2-566.2 ft), deep emergent (El. 564.0-565.2 ft), and SAV (≤El. 564.0 ft) habitat, of which, the latter two habitat types will be emphasized in the Frog Island HIP. The data used to develop these elevation ranges and planting zones are based on relatively current, and observed, water levels, however there are long-term fluctuations in water levels that could result in a shift in plant zone elevations as the plant communities respond to different “wetness” conditions. Therefore, to minimize the effects of such shifts, designs should incorporate sloped transition zones, rather than specific elevations for a single habitat type.

Risk Analysis

The Frog Island area is located in a dynamic river environment, which is subject to rapid and dramatic changes to water levels due to storm surges on Lake Erie, as well as long-term changes in both flow and water levels. There are two hazards associated with wave action at the proposed Frog Island: 1.) damage to the exterior rock armor from unit movements and dislocations, either from wave runup, or rundown, and 2.) overtopping waves plunging into the island interior, disrupting habitat, damaging sensitive wetland soils, or damaging SAV. The crest of the high-breakwaters would be approximately El. 569.0 ft, which will likely be overtopped by still-water levels on an annual basis. The crest of the low-breakwaters would be approximately El. 567.0 ft, with the crest about 0.5 ft above normal pool elevation and the breadth of the breakwater approximately 30-feet wide to achieve comparable protection to the higher breakwaters. Under high-water conditions for both approaches, where waves are more likely to enter the protected interior, the depths over the interior habitat will also be greater, which help to reduce damaging wave action since they would be less likely to contact the bottom features.

The ice model results show significant buildup of ice on the leading upstream edges of islands, including the proposed Frog Island, as ice movement is driven more by currents than

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wind and wave action. Ice thickness may reach 2 to 3 feet, and currents may push ice into the island interior if the breakwater is not of sufficient height.

The islands, shorelines, wetlands, and SAV habitat in the Upper Niagara are dynamic and have dramatically changed over time with regard to their footprints and biological and physical characteristics. These changes are in response to a disturbance regime that involves both natural and anthropogenic forces. The current design approaches should try to reproduce the function of naturally occurring reference conditions, which can be accomplished through the use of "hard" features such as rock breakwaters and geotechnical mattresses, combined with "softer" sloped vegetative surfaces to enable transitions in plant communities. These techniques should be supplemented with aggressive planting plans to speed initial establishment and stabilization of the site.

To be sustainable, the HIP will be required and expected to be able to respond to both seasonal variability and changes in long-term trends. To this end, we expect that forces such as ice, water levels, and waves will result in year-to-year changes in the vegetative community, with some subtle and some more dramatic. Such year-to-year changes are part of the HIP's design criteria, and are even desirable in as much as they mimic both the temporal and spatial habitat diversity found in nature.

Conclusions

Improving new habitat at the proposed Frog Island requires detailed civil engineering design, involved ecological assessments, hydrologic and hydraulic engineering, and a bit of art, all working in concert together. Several different approaches are available to try to create the objective habitats, but regardless of approach, the HIP needs to address significant risk issues, achieve the set goals, be sustainable, not require excessive maintenance, and be constructible without damaging existing habitats. The information and approaches outlined in this report will be used to develop appropriate designs that will give the riverine wetland complex the best chances of successful initial establishment.

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1.0 INTRODUCTION

The New York Power Authority (NYPA) is in the process of completing a series of habitat improvement projects in the Upper Niagara River, which are required in concert with the relicensing of the Niagara Power Project by the Federal Energy Regulatory Commission (FERC). One of the habitat projects is the re-creation and establishment of emergent marsh and submerged aquatic vegetation (SAV) habitat between the existing Motor and Strawberry Islands. This area, heretofore referred to as Frog Island, is currently a shallow shoal that is devoid of emergent vegetation or SAV, and is located within the larger Strawberry Island – Motor Island Shallows, an area designated by the NY Department of State as a Significant Coastal Fish and Wildlife Habitat (Figure 1). Improvements could include building the substrate up in a portion of this area, stabilizing and protecting the project from wave and ice action, and promoting the growth of emergent vegetation and SAV.

The goals of this design report are twofold. First, the report will summarize existing knowledge of the Frog Island area, which will provide insight into the environmental forces and human activities that have shaped this part of the river, as well as provide information on historical conditions that may be used as a template or reference conditions for the habitat improvement effort. Second, the report will summarize engineering analyses, approaches, and data for the development of the Frog Island Habitat Improvement Project (HIP). This report will outline various approaches and document the process used to arrive at certain conclusions. The design of Frog Island is still in the early stages and additional information obtained in the future, or different design approaches/goals, may affect the information contained in this document.

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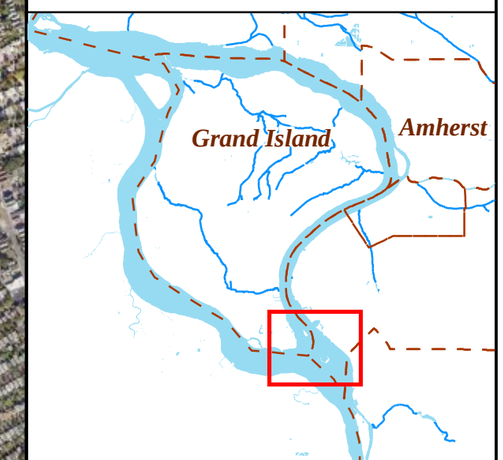
Figure 1

Frog Island
Habitat Improvement Project

Proposed Project Location

Niagara River
Erie County, NY

N



Feet
0 250 500 1,000

1 inch = 1,000 feet

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2.0 HISTORY OF FROG ISLAND

The following represents what appears to be the best available information concerning the history and morphology of Frog Island in the Upper Niagara River, a small shoal area that was formerly an island located in the Tonawanda Channel between Strawberry Island and Motor Island in Erie County, NY. As noted by EDI (1998), the formation of the modern Niagara River channel began after the final retreat of the Last Wisconsin ice sheet, and at this time Strawberry Island was formed when sediments were deposited in this part of the river. The formation/creation of this complex of islands that includes Frog Island and its history is not exhaustively documented, but the following narrative, and Table 1, summarizes what is currently known. Supporting maps and aerial photographs are located in Appendix A.

Human activities in this part of the river have alternated between periods of extensive dredge spoil disposal (1815-1910) and gravel mining (1912-1953), which have substantially altered the shape, size, and number of islands in this complex. Names of the islands have also changed over time, and we have used those shown on the U.S. Geological Survey (USGS) 7.5-minute topographic maps from both 1948 and 1995, with Strawberry Island upstream, Motor Island downstream, and the unnamed shoal area just upstream of Motor Island referred to as Frog Island. According to a review of the historical map and aerial photography record, an island in the area referred to as Frog Island was first indicated in the 1927 aerial photograph. Historical maps prior to 1870 do not indicate a feature at the location of Frog Island, although mapping standards and accuracy at that time may have precluded documenting small islands or wetland areas in the middle of the River. Frog Island reached its largest size around 1938, with an area of approximately 4 acres. By 1951, the island's area was greatly reduced, and by 1985, it is no longer visible in aerial photographs.

Several factors have likely contributed to the disappearance of Frog Island. For example, gravel mining activities up until 1953 at the adjacent Strawberry Island may have extended into the Frog Island area, and resulted in the removal of substrate.

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Another, less obvious factor influencing the size of the island are the relative water levels in the river during the point in time at which the size of the island was measured. For example, aerial photographs may have been taken during either a low-flow period, where lower water levels may have exposed a greater area of island and surrounding substrate, or during a higher flow period that submerged a greater area. Although it is difficult to determine actual water surface elevations at the time aerial photographs were taken, long-term annual flow records indicate that 1927 and 1938 photographs showing the largest island area coincide with lower-flow periods, and conversely, the 1951, 1966 and 1978 photos coincide with higher water levels and reduced island area.

Finally, and perhaps most significantly, much of Frog Island's more recent reduction in size appears to be directly related to the changing Lake Erie water levels and corresponding Niagara River flows. In 1986, U.S. Army Corps of Engineers (USACE) data indicates that both water levels in Lake Erie and average flows in the Niagara River had reached their historical peak. As a result of sustained high flows, wave action, overtopping, and ice scour, Frog Island likely experienced significant erosion. These erosive forces acted on the island mass at a time when its crest was located at or near the water surface, rather than substantially above or below the interface, where waves and ice could more effectively act to erode the top of the island.

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TABLE 1. TIMELINE OF EVENTS AND CONDITIONS AT FROG ISLAND AND SURROUNDING VICINITY

Date	Description	Source	Notes
12,300 yrs before present	Final retreat of Last Wisconsin ice sheet forms modern river channel; Strawberry Island formed by sediment deposition	Buehler and Calkin, 1982, in EDI, 1998 and Sault *et al.*, 1997	
1750	Earliest records indicate that settlers referred to island as Strawberry Island	Sault *et al.*, 1997	Origin of name is unclear; perhaps because strawberries grew on island
1814	Strawberry Island used by British to stage 1814 siege on Buffalo	Sault *et al.*, 1997	
1815	Strawberry Island, Motor Island, and Grand Island purchased from Seneca Indians for $11,000; Surveyor General of New York listed Strawberry Island as a 100 acre parcel with a value of $100	Sault *et al.*, 1997	
1819	Strawberry Island grew to 138 acres due to deposition of sand, gravel, and rock excavated during construction of the Erie and Barge Canal	Sault *et al.*, 1997	
1822	Single large island in the area of Strawberry Island	Map dated 1822	No discrete feature indicated in area of current Frog or Motor Islands
1873	Two large islands shown: one labeled as Strawberry island stretching from tip of Grand Island upstream to about the exit of the Black Rock Harbor, second labeled as Frog Island located in vicinity of current Motor Island	1873 International Bridge, Plan of Location Map	Several smaller islands shown in vicinity of current Frog Island, and upstream from Strawberry Island
1882	A two-story hotel built on Strawberry Island	Sault *et al.*, 1997	Included 11 acre grove of trees and canal dug through island so that ladies could enjoy the river without the swift currents
ca 1892	Hotel on Strawberry Island fell into disrepair due to popularity of larger resorts on Grand Island	Sault *et al.*, 1997	

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Date	Description	Source	Notes
1908	Strawberry Island increased in size again as excavated material from the construction of the Black Rock Lock was placed around its periphery	Sault *et al.*, 1997	
1910	Strawberry Island somewhat reduced in size vs. 1873 map; Motor Island present with irregular shoreline and labeled as Frog Island	USGS 1910 Topo map	No discrete feature indicated in area of current Frog Island
1910	Anecdotal report that the USACE began placing fill from construction of Black Rock Lock a short distance upstream of Strawberry Island.		
1912	Strawberry Island, now 205 acres, sold to Border Island Gravel Company	Sault *et al.*, 1997; Spierto *et al.*, 2003; EDI, 1998	USACE canceled the mining permits shortly afterwards
1926	Strawberry Island reduced by 100 acres on south side by dredging	EDI, 1998	
1927	Frog Island present (approx 3-4 ac) Excavation of Strawberry Island clearly evident in shape and size; Motor Island has current angular shape	Erie County aerial photo	First observation of a discrete feature at current location of Frog Island
1932	Oblique aerial photo shows a portion of Frog Island area and exposed vegetation/substrate	http://www.isledegrande.com/giimages15/gi1932b+w--.jpg	
1938	Aerial photo shows Frog Island at its largest point in photo history (approximately 4 ac). Image quality makes it difficult to distinguish between upland and what might be exposed substrate or vegetation	Aerial photo	Water levels in Frog Island area were 1-2 feet lower than 1951, with the lowest levels ever recorded around 1934. Shallow relief around low-lying islands exposed.
1938-1941	Dredging resumed on the northwest side of Strawberry Island	Sault *et al.*, 1997	
1948	Strawberry Island reduced to 36 acres	Sault *et al.*, 1997	

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Date	Description	Source	Notes
1948	Strawberry Island approximately half that of 1910, open water downstream in horseshoe shape, open water upstream in lagoon-like opening; Motor Island present and labeled as Motor Island	USGS Topo map	Frog Island may be present as indicated by wetland symbol
1949	USACE halted dredging beyond 100 feet of Strawberry island over concerns about changes in flow and water quality; dredging later resumed, but was restricted to center of Strawberry Island	EDI, 1998; Sault *et al.*, 1997	
1950	Strawberry Island reduced to about 25 acres, with large lagoon in center of island	Sault *et al.*, 1997	Dredging accentuated the horseshoe shape of island
1951	Aerial photos show Frog Island has almost disappeared; two separate high points shown	Aerial photo	Mid to high water period, potentially submerging shallows.
1953	Buffalo Gravel Company sold Strawberry Island to Town of Tonawanda	Sault *et al.*, 1997	Island to be used as a staging area for construction and maintenance of new water intake to be located off the shore of the island
1966	Aerial photo of Frog Island shows little change since 1951	Aerial photo	1966 water levels were slightly lower than 1951.
1966 to 1978	Aerial photos show little change at Frog Island	Aerial photo	Water levels continue to be several feet higher from approx. 1966 forward
1977	Navigation Chart shows Frog Island as semi-kidney shaped, similar in footprint to 1966 aerial. Motor Island labeled as such	National Oceanographic and Atmospheric Administration (NOAA) Navigation Chart	
1978	Aerial photo shows conditions similar to 1977 Navigation Chart	Aerial photo	Difficult to discern exposed substrate from surrounding submerged features

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Date	Description	Source	Notes
1981	Navigation Chart with few, if any, changes from 1977 version. Motor Island labeled as such	NOAA Navigation Chart	May not have updated base map features since 1977
1985	Frog Island no longer visible above water in aerial photo	Aerial photo	Poor image quality; Highest water period on record.
1989	Strawberry Island transferred to New York State Office of Parks, Restoration, and Historic Preservation (NYSOPRHP)	Sault *et al.*, 1997	
1992	Navigation Chart showing only shoal area in vicinity of Frog Island. Motor Island labeled as Pirates Island	NOAA Navigation Chart	Base map for navigation charts updated since 1981
1992	Severe fall storms resulted in accelerated erosion along southwest shoreline of Strawberry Island; river currents in December broke through the narrow spit, entering lagoon at Strawberry Island	Sault *et al.*, 1997	
1993	Breach at Strawberry Island was more than 50 feet wide and several feet deep, and split the island in two; breach repaired by alliance of local businessmen and government agencies (Phase I restoration)	Sault *et al.*, 1997	
1995	Aerial photo does not show exposed substrate at Frog Island	Aerial photo	
1995	Navigation Chart with few, if any, changes from 1992 version. Motor Island labeled as Pirates Island	NOAA Navigation Chart	May not have updated base map features since 1992
1996	New York State Department of Transportation (NYSDOT) provides some shoreline armoring and conservation plantings at Strawberry Island (Phase II)	Spierto *et al.*, 2003	
1998	NYSDEC purchases Frog Island, later known as Motor Island, and lands upstream from The Nature Conservancy	NYSDEC Deed for Motor Island	
2001	Strawberry Island Phase III Erosion Control and Wetland Habitat Restoration project completed in June	Spierto *et al.*, 2003	
Present (2005)	Aerial photos do not show exposed substrate at Frog Island	NY GIS aerial	

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3.0 REVIEW OF EXISTING HABITATS

When attempting to re-create and develop new habitats, the best indicator of a successful approach is to mimic established habitats near the proposed improvement site. A review of nearby established habitats allows the formulation of design criteria which may be used as guidelines to create new habitat that will ideally function in a similar manner. This includes effects due to water levels, ice loading, wave action, wind, water quality, sunlight, etc. Several key habitat locations have been inspected and surveyed in the Upper Niagara River; Table 2 outlines some of the key components of these habitats and their differences, which may be considered in the design of potential habitat improvements at Frog Island.

Elevations used in this report correspond to the U.S. Lake Surface 1935 (USLS 35), a common vertical datum used by NYPA for the NPP (USLS 35 = IGLD 1985 + 1.20 feet).

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TABLE 2. EXISTING NIAGARA RIVER HABITAT EVALUATIONS

Location	Habitat Type	Fetch/Depths	Breakwater	Vegetation	Additional Notes
East River Marsh	Emergent Wetlands & Uplands	2,100 ft at 60 degrees (NE) but not dominant wind direction, with deep fetch.	Riprap 2 ft above NWL (normal water level)*	Phragmites on shoreline only; created marshlands behind breakwaters dominated by natives	Emergent wetlands dominated by native species in protected area behind constructed breakwaters
Strawberry Island (West Arm)	Emergent Wetlands	2.2 mi at 270 degrees (W) or 0.5 mi at 230 degrees (SW), deep fetch but shallow west of western arm 300-600 ft	Riprap 2-2.5ft above NWL, 10 feet wide.	Phragmites has established, especially along the higher wetland elevations along the breakwaters.	Back side of breakwater has well established vegetation, but limited to no vegetation at depths >15 inches.
L. Beaver Island (Interior)	Emergent Wetlands	Limited to no fetch; protected behind Island	Little Beaver Island acts as breakwater for interior wetlands	Mostly desirable native emergent marsh vegetation	Very low energy environment, low velocities and protected from ice, waves and currents.
L. Beaver Island (Outside)	Emergent Wetlands	0.9 mi from South	Shallow shoal offshore	Mostly desirable native emergent marsh vegetation	Exposed, but well protected by shallow shoal
Black Rock Canal	Emergent Wetlands (at SAV Depths)	Fetch across length of Lake Erie; deep water >4ft	Sheltered by wide (~300ft) shoal and inside a bend of the 8ft high canal wall	Vegetation dominated by dense stand of invasive cattail *Typha x glauca*, which is only emergent species that can grow in traditional SAV zone depths.	Deep water (>4ft); corresponds to SAV zone depths

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Location	Habitat Type	Fetch/Depths	Breakwater	Vegetation	Additional Notes
Grass Island	Emergent Wetlands	Short northerly fetch protected by Grand Island; deep water >4ft	Grand Island acts as breakwater for southerly winds; currents directed towards opposite side of River	Vegetation dominated by dense stand of invasive cattail sp. (Typha x *glauca)*, which is only emergent species that can grow in traditional SAV zone depths.	Deep water (>4ft); corresponds to SAV zone depths
Gratwick Park	SAV / Bare	0.75 mi at 180 degrees (S), deep fetch	Low profile narrow riprap, immediately deep habitat on both sides	Limited to no SAV	High-energy environment, breakwaters regularly overtopped, high flushing rate, generally too deep for emergent vegetation.
Buckhorn Marsh	Emergent Wetlands	No fetch exposure; some exposure to ice and boat wakes along extreme western edge of marsh which also has some erosion.	Protected wetland habitat in Island Interior	Native bulrush and sedges on western edge; cattail and Phragmites mixed with native sedges and rushes in interior	Very low energy environment, low velocities and protected from ice, waves and currents except along western shoreline.
Cherry Farm	Emergent Wetlands	Short northerly fetch protected by Grand Island; deep water >4ft	Grand Island acts as breakwater for southerly winds; currents directed towards opposite side of River	Vegetation dominated by dense stand of invasive cattail sp. (Typha x *glauca)*, the only emergent species that can grow in traditional SAV zone depths.	Deep water (>4ft); corresponds to SAV zone depths

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Location	Habitat Type	Fetch/Depths	Breakwater	Vegetation	Additional Notes
Frog Island (Existing)	SAV / Bare	1.25 mi at 230 degrees (SW), deeper fetch with limiting approach ~6ft	No existing breakwater other than shallower approach depths	Muskgrass, some Wild celery	SAV growth on bare spot limited from either ice, waves or human impacts. May also be compacted from former island overburden.
Motor Island (Outside Shoreline)	SAV Habitat / Wetland	0.9 mi at 180 degrees (S), deeper fetch but limited by southern tip of Grand Island	Vertical wood cribwall with concrete blocks on top along western side; sloping cobble approach with wood cribwall along southern and eastern sides	Wild celery, Muskgrass	Wetland habitat all located in terrestrial areas behind breakwater barrier along shoreline
Northern Grand Island Wetland – West River Road	Emergent Wetlands	2.5 mi at 220 degrees (SW), deep fetch across river but wetlands are somewhat sheltered behind point of land	No existing breakwater other than shallower approach depths	Three-square and Narrow-leaved cattail	Longest fetch hits wetland areas obliquely; wetlands located on broad, shallow shelf averaging about 22 inches deep; no vegetation in deeper parts of shelf on river side, or in shallower water on landward side of wetlands

**Depths are with respect to Long Term Average Water Surface Elevation (WSEL) (El. 566.5 ft)*

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Several key trends may be identified in the above table with respect to habitat type, location, and environment:

- Established emergent wetland habitat is only located in well protected areas and low energy environments,
- SAV may establish in higher energy areas, but needs to be protected from ice scour, and wave action (*i.e.* sufficient depth),
- Areas of shorter fetch / greater protection are able to support healthy SAV and emergent habitats.

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4.0 DESIGN REQUIREMENTS AND OBJECTIVES

A number of specific objectives for the Frog Island habitat improvement project were identified through a series of collaborative discussions with the Ecological Standing Committee (ESC) and its members and these have been used to shape the design and approaches to the HIP. These objectives are:

- Create a HIP that meets NYPA's responsibilities under the FERC license for the Niagara Power Project and Settlement Agreement:
  - NYPA will make a reasonable effort to design, build, and maintain a sustainable island/wetland complex.
  - This HIP is subject to several substantial risk factors, including risk to structural stability of the breakwater and internal substrate, as well as the risk of environmental conditions being too dynamic to enable the establishment, or long-term sustainability, of the desired vegetation. These risks increase as the robustness of the design decreases.
  - To the degree obtainable, utilizing standard engineering practices:
    - Significant storm, wave, and ice events should be a significant consideration in the HIP design.
    - The island is likely to be subject to changing environmental and hydrologic forces over the next several decades. To the greatest extent practical, this habitat improvement project will be designed to allow change and maintain some desirable habitat. Monitoring will be performed and future adjustments (*e.g.*, cut, fill, plantings, etc.) may be needed as part of an adaptive management process in response to changing forces and biological utilization.

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        - The island complex will be designed to withstand the modeled normal average ice flow conditions as documented in work by Dr. Shen (Clarkson University) utilizing 40-years of data.

    - While the HIP goes through an initial stabilization period, minor maintenance activities, such as replacement of dead plants, control of exotic invasive species, and minor repairs to breakwater structures, are anticipated. After that initial period, some adaptive management adjustments may be needed, approximately 5 to 10 years after construction. After that time, periodic routine maintenance of breakwater structures may be required.

- The improvements should enhance habitat transition zones and species diversity, and minimize adverse affects on nearby habitats or sensitive species. This includes incorporating design elements that could minimize the establishment of non-native, invasive vegetation and woody vegetation.
- The design must be cost effective, maximizing total area improved with the available funds.
- Designs will attempt to reach a balance between the need for long-term structural integrity (i.e., a robust design), natural variability in habitat (i.e., seasonal changes and/or gradual transition over time), and aesthetics with the following characteristics:
    - Low Profile – Minimize the height and exposure of breakwaters
    - Flow Through / Flushing – allow for flow through, over, or around the area of habitat
    - Integrity – maintain structure and habitat integrity with minimal annual and long-term maintenance required.
- Create submergent habitat zone (approx. 2-6 ft deep, based on current annual average depths). Target species are:

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- Wild celery, sago pondweed and other native species of submerged aquatic plants found in the area currently, or were historically present (e.g., 1928 botanical survey)
- Centrarchids, esocids, and cyprinids
- Waterbirds

- Create deep emergent habitat zone (approx. 2 ft deep, based on annual average depths). Target species are:
  - Bulrush and other native historical emergent wetland species
  - Waterbirds, crayfish, mink, turtles, otter, water snakes and other animals
  - Centrarchids, esocids, and cyprinids
- Design habitat elevations to the recent record of surveyed species, which have adapted to the current hydrologic conditions (*i.e.*, flows, water levels).

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5.0 ENGINEERING DESIGN

This section outlines the various considerations involved in the engineering design of Frog Island to date, and how these considerations may affect the layout and sustainability of the project. Further details, references, and calculations are available with respect to much of the information listed below and are available for review.

5.1 Hydrology and Wave Environment in the Frog Island Area

Frog Island is subjected to a number of wind, wave, and water level forces that need to be considered in any design scenario. As wind moves over broad expanses of water without obstruction (*i.e.*, fetch), it causes waves to form, and therefore wind characteristics are a key component in determining the frequency, direction, and magnitude of wave action against the shoreline. In turn, wave action against a shoreline is influenced by a number of factors including, water depths, wave direction, and shoreline slope and height. Changes in water levels, whether in response to storms, seasonal patterns, or long-term trends, also influence shoreline condition and available habitat. The following sections analyze the hydrology and wave environment at the Frog Island location.

5.1.1 Wind Analysis

A local wind analysis was completed using historic 2-minute wind records for the Greater Buffalo International Airport, starting in 1948, up through 2007. The airport is located approximately 10-miles to the east of Frog Island. This data was reviewed to determine the average direction and magnitude of winds, along with the peak winds for each direction. The 2-minute winds are readings taken by hand (until approximately 1996 when Automated Surface Observation System [ASOS] was installed) by averaging the wind readings for 2 minutes at the top of every hour. In essence, it represents a statistical sample of the hourly winds; although the data may represent the average hourly wind if there is not a significant variation between abutting observations. The data does not represent the highest winds during each hour, but is rather a systematic sample of the wind speeds.

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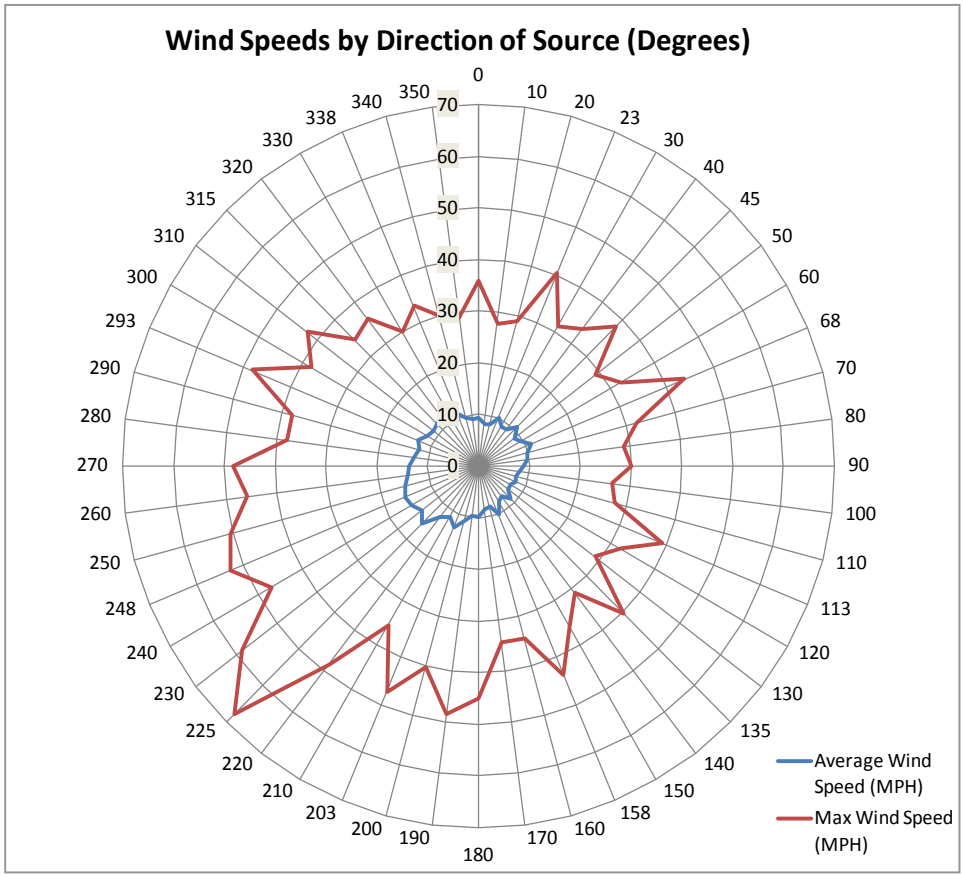
The 2-minute wind record data is summarized in a wind rose below, which shows that the highest average and peak hourly winds come from the southwest (225 degrees); however, the wind rose also shows that overall, high winds typically occur in a slightly broader range at an angle of 220 to 250 degrees relative to Frog Island (Figure 2). These directions correspond to the broadest fetch for Frog Island, a distance of approximately 1.25 miles (Figure 1).

Additionally, statistics were compiled on this available period of record for both the maximum 1-hour annual winds, and the maximum annual 2-minute readings.

FIGURE 2. AVERAGE AND PEAK WIND SPEEDS BY DIRECTION



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Additionally, local wind records were evaluated to estimate the highest typical sustained and peak wind speeds one could expect to see over a 1-year period as well as over a 50-year period. These estimates were calculated using statistics compiled on the available period of record for both the maximum 1-hour annual winds, and the maximum annual 2-minute readings (Table 3).

TABLE 3. STATISTICS OF WIND DATA (1948-2007)

	1-Year Return	**50-Year Return**
1-Hr Wind[1]	43 mph	50 mph
Peak Gust Wind[2]	54 mph	60 mph

Although the effects of wind is not expected to directly affect the shoreline and erosional processes in this part of the river, winds can be a significant factor in the formation of waves, which would be expected to have a considerable affect on shoreline and erosional processes. As such, this information on wind speed and direction was used, as noted in the following section, as a key input variable in the analysis of the effects of wind-driven waves in this portion of the river.

5.1.2 Wave Height Analysis

As noted above, the length of unobstructed water (fetch) is a major factor in the development of waves. The longest fetch, out of the southwest, is approximately 1.25 miles and is long enough to influence the formation of waves under gust conditions, which could develop short-term peak wave heights with increased wave runup (*i.e.,* how high the breaking waves push up against a beach), although this is not a typical or sustained condition.

The dominant wave-approach fetch to Frog Island consists of deeper water extending from the Canadian shore that gets shallower as the waves approach Frog Island. Depths are on the order of 6-9 ft for a majority of the approach, but decrease around the island to 3-6 ft.

[1] Two-minute reading at top of hour, assumed representative of typical, sustained winds during hour.
[2] Peak gust data is only available from 1996 to present, which represents a smaller record than the hourly 2-minute winds.

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For the purposes of calculating wave development and wave height, deepwater wave equations were utilized in this analysis, which presents a worst-case scenario.

Using the wind, fetch, and depth data, a series of wave-height sensitivity analyses were completed (Appendix B). Table 4 summarizes the sustained wind speed and resulting wave parameters. Wave heights are measured from trough to crest, and those in the table represent the mean wave height for the approaching fetch under the given wind speeds. Thus the wave crest above a still water level is half the wave height. It should be noted that these heights do not include wave runup heights on shorelines.

TABLE 4. WAVE PROPERTIES AT VARIABLE WIND SPEEDS

Sustained Wind Speed	Mean Wave Height	Wave Period(s)
40 mph	0.48m (1.6 ft)	2.0
50 mph	0.63m (2.1 ft)	2.2
60 mph	0.78m (2.6 ft)	2.4

5.1.3 Wave Runup Analysis

Waves generated offshore will eventually contact the shoreline, where the wave energy is dissipated. There are several mechanisms of this energy dissipation, but one of the most significant is wave runup, or the 'pushing' of flow up onto the shoreline, higher than the wave's original height. The height of this runup varies depending on the shore slope, shoreline permeability, and material roughness. The process of runup and wave cresting was evaluated to understand the transmission of energy beyond the breakwater (*e.g.*, velocity, and flow rate), which can then be utilized in the design process.

For the evaluation of wave runup and transmission across breakwaters, two different breakwater options were utilized:

- Low-Crested Breakwater – this is a low-sloped breakwater which is at or even slightly below normal water levels that breaks up wave energy before it can be transmitted into the area protected by the breakwater. A requirement of this design approach is to have

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sufficient breadth (distance from outside edge to interior) to dissipate the energy due to the sustained shallow zone. These breakwaters require a more substantial footprint due to their breadth and they allow wave energy to be transmitted across the breakwater at higher water levels, potentially exposing the areas to be protected.

- High-Crested Breakwater – A sloped breakwater that achieves a height many feet above the water surface may also be used as a physical barrier to the entire wave front. The height of this type of structure is used to dissipate the runup forces and prevent excessive flow from passing over the breakwater. Although this approach does not require as large a footprint as a low-crested breakwater, high-crested breakwaters are typically taller and more massive than their low-crested counterparts. A high-crested structure would also be more effective at preventing wave or ice damage at increased water levels.

Both of these options will allow some wave transmission through and over the breakwater, but both can be designed so energy is dissipated sufficiently to prevent major damage to the areas they are intended to protect. In particular, determination of wave runup height is critical in the design of breakwaters to limit overtopping waves damaging the protected leeward areas. The size of the rock needed for the breakwaters is dependent upon the amount of the wave energy, rather than the actual runup height. As a special note, water surface elevations in the vicinity of the island may vary considerably due to storm surges or seiches, but it is expected that slightly deeper water depths needed for deep emergent and SAV habitat behind the breakwaters should result in more protection from overtopping wave action. This is a somewhat different situation than if the protected habitat behind the breakwater is covered by just inches of depth (shallow emergent), where waves cresting over a breakwater would have more energy and potential to damage the protected habitat through scouring action. As such, normal water levels where the habitat has the shallowest covering depth of water become the critical design level to prevent wave action.

The low-crested breakwater approach was evaluated using the EM 1110-2-1100 (Part VI), Table VI-5-15, *Wave Transmission Formula for Rock Armored Low-crested, Submerged, and Reef Breakwaters* (van der Meer and d'Angremond, 1991). This approach is used for ‘reef’ type structures, where a percentage of the wave is transmitted into the interior.

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Reduction of the transmission of waves can be accomplished by either providing a greater height above the normal pool (freeboard), or by increasing the breadth of the reef. Calculations were performed using the wave height values, and varying the dimensions of the low profile breakwater. In order to minimize the transmission of waves (Ct, Coefficient of Transmission < 10%), a breakwater breadth of 25-30 feet is recommended as calculated using the water level and wave data.

Using the information from the above analysis, low-crested breakwaters in the vicinity of Frog Island would need a reef breadth of approximately 30 feet, with a crest at approximately El. 567.0 ft (0.5 ft above the long-term average water level), so they could protect leeward areas from waves and ice loading. This type of low-crested breakwater would need to be located on the western side of the HIP to limit wave energy generated by the long fetch. Additional protection against ice loading on the head of the island could be addressed with the addition of larger boulders.

If a traditional high-crested breakwater is utilized, the freeboard (distance between water level and breakwater crest) is critical to reducing the transmission of waves into protected leeward areas. To evaluate the runup potential of the significant wave height, the USACE Coastal Hydraulics Laboratory Technical Note, *Estimating Irregular Wave Runup on Rough, Impermeable Slopes* (USACE, 2005a), was utilized for calculations.

Using the high breakwater approach, a sensitivity analysis was completed to determine a reasonable design for wave runup. The sensitivity variables include the slope of breakwater (*i.e.*, 2:1 to 4:1, in 1/2ft increments) and the sustained wind speed (*i.e.*, 40, 50 and 60 mph). For the high-crested breakwater, the worst case conditions (highest runup) occur with the steepest breakwater slopes, which result in a wave runup between 3.3-4.7 feet over the range of wind speeds evaluated. At lower slopes, such as 3:1, the runup range is reduced to 2.5-3.6 feet and is minimal at a 4:1 slope with runup heights of 2.1-3.0 feet. The higher range of sustained wind speeds is quite rare according to the data reviewed, thus the design should focus on the 40-50 mph sustained range if a high breakwater design approach was used for the HIP. This range results in a wave runup height of approximately 3.0 to 4.5 feet; with an average still-water level of El. 566.5 ft in the vicinity of Frog Island, this would

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require a breakwater crest elevation of El. 569.5 ft to El. 571.0 ft to prevent overtopping at normal pool.

If breakwater elevations are too low, it would likely result in more frequent, and greater volumes, of overtopping flows entering the protected interior of the HIP, potentially damaging more sensitive habitat. As a precaution, the design of protected areas within the breakwaters should allow for some wave overtopping through the use of energy dissipation zones on the backside of the breakwaters. These areas will likely be devoid of significant growth of aquatic vegetation.

5.1.4 Water Level Analysis

Several studies have evaluated long-term water levels along the river, and increases in stage and flow due to wind setup in Lake Erie. Historic records and seasonal/yearly statistics are available for water levels along the river in a water level fluctuation study (NYPA, 2005).

For the purposes of this design, most of the river stage information was obtained from both the Frenchman's Creek gage, located slightly upstream from Frog Island on the Canadian shore, and the Huntley gage, situated slightly downstream along the Tonawanda Channel on the U.S. shore. Frog Island is located roughly equidistant from these two gages, and data from NYPA (2005, 2009) were used to develop exceedence levels, or the percentage of each year that water levels are above the listed elevation (Table 5).

TABLE 5. WATER LEVEL EXCEEDENCE FREQUENCIES

Exceedence Level[3]	**Strawberry Island WSEL** (ft)	**L. Beaver/Motor Islands WSEL** (ft)
10%	567.4	567.4
50%	566.5	566.4
90%	565.7	565.6

[3] Period 1991-2002, Table 4.2.1, in NYPA, 2009

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5.1.5 Daily Fluctuation Ranges

Water level gages along the Niagara River provide temporal water level (stage) data that have been reviewed extensively (NYPA, 2005). Water levels in the vicinity of Frog Island are influenced by two primary factors. Operation of the hydroelectric projects downstream may result in relatively small fluctuations in water levels on a daily, or even hourly basis. In contrast, wind setup and storms on Lake Erie can result in seiche events that cause extreme water level fluctuations that range up to a few feet of water level change in the Niagara River. Although less frequent than the water level regulation, these storm surge events can cause substantial impacts. Additional review of the historical data indicates that ice does not appear to be a significant factor in the largest daily water level fluctuations.

Using hourly water level data, Table 6 provides the annual and seasonal minimum, maximum and average water level elevations at the Huntley gage from 1991 to 2002. The average tourist season levels (*i.e.*, April through October) are higher than either the average non-tourist season (*i.e.*, November through March) or average yearly water levels. This seasonal difference in average hourly water levels is approximately 0.33 feet (4 inches), as indicated by the Tourist/Non-Tourist Comparison, which reflects the naturally higher spring and summer flows (NYPA, 2005).

TABLE 6. ANALYSIS OF WATER LEVEL AT HUNTLEY GAGE (NYPA, 2005)

Year	Tourist Season Water Level (USLS 1935)			Non-Tourist Season Water Level (USLS 1935)			Yearly Water Level (USLS 1935)			Tourist/Non-Tourist Comparison (Diff. in Feet)		
	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
1991	565.99	567.63	566.78	565.74	568.6	566.76	565.74	568.6	566.76	0.25	-0.97	0.02
1993	565.5	569.21	566.81	565.25	569.41	566.73	565.25	569.41	566.77	0.25	-0.2	0.08
1994	565.8	567.66	566.66	564.6	568.95	566.3	564.6	568.95	566.34	1.2	-1.29	0.36
1995	565.6	567.6	566.42	565.52	568.84	566.35	565.52	568.84	566.36	0.08	-1.24	0.07
1996	565.27	567.51	566.63	565.42	568.79	566.32	565.27	568.79	566.46	-0.15	-1.28	0.31
1997	567.05	569.47	567.56	565.54	569.51	567.07	565.54	569.51	567.24	1.51	-0.04	0.49
1998	566.05	568.32	567.14	565.45	569.35	566.7	565.45	569.35	566.95	0.6	-1.03	0.44
1999	565.21	567.57	566.27	564	567.75	565.92	564	567.75	566.07	1.21	-0.18	0.35
2000	565.22	567.74	566.33	564.63	569.96	565.69	564.63	569.96	565.99	0.59	-2.22	0.64
2001	565.41	568.23	566.05	564.22	567.29	565.7	564.22	568.23	565.86	1.19	0.94	0.35
2002	565.05	567.44	566.38	564.16	570.71	565.81	564.16	570.71	566.13	0.89	-3.27	0.57

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5.1.6 Storm Surge Fluctuation Ranges

Recent water level data from 1991 to 2002 show storm surge fluctuations in the vicinity of Frog Island from normal pool (approximate El.566.5 ft) up to El.570.3 ft[4]. This variation represents a 4-foot increase over normal water surface elevations (WSELs) in this part of the river; during low-water periods, this represents a range of approximately 5.5 feet. These surges are still-water increases and do not consider wave heights or additional runup. It is anticipated that during extreme events, the entire Frog Island complex and breakwaters will be submerged, as will be many low-lying points along the river.

5.1.7 Long-Term Fluctuations in Water Surface

A review of the data on the historic water levels of the Great Lakes assembled by the USACE indicates that long-term fluctuation of the average water surface elevation of Lake Erie are mirrored by those in the Niagara River (Figure 3). These water surface elevations also correspond to the amount of flow in the river. Historically, lower flows were noted in the mid-1930s and mid-1960s, and the highest flows were observed from approximately 1970 to the mid-1980s. Current water levels are somewhat lower now, and are close to the long-term average level.

As evident in Figure 3, the range of annual average flows in the Niagara River varies over time and such changes in the future would likely affect the design of the new Frog Island HIP. To accommodate changes in water levels, the designs should not rely solely upon specific, contemporary, elevations in anticipation of static water levels. Rather, designs should anticipate water level changes and utilize features that would allow vegetation to respond over time to changes in water levels (*e.g.*, vegetation species would “march” up and down a slope over time according to its preference/tolerance for water). Water levels at Frog Island were calculated using the average flow rates in a calibrated 1-dimensional hydraulic model of the Upper Niagara River.

[4] Water Level Fluctuation Report (NYPA, 2005)

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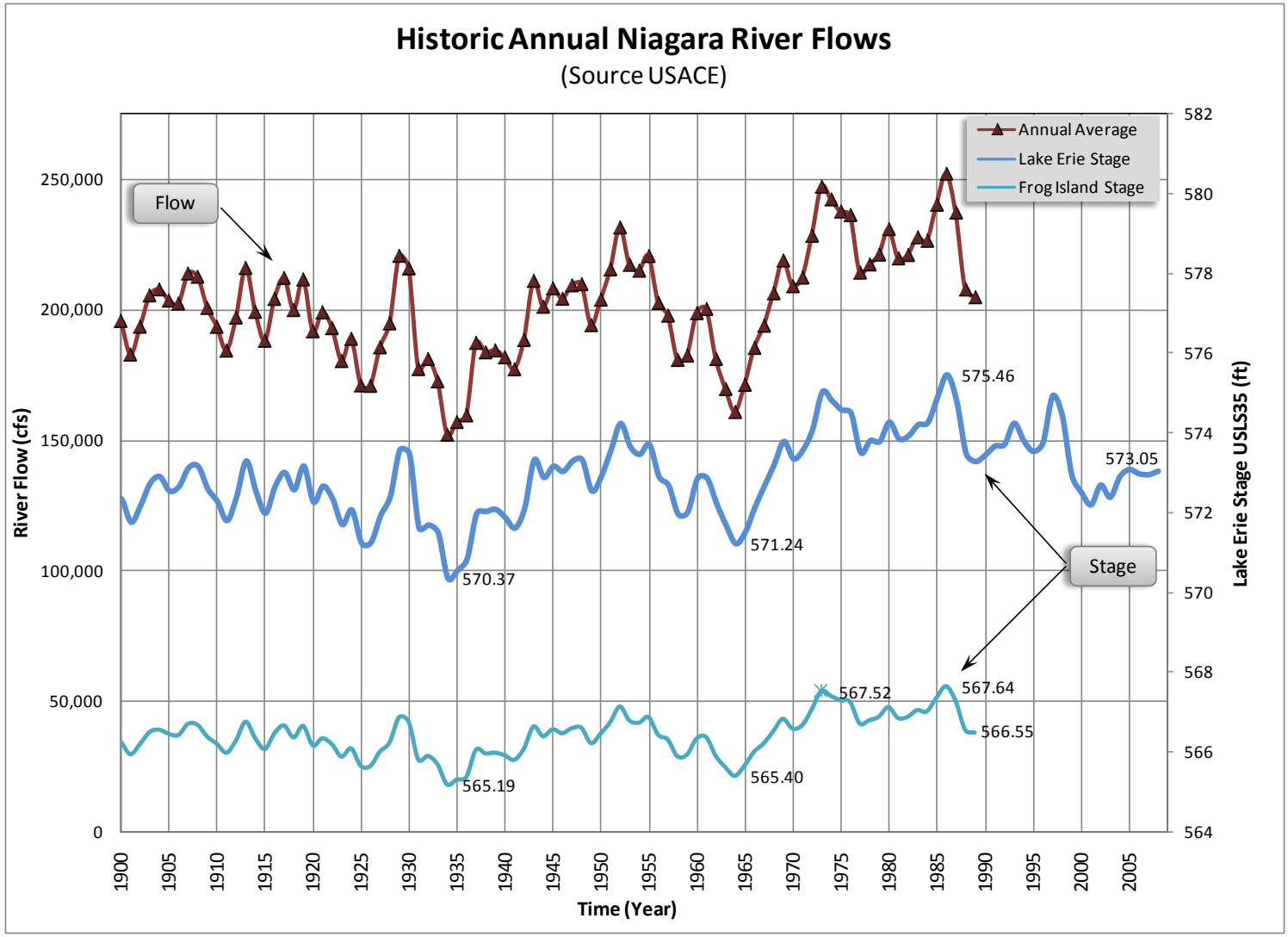
FIGURE 3. HISTORIC ANNUAL FLOWS IN NIAGARA RIVER AS COMPARED TO WATER LEVELS IN LAKE ERIE AND NIAGARA RIVER



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5.2 Open Water Hydraulic Model

Computer modeling was used to help identify and evaluate potential hydraulic affects associated with the proposed instream habitat modifications. Analysis was performed using preliminary designs for the Frog Island HIP and was coordinated with Dr. Hung Tao Shen of Clarkson University, Potsdam, NY, using his DynaRICE model.

5.2.1 Model Description

Dr. Shen started developing the DynaRICE model in 1997, with many updates and improvements since then (Shen and Liu, 2001; Ji, *et al.* 2004; Liu and Shen, 2003). His work has resulted in a 2-dimensional open water and ice formation/loading model to evaluate ice jamming, specifically on the Upper Niagara River. DynaRICE allows for the analysis of both steady state and unsteady (flood hydrograph) conditions on the Niagara River. The model domain extends from within Lake Erie, passes downstream towards Grand Island, includes the Chippewa and Tonawanda Channels, Navy Pool, and terminates at the Falls. The downstream boundaries include a rating curve at the falls, and fixed withdrawals at the intakes for both the U.S. and Canadian hydropower facilities. The upstream boundary is Lake Erie and uses a fixed (excluding seiches) water surface. Seiches may be developed on Lake Erie for creating these storm surges, or flood hydrographs.

The model was divided into a ‘far field’ and a ‘near field’ hydraulic model. The far field represents the bounds as defined above, whereas the near field solely represents the vicinity around Frog Island. This near field model allows for a greater definition of geometry and resolution of results around the HIP project. Bathymetric data, as collected from numerous sources, has been utilized to create a single geometry representing the channels. In addition, the geometry defining the channel in the HIP area was updated using more recent bathymetric surveys. Bathymetry in the vicinity of Frog Island was then modified for the proposed conditions based on the initial high crested breakwater design approach. Finally, the same hydrologic conditions were run through the model to compare differences between the existing and proposed conditions.

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5.2.2 Model Scenarios

For the open water conditions model, nine different steady state flows were analyzed in the DynaRICE model. These conditions evaluated flows from the long-term average, up to the 100-year discharge, at a series of variable Chippewa-Grass Island pool levels. These variable pool levels evaluate the boundary condition fluctuations present, and described in NYPA (2005). Tables 7 and 8 outline the conditions used for the flows and stages in the open water conditions.

TABLE 7. OPEN WATER FLOW RATES

Event	Discharge (cfs)	Discharge (cms)
Long Term Average	204,600	5,794
5 Year	276,200	7,821
100 Year	317,900	9,002

cfs = cubic feet per second; cms = cubic meters per second

TABLE 8. OPEN WATER DOWNSTREAM BOUNDARY CONDITION

Water Level Condition	Elevation (ft)
Low	561.24
Long Term Average	562.75
High	564.22

5.2.3 Impacts to Water Levels

The results of all nine scenarios, for both the existing and proposed conditions, indicate that there is no impact on the open water levels due to the construction of the Frog Island HIP. The modeled geometry utilized the 'worst-case' scenario in terms of a large island footprint extending over five-acres, which was the largest improvement scenario under consideration. If improvements with smaller footprints for Frog Island were evaluated, they would result in a smaller difference between existing conditions and that modeled as described above, which was essentially no effect on water levels.

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5.3 Ice Hydraulic Model

Ice in the Niagara River is a yearly occurrence, coming from Lake Erie as the lake ice breaks up in the spring, and forming locally within shallower, calm sections of the river. The ice can form floes and ice jams that can cause significant damage to in-river structures, substrate, and habitat. In fact, one theory is that ice scour in the shallows around Frog Island has increased the rate of erosion of the island and prevented the establishment of SAV. Evidence of ice scaring is visible at the base of trees lining the upstream edges of Strawberry Island and Motor Island, indicating that ice piles up against these shorelines, damaging vegetation and working against the shoreline.

To better understand how the creation of Frog Island HIP would affect ice movement down the river, the DynaRICE model was employed to examine the potential for forming damaging ice jams and the potential effect of ice on the improvement project.

5.3.1 Ice Model Description

After running the open water scenarios described in Section 5.2, the ice conditions module was run to evaluate the potential effects on the formation of ice jams in the river and to check potential impacts from ice on the island structures. Both synthetic and significant historic ice events were modeled and certain parameters were varied to evaluate the sensitivity of the model to differing environmental conditions (Table 9). Baseline reference conditions modeled in Case 1, were used to compare the proposed projects under different environmental conditions in Cases 2 through 6. Additionally, for Cases 7 through 11, failure of the ice boom on Lake Erie, which has been historically observed, was modeled to factor in supplemental ice loading conditions.

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TABLE 9. SUMMARY OF ICE MODEL SCENARIOS

Case	Parameters							Remarks
	θ_a	V_a	h_i	$H_{d/s}$	Q_{NYPA}	H_o	σ_t	
	degree	*mph*	*ft*	*ft*	*cfs*	*ft*	*hrs*	
1*	240	30	1	561.2	80,000	571.7	5	Reference case
2**		R	R	564.2	R	R	R	Effect of water level at CGIP
3**		40	R	R	R	R	R	Effect of wind velocity
4**		R	1.5	R	R	R	R	Lake ice thickness effect
5**		R	R	R	R	573.7	R	Effect of base water level at Lake Erie
6**		R	R	R	R	R	10	Wind duration effect
7a*	Case 1 with assumed partial boom failures a: Failure of spans I-M b: Failure of spans N-R							Boom failure conditions
7b*								
8*	Feb. 1975 event without assumed partial boom failures							Historical events and boom failure conditions
9a*	Feb. 1975 event with a: Failure of spans I-M b: Failure of spans N-R							
9b*								
10*	Jan. 1992 event without assumed partial boom failures							Historical events and boom failure conditions
11a*	Jan. 1992 event with a: Failure of spans I-M b: Failure of spans N-R							
11b*								

* *Cases simulated for both existing and proposed conditions.*
** *Cases simulated for the proposed condition with riverine HIPs.*
R = *Reference base case*
θ_a = *wind direction from north [degrees]*
V_a = *wind velocity [mph]*
h_i = *thickness of the ice in Lake Erie [ft]*
$H_{d/s}$ = *Water level at CGIP [ft, USLS 35]*
Q_{NYPA} = *water withdrawals at the NYPA intakes [cfs]*
H_o = *water level at Lake Erie [ft, USLS 35]*
σ_t = *wind duration [hrs].*

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5.3.2 Island Effects on Ice

Analysis of the reference and proposed condition ice model runs performed by Dr. Shen indicate that the construction of the HIP at Frog Island would not increase the probability that an ice jam would form in this part of the Niagara River. The model does indicate that ice would collect on the leading upstream edge of the HIP at times, but the ice would be easily shed into the main channel without affecting the potential for ice jamming.

5.3.3 Ice Thickness/Elevations

Ice model results show that ice thickness may reach 2-3 feet at the upstream head and southeastern edge of Frog Island. This ice thickness loading corresponds to high wind conditions; therefore, with water levels under these conditions between El. 568 ft to 569 ft, the top of the ice would be expected at approximately El. 570 ft to 571 ft. Under these circumstances, ice would ground out around El. 567 ft to 568 ft.

5.3.4 Ice Loading Forces

Ice forces could act against the HIP in two primary ways. First, normal ice loading is related to compression force, in which the water pushes a mass of ice directly into or against a structure. Second, shear stress occurs as the ice slides over the substrate or structure, and is a function of both the weight of the ice and the force of the water pushing against the ice. Calculation of peak normal ice loading against the edge of a breakwater surrounding the HIP was calculated at 47 pounds per linear foot (lb/ft) during peak storm events[5]. Shear stress estimates for ice at the head of the HIP are 75 pounds per square foot (lbs/ft^2). Within the lee of the breakwater, some ice loading and shear is expected, and is estimated to be on the order of 35 lb/ft^2, but again, this is a rare occurrence associated with higher water levels.

The potential for ice runup was evaluated at these normal forces[6]. It was determined that normal force at Frog Island is less than half that needed to push ice over a breakwater at normal water levels; to have ice overtopping would require approximately 100-200 lb/ft of force.

[5] Head of Frog Island, Ice Model Case 11b
[6] USACE (2006),Part VI, 5-278

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The breakwaters are the primary means of protecting the HIP interior, but if ice does get past the breakwater, the interior should be shaped and graded to allow the easy passage of ice towards the downstream end.

5.4 Geotechnical Analysis

The Niagara River in the vicinity of the Frog Island HIP has experienced extensive modification over the last 150 years as a result of the placement and removal of excavated materials, as noted in Section 2. In order to build a sustainable improvement project, it is necessary to understand the physical properties of the substrate upon which the HIP would be constructed and analyze various foundation and substrate components of the design.

5.4.1 Soil Boring Data

In September 2007, several marine borings within the center and around the perimeter of Frog Island were completed. Borings were completed to depths of 10-16 feet below ground surface, and included split spoon samples, blow counts and descriptions of the soil profile. Additionally, several sieve analyses were completed at various depths from these borings. In general, the surface was described as both silty sand or sandy silt with trace gravel, which extended several feet below grade. Lower in the boring profiles, the material continued to vary between silt, sand and traces of gravel.

5.4.2 Field Test Pits

Hand-dug test pits and surface bed material samples have been collected during field visits to the Frog Island area. Test pits completed while evaluating SAV habitat in 2007 showed a mix of silty sand, sand and course sand, corresponding well with the results of the soil borings.

Additional investigations around Motor and Strawberry Islands have also shown a similar mix of surface materials, consisting of sandy material interspersed with a few cobbles and some gravel. Some large cobble-sized rocks were noted in the vicinity of the western breakwaters of Strawberry Island, but these are likely displaced armor from the breakwater, rather than native material.

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5.4.3 Foundation Design

Soils beneath the proposed footprint of the Frog Island HIP consist mostly of sands, with very little organic and clay materials, and the geotechnical properties of these materials must be factored into the foundation design of the HIP. Placement of foundation and breakwater materials, as well as the redistribution of sediment to create habitat features, has the potential to compress and displace water from within the underling riverine substrate material. However, given that the substrate in the "bare spot" location was likely compressed by previously placed fill material (subsequently removed during gravel mining activities) and that the amount of material proposed to be placed into the river as part of the HIP is less than that removed during gravel mining, substantial settlement is not anticipated. In addition, a geotechnical analysis of soil boring and other data indicates that less than 1-foot of settlement is expected, with most anticipated to occur during construction of the HIP.

One of the goals of the HIP is to incorporate additional SAV habitat into the design, which will require excavating material to increase depth in these habitat areas. The designs should attempt to balance the cut and fill of materials, and material excavated from the SAV areas could be used to build up the core of the breakwaters and provide a diversity of interior depths.

Rock filled marine mattress systems may be used to establish the breakwater foundations, with larger stones placed on top of these mats. Some settlement of the core material should be expected immediately after the placement of the mattresses and large rocks, and settlement may be on the order of 20% within a few days after placement. Continued long-term settlement should not be expected.

5.5 Breakwater Design

5.5.1 General Layout

In order to create and maintain the desired deep emergent and SAV habitat, the outside edges of the improvement area will need to be protected with breakwaters. The structures need to be designed to help prevent wave action and reduce ice damage and scour, yet allow water to flow through to the interior habitat to enable the dynamic exchange of

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water and nutrients. As noted in the earlier analysis of environmental forces, the risk from wind, waves and ice are not uniformly distributed, rather, the western side of the HIP would be subjected to the greatest forces from wind and wave conditions while the head of the island would be subjected to the greatest ice loading forces.

If a high-crested breakwater option is used, and openings in the breakwaters are utilized, the layout should be situated to help limit the direct transmission of waves to the island interior, but still allow flows to move through. On the outside edge of the high-crested breakwaters, a shelf should be provided just below the normal waterline. This shelf will serve several purposes: 1.) to limit the wave action against and runup over the breakwater, and 2.) to be a sacrificial section that will prolong the life of the breakwater.

If a low-crested breakwater option is used, openings in the breakwater are not required because the semi-permeable breakwater would allow regular flow-through and overtopping with varying water levels and wave action. A horseshoe shaped structure should allow sufficient protection from wave energy, yet allow regular flushing of the island interior. If desired, openings in the breakwater could be situated on the east side of the HIP to provide deep-water access to interior SAV habitat without jeopardizing the integrity and protection of the breakwaters.

For either high or low-crested approaches, the head of the island is exposed to ice loading from upstream, and may be subject to ice being pushed partway up the riprap breakwater slope. Breakwaters in this part of the HIP should be designed slightly higher, using either large boulders or a higher crest to allow more protection against ice ride-up, and help to deflect ice to either side of the island. Any openings at the head of the island should be relatively narrow and configured to help limit ice and debris from entering the protected interior.

5.5.2 Toe Design

Larger breakwaters typically require treatment at the toe of the structure. Toe protection can help to prevent scour at the upstream base of the structure that would result from wave runup/rundown on the face. Toe protection can also help support overlying layers

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of stone on the structure's face, thereby preventing stones from sliding away from the base of the protected slope face.

Protection should be included with either of the two breakwater approaches, but does not need to be keyed into the foundation materials. It is recommended that toe protection be provided through the use of a stone-filled marine mattress system. Movement of armor stones above the mattress system may migrate down onto the stone mattress toe, but excessive erosion or disturbance of this area is not expected.

5.5.3 Armor Design

Regardless of either high or low-crest approach, the breakwaters (both inside and outside faces) will need to be layered with armor stone. This armor stone protects the smaller-diameter stone making up the core of the breakwater. The finer core stones help limit wave transmission through the foundation and base of the breakwaters, which can lead to washing out of fines within the HIP interior. This stone armor needs to be sized to protect against both wave and ice action. The following hazards exist for stone armor, and should be factored into the design:

- Displacement from wave runup and rundown
- Displacement from toe erosion
- Plucking of armor locked within an ice sheet during rising waters
- Displacement from ice pushed onto the shore

Overall, some damage of the breakwaters from wave action is expected, and may require repairs, but catastrophic failure should be prevented. Design approaches allow the determination of acceptable failure levels as a percentage of stones displaced in the average cross-section, which determines the minimum size of required armor stone. Plucking may be prevented if the area is not subject to freezing ice sheets, and if an area is susceptible, armor should be roughly twice as thick as the expected ice sheet. It is not expected that the interior of the HIP will develop significantly thick ice sheets.

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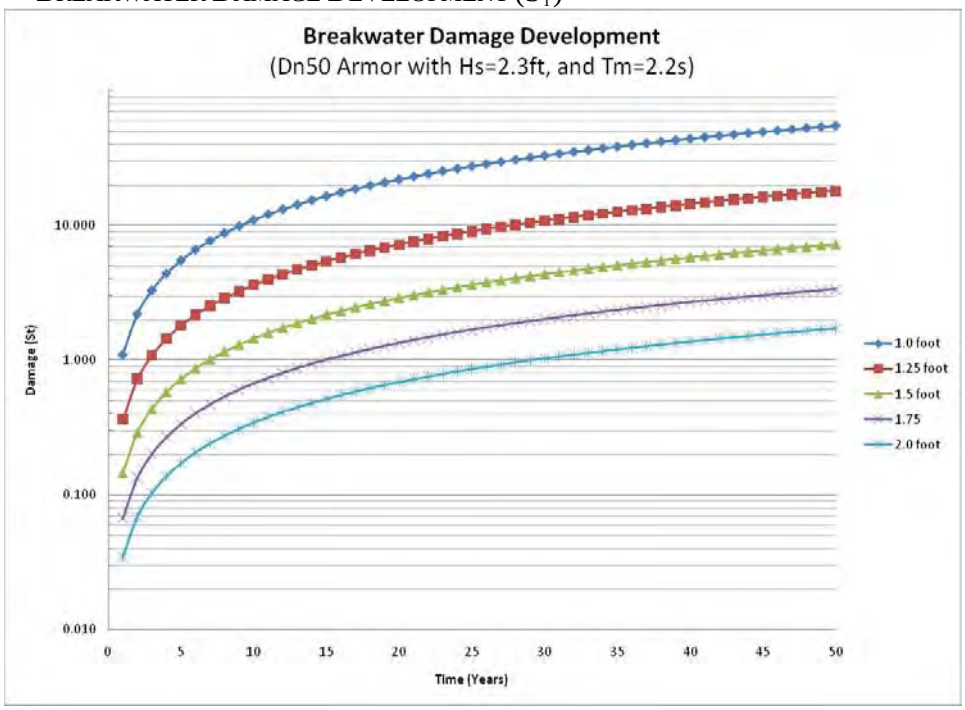
A USACE Coastal Hydraulics Laboratory procedure (USACE, 2005b), developed to make storm-related damage estimates for high crested stone-armored breakwaters, was used to estimate the annual damage that might be expected from a single, statistically-significant annual event (Appendix C). This damage assessment scenario is based on the assumption that no other annual damage is incurred other than the single, modeled event. A sensitivity analysis for damage was completed by evaluating various median stone sizes (D_{n50}), with a given controlling annual event. Figure 4 shows an estimate of the possible accumulation of damage over a period of 50-years, where damage (S) is defined as the ratio of area damaged to the square of the mean armor diameter. Full failure may be defined at approximately a damage level of 10-12, with intermediate damage at 6-9 and initial damage at 2[7]. Using a log scale to display damage progression, it can be seen that a mean armor diameter of 12 inches (1.0 ft) could potentially experience significant damage after 50-years, whereas increasing this diameter to 15-18 inches (1.25 to 1.5 ft), could dramatically decrease the degree of damage risk by two to three times.

FIGURE 4. BREAKWATER DAMAGE DEVELOPMENT (S_T)



[7] USACE EM 1110-2-1100, Table VI-5-21

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The breakwater armor found on the western arms of Strawberry Island may be used for comparison to help evaluate the selection of material sizes and field conditions. These breakwaters are exposed to a similar fetch as Frog Island, and a similar wave / water level environment. The southernmost (first) breakwater on the western arm is a lower profile section constructed in approximately 1996, with a crest about 24 inches above water level. As noticed during a May 2009 visit to Strawberry Island, the rocks used in the breakwater range from 6 to 24 inches in diameter, and appear to have been pushed back and displaced both in-front of and behind the breakwater. A small number of stones were observed to have been plucked out of the breakwater and located at depths of up to 30 inches, presumably by ice or wave action, and deposited up to 10 to 15 feet away from the breakwater. Vegetation on the back side of the breakwater had been uniformly flattened, signifying either wave action or ice action over the top of the breakwater. Further north (downstream) breakwaters were constructed in approximately 2001 on the western arm and consist of larger stone (18 to 30 inches), with a crest at approximately 30 inches above the water level. In this region, the vegetation was well established and not damaged like the breakwater towards the south. Additionally, the form of the breakwater was more distinct and appeared to vary less from the original design than the older, more southern breakwaters. The newer, downstream breakwaters have been in place since 2001 and have seen 7 to 8 years of wave and ice action. Considering this information, the performance of abutting breakwaters, and the above storm-related damage estimates, we would recommend a D_{50} of at least 15-18 inches on the breakwaters.

As an additional note regarding breakwater armor design, the leading upstream edge of Strawberry Island consists of a higher profile island with well-established vegetation and trees. This leading edge helps to protect and shed off ice that would otherwise overtop the island. Frog Island does not have this high profile leading edge, and is subjected to these higher ice forces; the armor on this leading edge needs to be designed to withstand these forces and at a height and slope to prevent excessive ice ride-up and overtopping.

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5.6 Habitat Engineering

5.6.1 Habitat Water Level Ranges

Surveys of wetlands were completed at a number of locations along the Upper Niagara River to help identify reference wetland conditions for the HIPs (NYPA. 2009). Where key plant species were found, their location was documented by global positioning system (GPS) units and the depth at which the species were located was surveyed and recorded (Figure 5). These elevations were then used to develop recommended elevation ranges and planting zones, as shown in Table 10, for vegetation community types at Frog, Motor, and Strawberry Islands. Appendix D contains a more extensive list of native plant species that may be found along the river in each of the listed planting zones identified in Table 10. This information is critical in the design of optimum planting elevations for desirable species, and may actually be used in discouraging the establishment of invasive species by the limitation of specific elevation bands where undesirable species tend to occur.

TABLE 10. ELEVATION RANGES FOR WETLAND COVER TYPES AT STRAWBERRY, FROG & MOTOR ISLANDS (NYPA, 2009)

Elevation Range	Habitat Type	Planting Zone**
566.2-Higher Elevations	Wet Meadow*	A
565.2-566.2	Shallow Emergent	B
564.0-565.2	Deep Emergent	C
Lower Elevations-564.0	Submerged Aquatic Vegetation (SAV)	D

* Wet meadow habitat should be minimized as this zone is the primary habitat of invasive species
** NYPA (2009) contains a list of native plant species that may be found along the river in each of the listed planting zones

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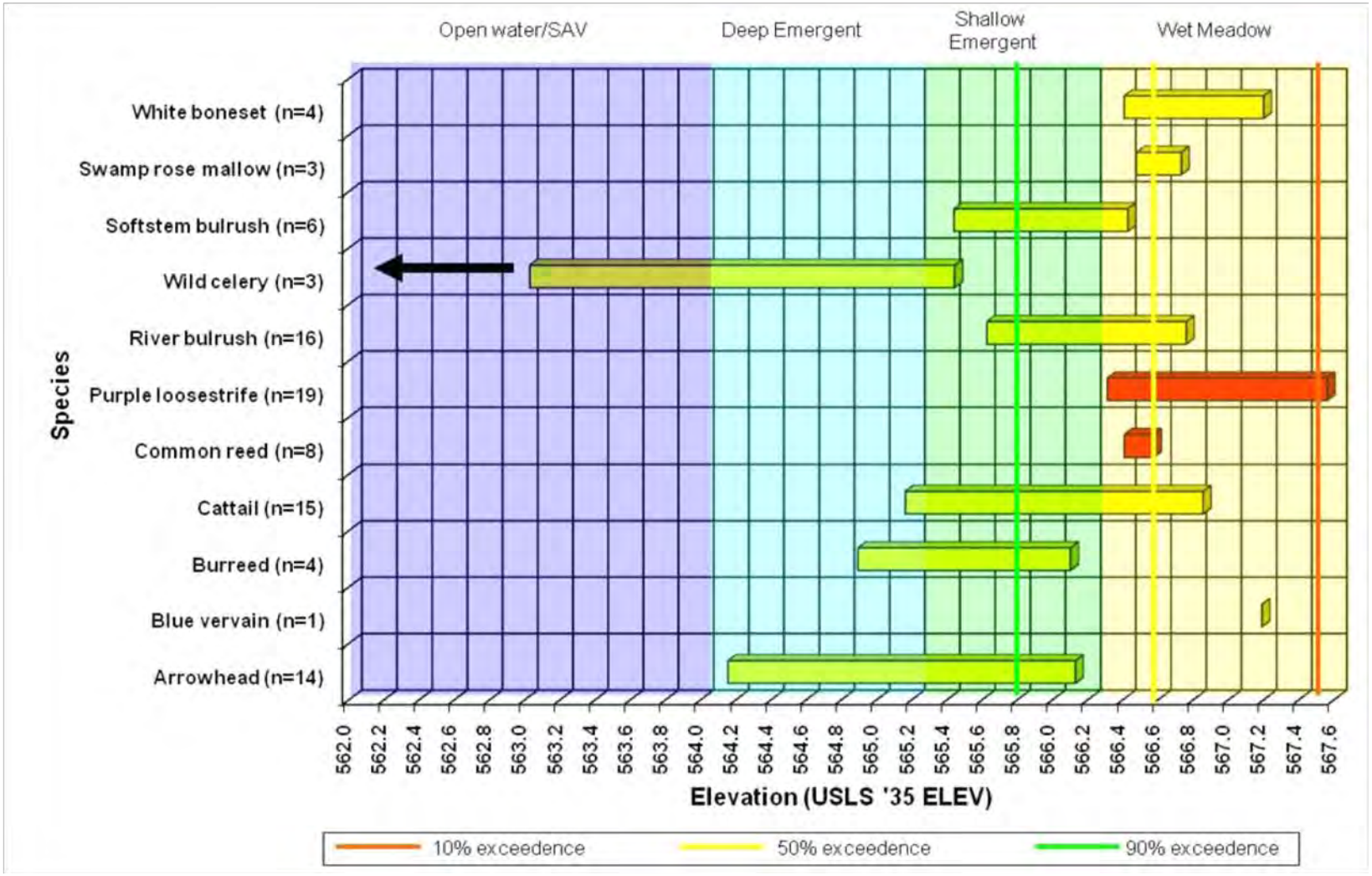
FIGURE 5. WETLAND PLANT DISTRIBUTION AT STRAWBERRY, FROG & MOTOR ISLANDS (BASED ON OBSERVED ELEVATION) (NYPA, 2009)



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In general, all efforts should be made to minimize the potential habitat in the 'Wet Meadow' elevation band, otherwise known as Scrub-Shrub, because invasives such as Purple Loosestrife (and to a lesser degree Phragmites) favor this elevation band. Normal water elevations are El. 566.5 ft, which approximately matches the lowest elevation of the Wet Meadow zone. As noted in the design criteria, habitat in the Deep Emergent and SAV zones should be encouraged (Table 10).

It is worth noting that the data used to develop these elevation ranges and planting zones are based on relatively current, and observed, water levels. As noted in Section 5.1.7 and Figure 3, there are long-term fluctuations in water levels that could result in a shift in plant zone elevations as the plant communities respond to different "wetness" conditions. To minimize the effects of such shifts, designs should incorporate sloped transition zones, rather than specific features for a single habitat type (*e.g.*, a deep emergent bench), where plant species could "march" up and down a slope to match their preferred hydrology. While this may seem contradictory to the aforementioned statement about minimizing the Wet Meadow zone to prevent the establishment of invasive species, this recommendation applies primarily to the Deep Emergent and SAV zones.

5.6.2 Emergent Wetland Engineering

One of the stated design objectives for the HIP is to emphasize deep emergent wetland habitat. To obtain this desired habitat, with either a high or low-breakwater approach, wet meadow and shallow emergent marsh elevation zones should be relatively narrow on the leeward side of the breakwaters to 1.) transition to deeper water that would help to protect from rundown scour of overtopping waves, 2.) maximize the amount of desired habitat area within the HIP, 3.) allow flow and circulation throughout the HIP, and 4.) minimize the area which could host invasive species.

The interior of either design approach should consist of a gentle slope downward towards the middle of the HIP, which then could tie into existing grade on the downstream side. This would allow flushing out of the HIP interior, but the slope would allow a

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transition between the deep and shallow emergent zones, without achieving extensive wet-meadow elevations.

Invasives can be partially controlled using the natural elevations of water levels and fluctuations in the river (Table 9), which either support or inhibit the establishment of certain plant species. Additional control methods, such as placement of inhospitable substrate (*i.e.*, bare rock), using plantings (*e.g.*, larger stock or higher densities) to encourage rapid establishment of desirable species, and stabilizing the substrates with erosion matting during the growth stage, can also be incorporated into designs to help limit the establishment and proliferation of undesirable species.

5.6.3 Submerged Aquatic Vegetation Engineering

A second stated design objective for the HIP is to emphasize SAV habitat. Minimal engineering is required for establishment of SAV, except for meeting depth ranges and protection from damage. From the evaluation of existing SAV beds around Frog Island, the habitat requires a minimum of 2.0-2.5 feet of depth to maintain a well-established bed. There are a number of theories about why this depth appears to be limiting, including damage from ice action, human foot/boat traffic, and wave action in the shallower depths. Regardless of cause, observation of existing exposed, mid-river areas similar to Frog Island indicate that SAV needs at least 2.0-2.5 feet of depth to become well established.

Substrates found in existing SAV beds in the River were observed to vary between a silty sand, sand, or course sand. In particular, Wild Celery appears to prefer sand to silty sand at depths of 2.5 to 3.0 feet[8], with rooting depths of approximately 12 inches. Slightly coarser sand may also be acceptable.

Designs for SAV beds can be accomplished by excavating to the required depths within the protective interior of the breakwaters. By excavating within the protection of the breakwaters, the SAV beds would provide additional depth and habitat diversity within the HIP that is contiguous with the Deep Emergent Marsh zone. Excavation may also help to

[8] Table 3.1.1 in NYPA (2009)

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"loosen" the substrate if it had been compressed under the weight of the historic fill material placed in this part of the river. In addition, it is anticipated that the protection provided by the breakwaters from waves and ice scour would enable SAV to establish where previously it has been limited. The redistribution of material excavated to deepen the SAV areas could be used beneath the breakwaters or to build up some areas within the HIP, which would provide additional depth diversity and may help to create a balanced fill/cut volume.

5.7 Sediment Analysis/Flushing

Frog Island should be designed to allow the passage of flows through the breakwater, to supply the interior with sediment, nutrients and flushing flows. There are no specific minimum velocities required within the island, other than maintaining a dynamic, yet stable, environment. Given the semi-permeable nature of the low-crested breakwaters, additional flushing would occur as water is transmitted through or over the breakwater. Excessive settlement and filling of the Frog Island interior is not anticipated due to the limited sediment (*i.e.*, bed, suspended) load in the river.

A preliminary level analysis of the impacts to sediment mobilization and transport capacity was completed. This review was performed to determine if the altered hydraulic properties of the river due to a small loss of available flow area from the establishment of the island would result in a change of sediment mobilization capacity. This review showed that there was minimal to no change in sediment mobilization capacity near the island.

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6.0 RISK ANALYSIS

6.1 Wave Damage

Frog Island is located in a dynamic river environment, which is subject to rapid and dramatic changes to water levels due to storm surges on Lake Erie, as well as long-term changes in both flow and water levels. There are two hazards associated with wave action at Frog Island: 1.) damage to the exterior rock armor from unit movements and dislocations, either from wave runup, or rundown, and 2.) overtopping waves plunging into the island interior, disrupting habitat, damaging sensitive wetland soils, or damaging SAV.

There is a potential for overtopping of Frog Island from waves during normal pool levels (El. 566.5 ft), but the risk increases as the river stage around the island increases or as the height of breakwaters above normal pool level decreases. Consequently, a seiche caused by a westerly to south-westerly wind also exposes Frog Island to the greatest fetch, and the most vulnerable conditions are a slightly elevated river stage with larger waves. Under these conditions, the HIP area would be subject to a greater degree of overtopping of exposed breakwater, which would then pass more waves toward the HIP interior. However, as the river stage continues to rise, the inundation of the HIP results in greater water depths. With greater water depth, the waves are able to move over the riverbed without inflicting substantial damage to the submerged features. As a result, the inundation could act to protect the breakwaters and even the interior wetlands.

The crest of the high-breakwaters would be approximately El. 569.0 ft, which will likely be overtopped by still-water levels on an annual basis. The water level and fluctuation report lists annual maximum water levels at Huntley and Frenchman's Creek gages from 1991-2002 (NYPA, 2005), and the top of the proposed breakwater would have been exceeded by these still-water levels each year except for two during this period. Wave action, which will likely be included with increased stages, would result in more frequent overtopping of the breakwaters. Water levels at the 5% exceedence level are El. 567.6 ft, which allows only 1.4 feet of freeboard for runup wave action for the higher crest, compared to normal still-water levels that allow 2.5 feet of freeboard. Overtopping is expected, and

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will be considered a regular occurrence, but greater depths, as noted above, could also allow for increased protection to the island interior.

The crest of the low breakwater would be approximately El. 567.0 ft, which is approximately 0.5 feet above the long-term average water level. At this level, waves would approach this shallow shelf and ground out so that they are unable to sustain their form, which would result in a breaking wave. The length of the shallow breakwater allows this breaking wave to runout and dissipate its energy over the shallow, armored bottom before reaching the internal island habitat. As the water level rises due to lake level variations or seiches, the shallow breakwater will become inundated. Under these conditions, large waves would still ground out and dissipate energy as they pass over the breakwater. But smaller, shallower waves would progress into the interior, where the increased depth would assist in limiting damage to the sensitive interior habitat. The breakwater is designed to allow protection from wave energy over a range of water levels and wave heights.

6.2 Ice Damage

It is difficult to evaluate the frequency or risk incurred from ice damage to habitat within the interior of the HIP, and thus subjective observations are required. Ice loading on the head of the HIP is an important issue in this part of the river, as evidenced by ice damage to tree trunks approximately 30-inches above average water levels at the heads of both Strawberry and Motor Islands. Early spring (May 2009) observations on the western side of the head of Strawberry Island also identified a section of low-profile breakwater (approximately 22 inches above WSEL), where all the vegetation had been pushed down, and several rocks had been pushed towards the island interior. This damage was apparently due to either direct pushing by ice blocks, or ice blocks subject to wave action.

Although it is not fully understood why, the shallow areas at Frog Island, which are largely at a depth of 2.5 feet or less, is absent of established SAV. One theory is that the scraping effect of ice at this shallow depth each winter limits plant growth. Regardless of cause, SAV was not observed in any part of the Upper Niagara River that had similar depth,

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fetch, and velocity conditions as Frog Island. Therefore, it is relatively certain that unprotected habitat in this area cannot sustain SAV. It should be noted that conditions at Frog Island are quite different than those at Strawberry Island, whose head is well protected with trees, bushes, and a larger height of land and riprap breakwaters above normal water levels. These features help to protect the shoreline from rideup ice, and help keep ice from pushing over the head of Strawberry Island into the interior.

The ice model results show buildup of ice on the leading upstream edges of islands, including the proposed Frog Island, as ice movement is driven more by currents than wind and wave action. Based on historic data of major ice events, thickness may reach 2 to 3 feet, and currents may push ice into the island interior if the breakwater is not of sufficient height. With estimated shear forces of 30-75 lb/ft of force, the breakwater crests are also subject to armor being pushed over if the height is too shallow. Ice that enters the protected interior could potentially scour the vegetation and damage the root zones. Ice that forms in the interior is not viewed as a threat, and may actually help protect portions of the island interior, but large blocks pushed over the breakwater can be potentially quite damaging to the island interior.

6.3 Habitat Sustainability

The islands, shorelines, wetlands, and SAV habitat in the Upper Niagara are dynamic and have dramatically changed over time with regard to their footprints and biotic (plant communities) and abiotic (topography, bathymetry, soils) characteristics. These changes are in response to a disturbance regime that involves both natural (long-term climatic changes, ice, seiches, wind waves, etc.) and anthropogenic (dredge disposal, gravel mining, boat wakes, shoreline hardening, water level controls, ice booms) forces. The current design approaches should try to reproduce the function of naturally occurring reference conditions, which can be accomplished through the use “hard” features such as rock breakwaters and geotechnical mattresses, combined with “softer” sloped vegetative surfaces to enable transitions in plant communities. These techniques should be supplemented with aggressive planting plans to speed initial establishment and stabilization of the site. These steps will

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enhance the chances that the wetland complex will persist against the dynamic forces present, while at the same time attempting not to over-design with obtrusive structural features with a narrow range of depth tolerances that would prove to be unrealistically difficult to construct or result in undesirable ecological effects.

The design approaches should also try to protect substrates and plants from ice and waves. It is hoped that roots of perennial marsh species such as soft stemmed bulrush will be able to "hide" in protected areas such as under rocks, so that even if a winter event scours the emergent habitat, there will be live plant material remaining within the sheltered spaces to re-colonize the marsh zone.

It is important to note that the collaboratively developed design criteria call for creating a sustainable HIP that emphasizes deep emergent marsh and SAV habitat. To be sustainable, the HIP will be required and expected to able to respond to both seasonal variability and changes in long-term trends. To this end, we expect that forces such as ice, water levels, and waves will result in year-to-year changes in the vegetative community, with some subtle and some more dramatic. Such year-to-year changes are part of the HIP's design criteria, and are even desirable in as much as they mimic both the temporal and spatial habitat diversity found in nature. We also expect that some maintenance of the breakwater structures and interior habitats may be needed as a result of the cumulative effect of typical conditions, or after extreme storm events. Because many of these conditions and resulting effects cannot be accurately predicted, an adaptive management approach will be used to respond to and address identified needs throughout the life of the project.

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7.0 CONCLUSIONS

The development of new habitat in the vicinity of Frog Island requires detailed civil engineering design, involved ecological assessments, hydrologic and hydraulic engineering, and a bit of art all working in concert together. There are several different approaches to try to create the objective habitats, but regardless of approach, the HIP needs to achieve the set goals, be sustainable, not require excessive maintenance, and be constructible without damaging existing habitats. There is some uncertainty and risk involved in development of the Frog Island habitat because this area is dynamic in nature and severe conditions (either from wind driven waves or ice) are expected to occur at some point in time. There is additional uncertainty with respect to changing flows (hydrologic availability), long-term meteorological conditions and water levels, and even new invasive species. It should be recognized that Frog Island will be designed to be a dynamic habitat capable of adjusting to changing conditions. The information and approaches outlined in this report will be used to develop appropriate designs that will give the riverine wetland complex the best chances of successful initial establishment.

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8.0 ADDITIONAL RESOURCES

Design of the island and the shoreline protective structures involved extensive guidance from the USACE's Coastal Engineering Manual (2006). Pertinent design sections include the following:

- Part VI Chapter 3 Site Specific Design Conditions
- Part VI Chapter 4 Materials & Construction Aspects
- Part VI Chapter 5 Fundamentals of Design, Part I
- Part VI Chapter 5 Fundamentals of Design, Part II
- Part VI Chapter 5 Fundamentals of Design, Part III
- Part VI Chapter 6 Reliability in Design

Additional guidance was developed from technical notes from the USACE Coastal Hydraulics Laboratory (CHL), in Section III – Coastal Structures. These notes are available at: http://chl.erdc.usace.army.mil/chetn.

- CHETN-III-64 Damage Development on Stone-Armored Breakwaters
- CHETN-III-67 Wave Momentum Flux Parameter
- CHETN-III-71 Breakwater and Revetment Armor Stability
- CHETN-III-72 Uses for Marine Mattresses in Coastal Engineering

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APPENDIX A

HISTORICAL MAP AND AERIAL PHOTOGRAPHS

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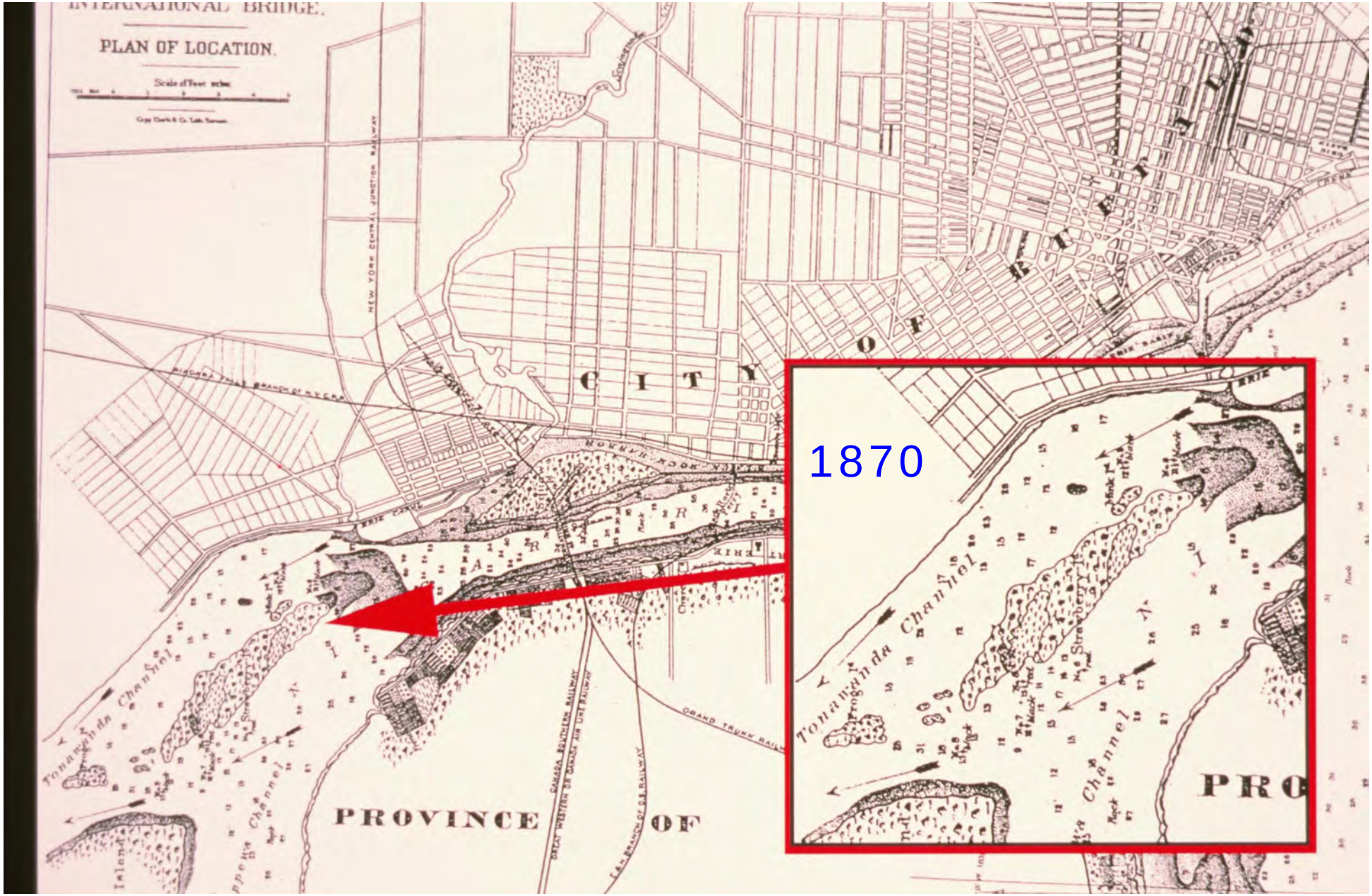
Black Rock

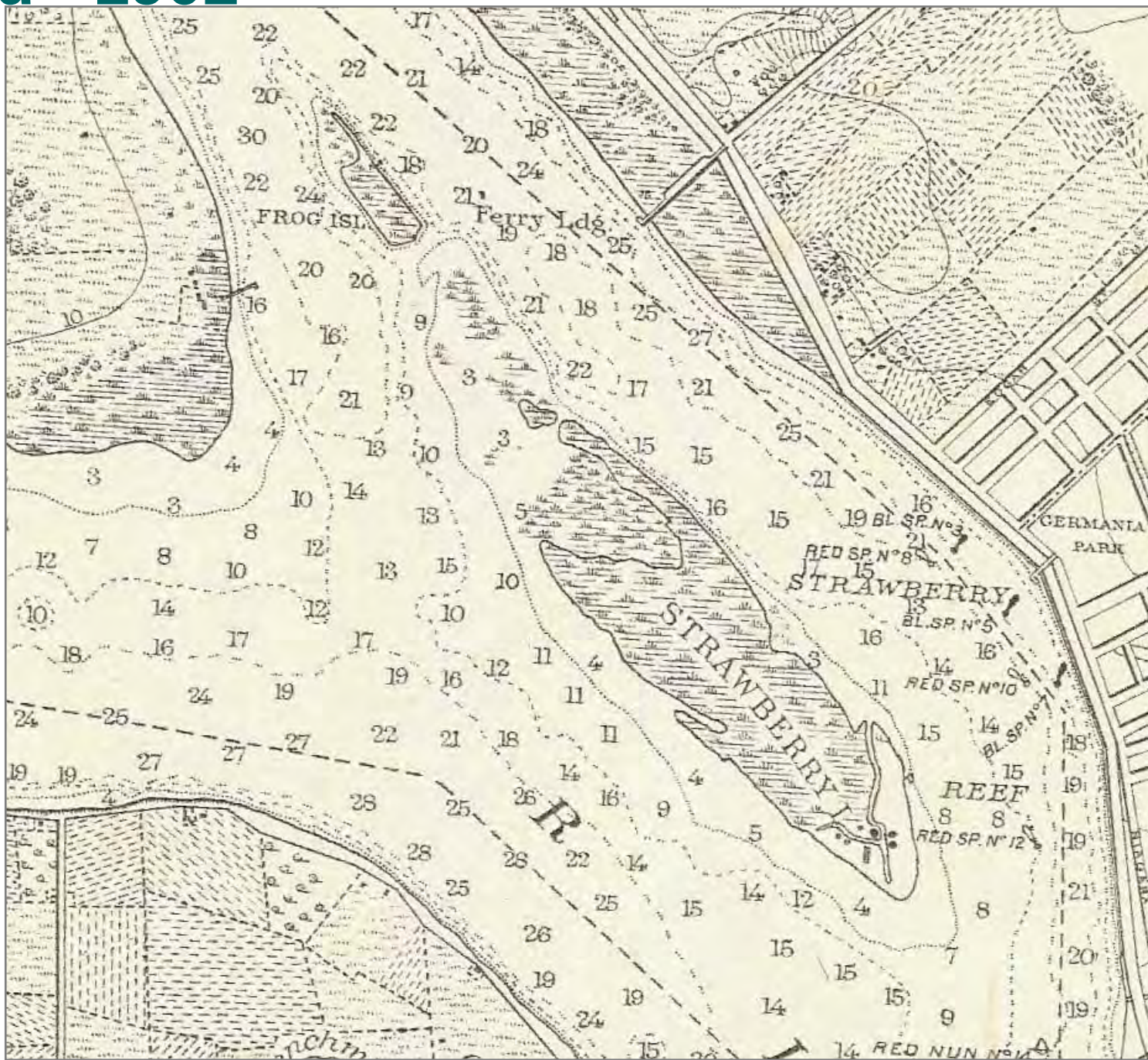

INTERNATIONAL BRIDGE.
PLAN OF LOCATION.
Scale of Feet
NEW YORK CENTRAL JUNCTION RAILWAY
CITY OF BUFFALO
PROVINCE OF
Tonawanda Channel
Strawberry Island
Island
GRAND TRUNK RAILWAY
CANADA SOUTHERN RAILWAY
ERIE CANAL
1870
Tonawanda Channel
Strawberry Island
PRO

Frog Island - 1902

Below average water year

First evidence of unique shape on downstream end of Strawberry Is

Is shape from dredge spoil dumping from the east channel or was material removed to cause shape?

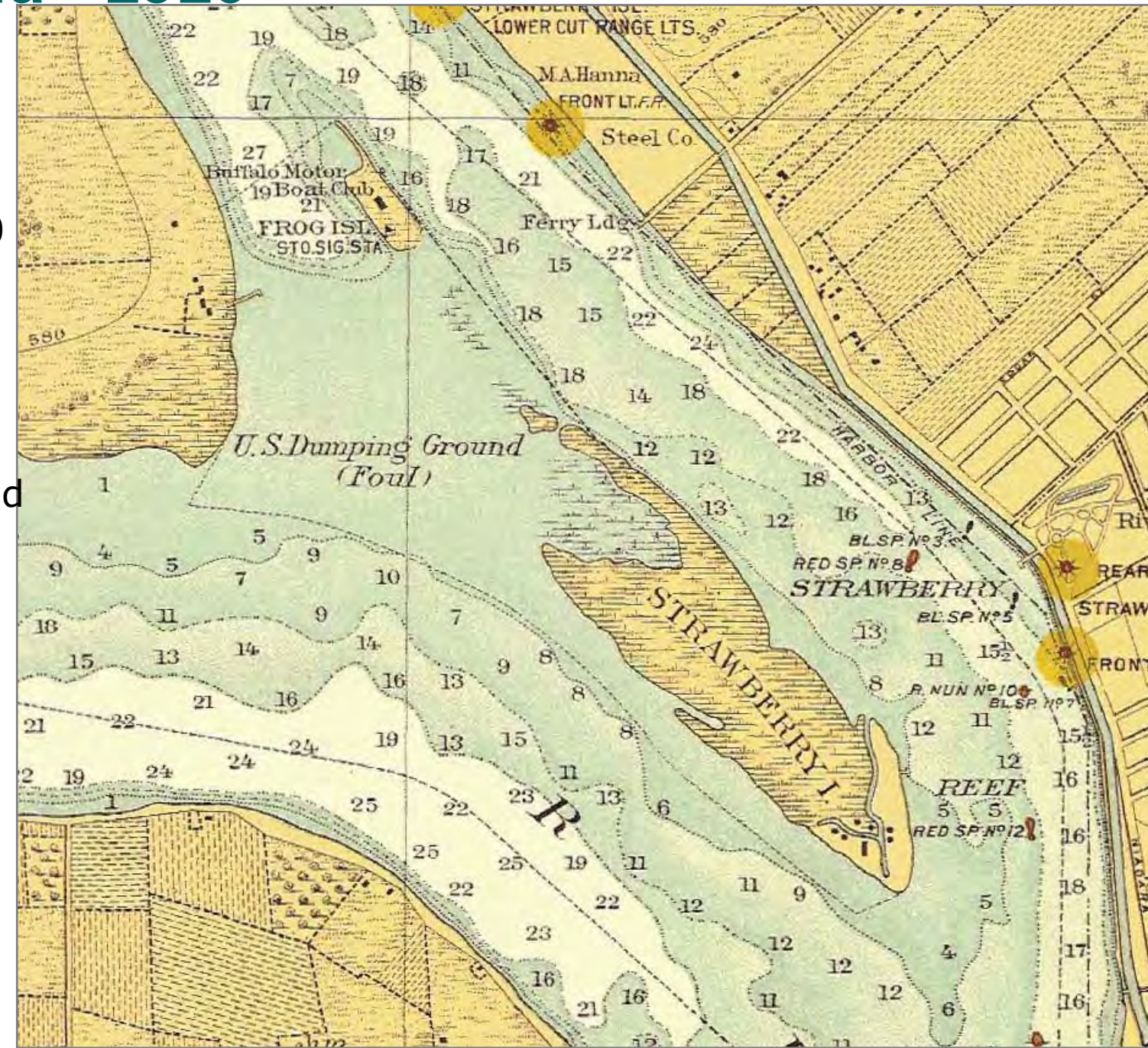


Frog Island - 1910

Below average water year

Doubled to 200 acres since 1820 from dredge spoils from Erie Canal and Black Rock Lock

Strawberry Island had a two-story hotel, and a small canal was constructed through the island for fishing

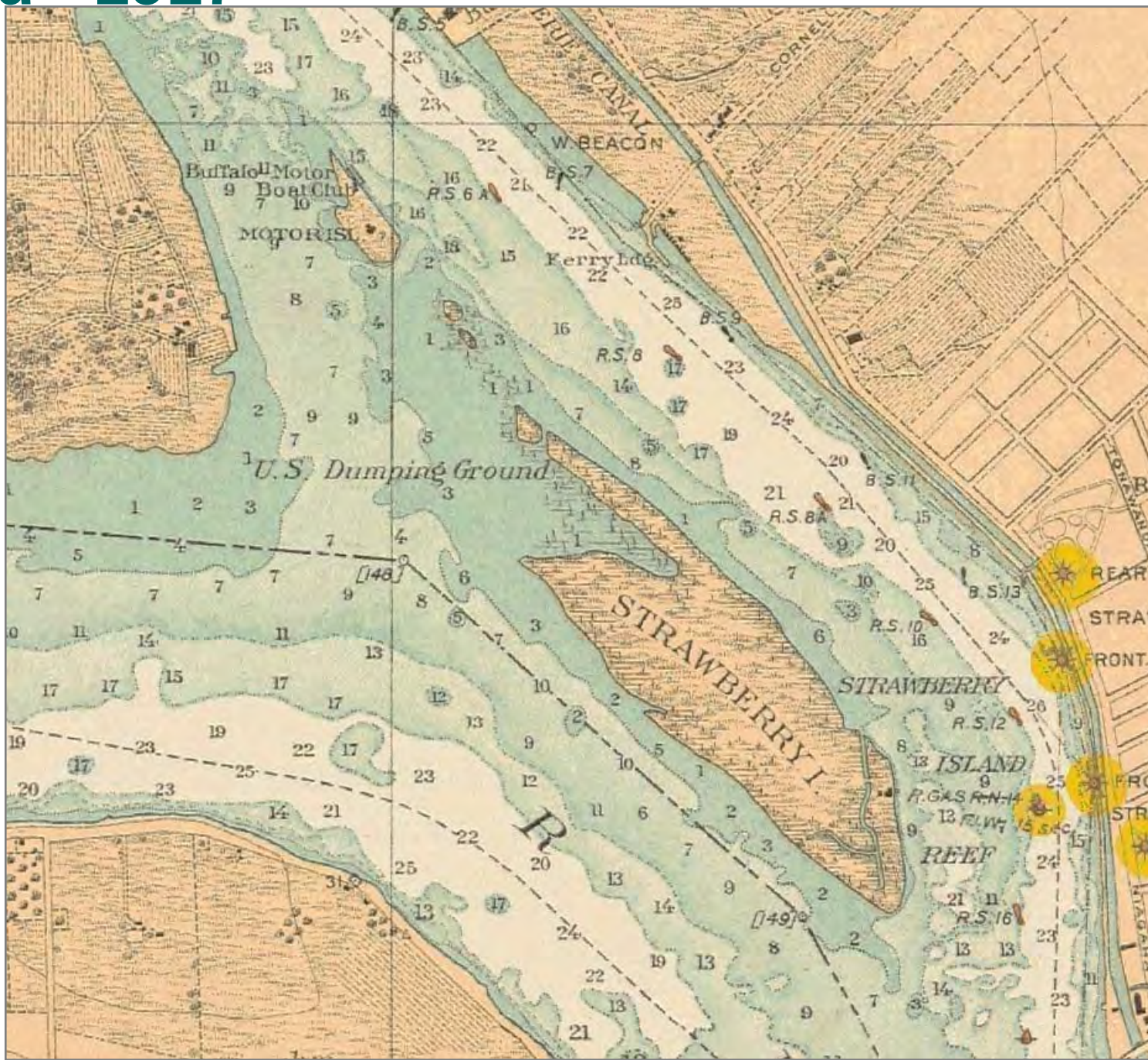


Frog Island - 1917

Average water year

7 years later – similar shape and size

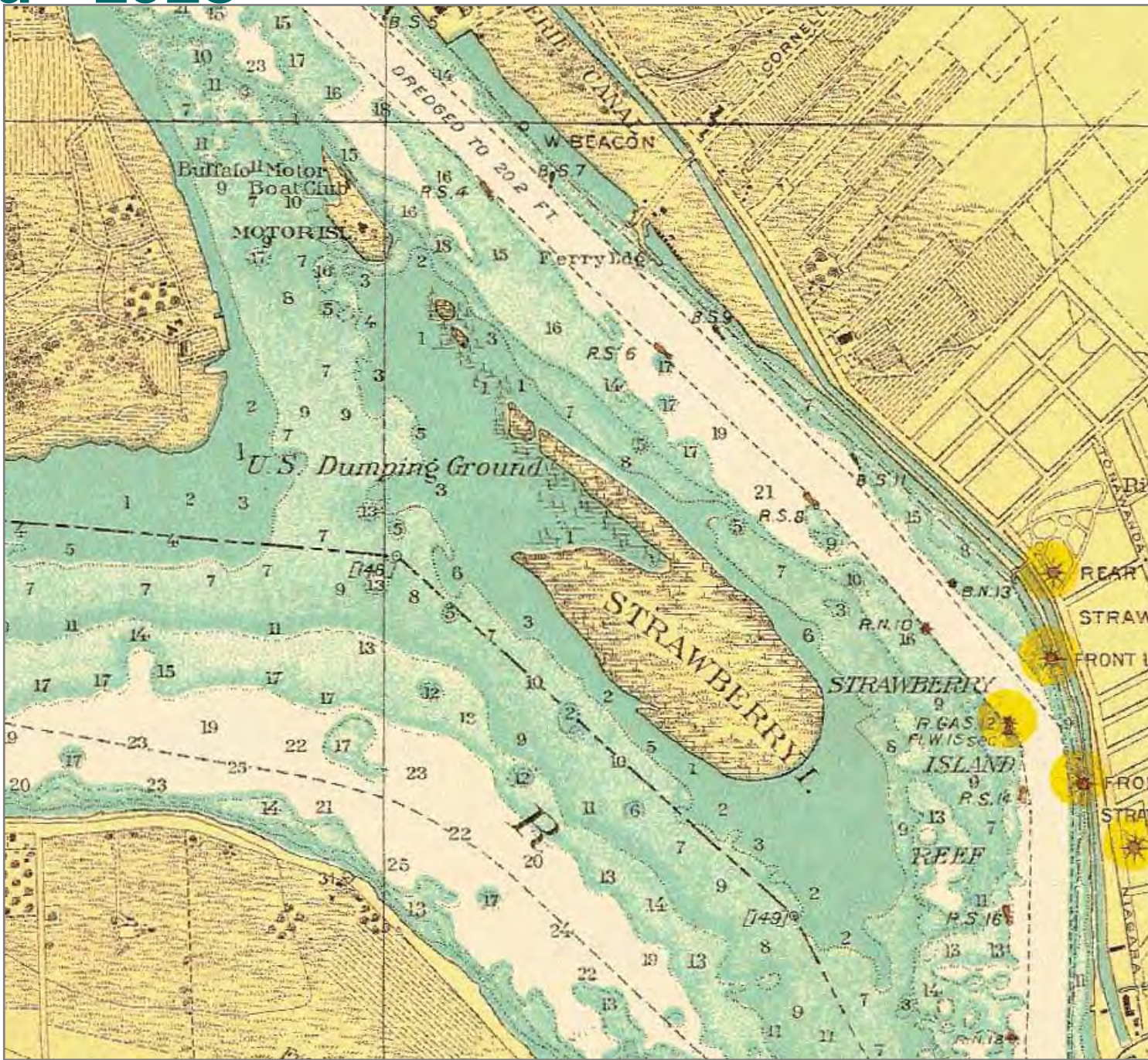
First evidence that Frog Island is renamed "Motor Is"



Frog Island - 1923

Below average water year

6 years after 1917, upper tip of Strawberry seems to be missing



Frog Island - 1927

Below average water year

First aerial

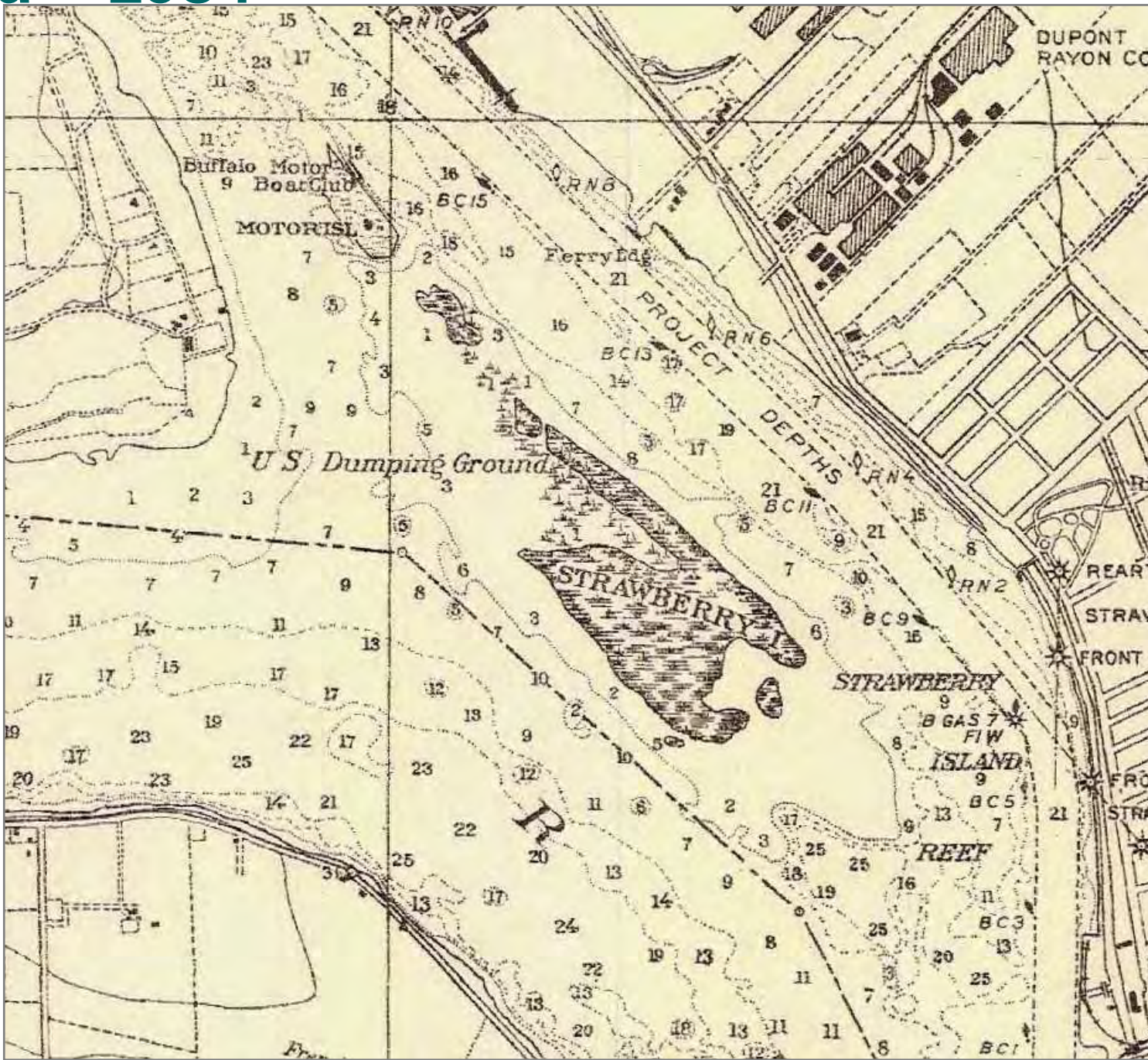
Sand and gravel mining mid-1920s to 1953

1932

Frog Island – 1934

Historic low water year

More changes to Strawberry Is – particularly at the upper tip



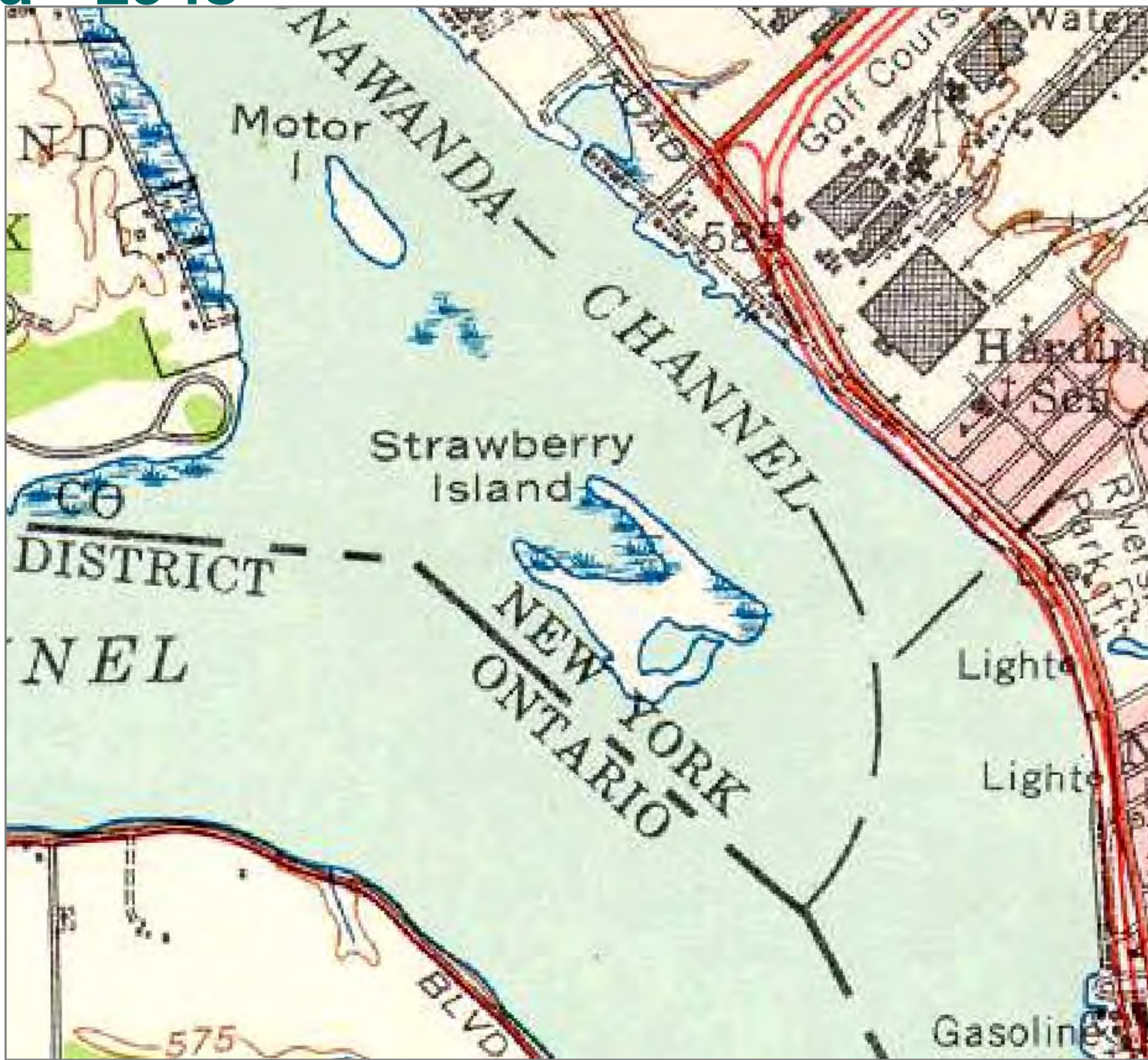
Frog Island - 1938

Below average water year

Largest point in photo history ~ 4 ac.

Frog Island - 1948

Average water year

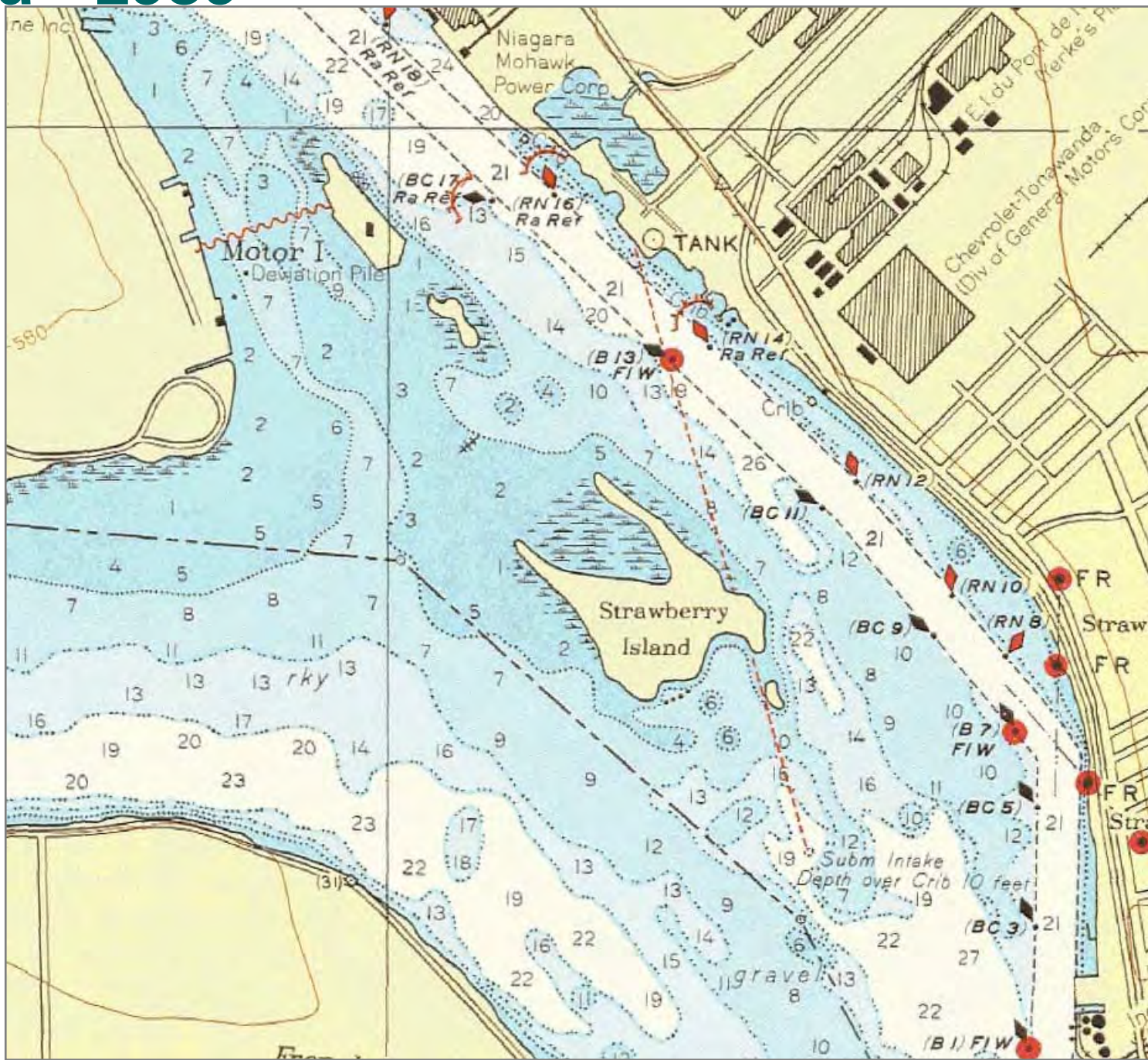


Frog Island - 1951

Average water year

Frog Island - 1959

Below average water year



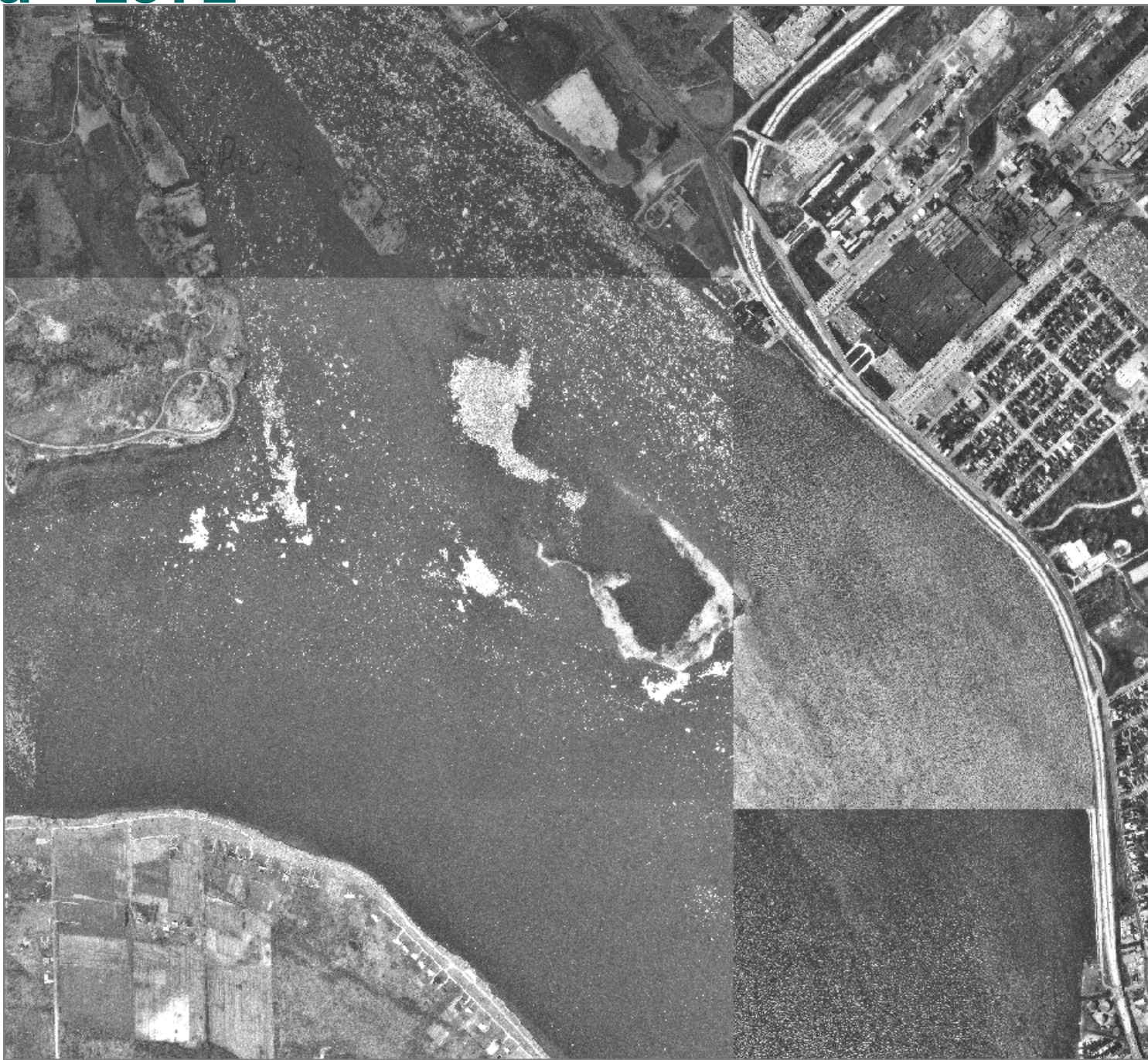
Frog Island - 1966

Low water year

Frog Island - 1972

Above average water year

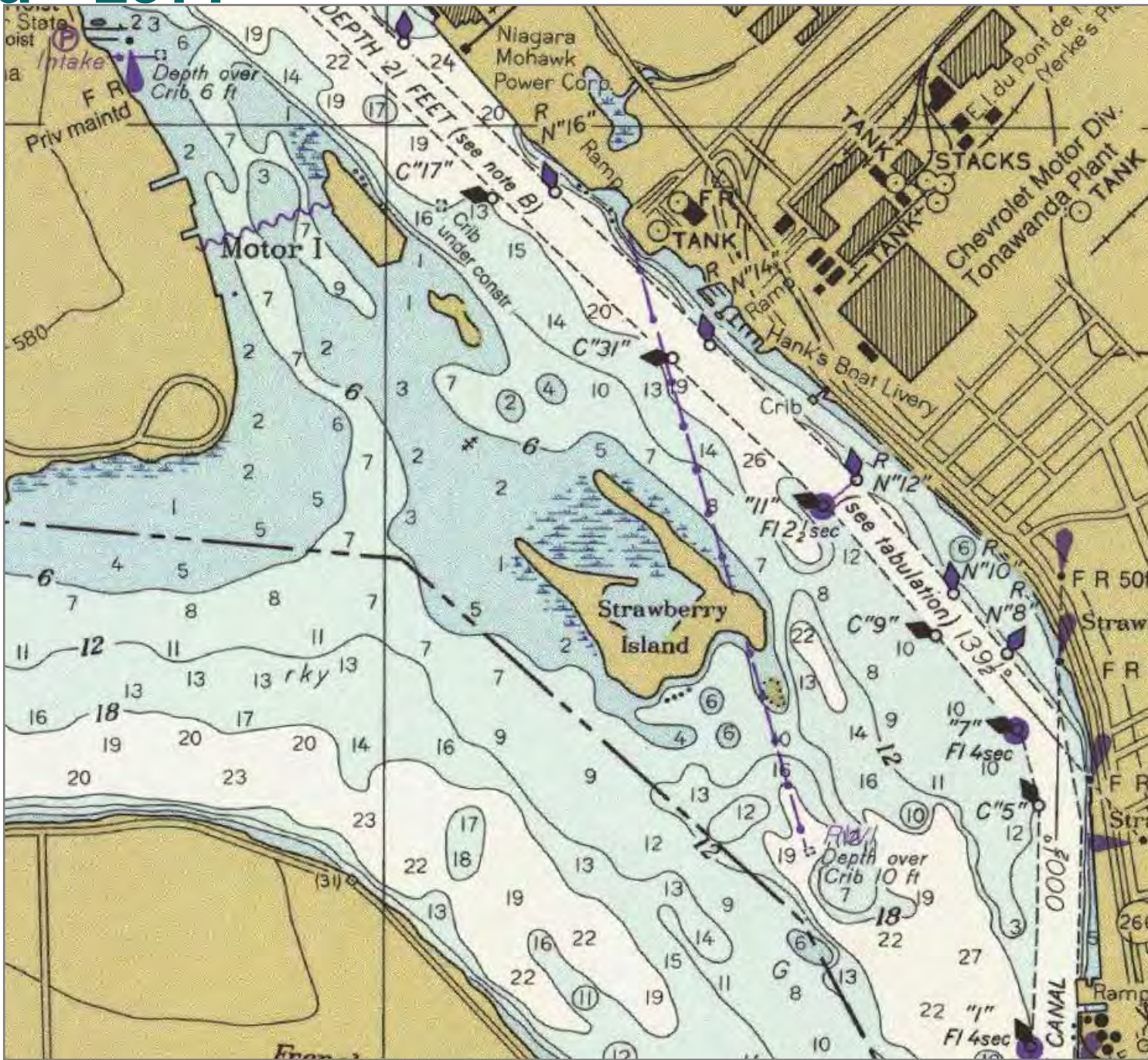
Still visible above water?



Frog Island - 1977

Historic high water year

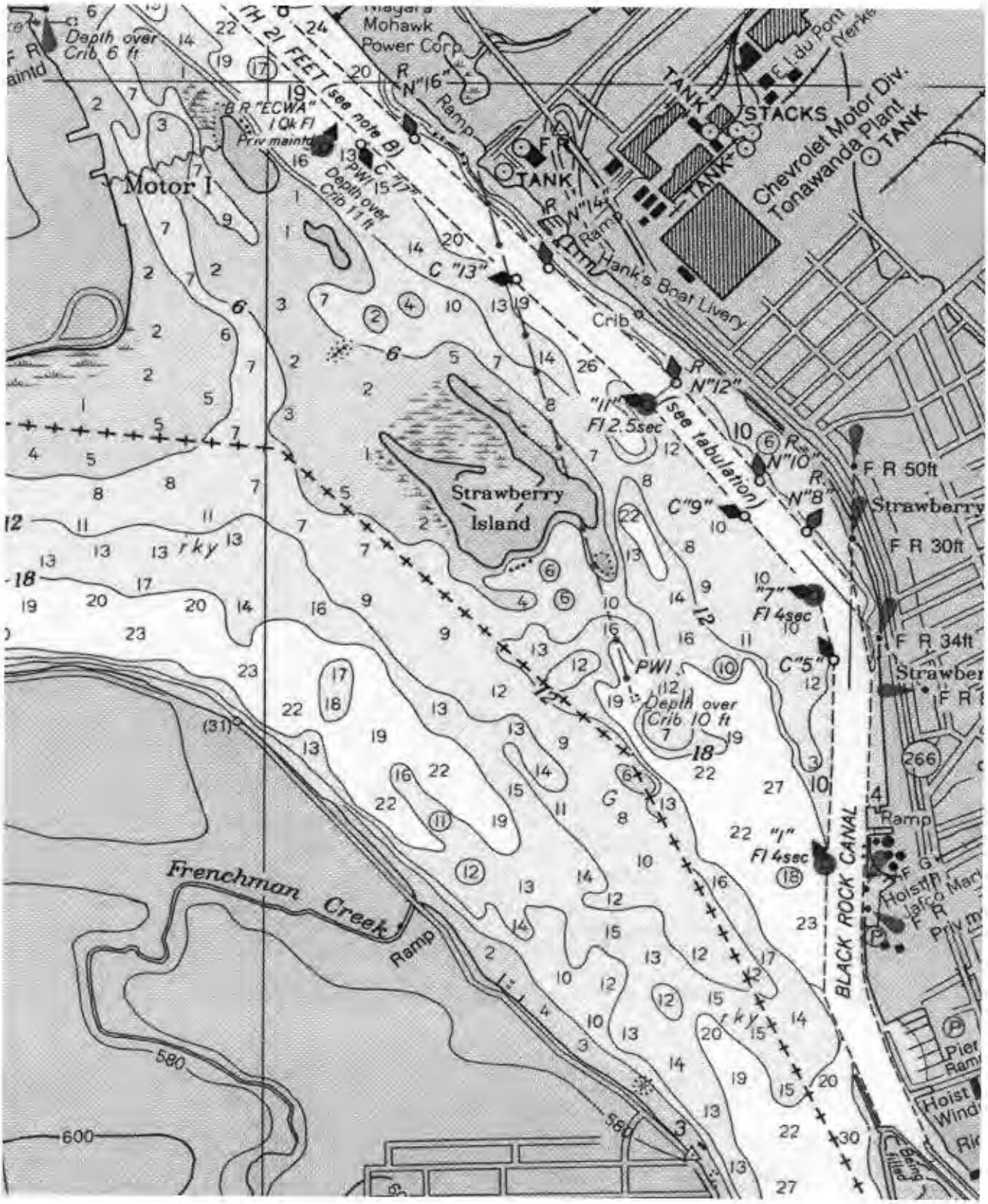
Erosional processes appear to be evident



Frog Island - 1978

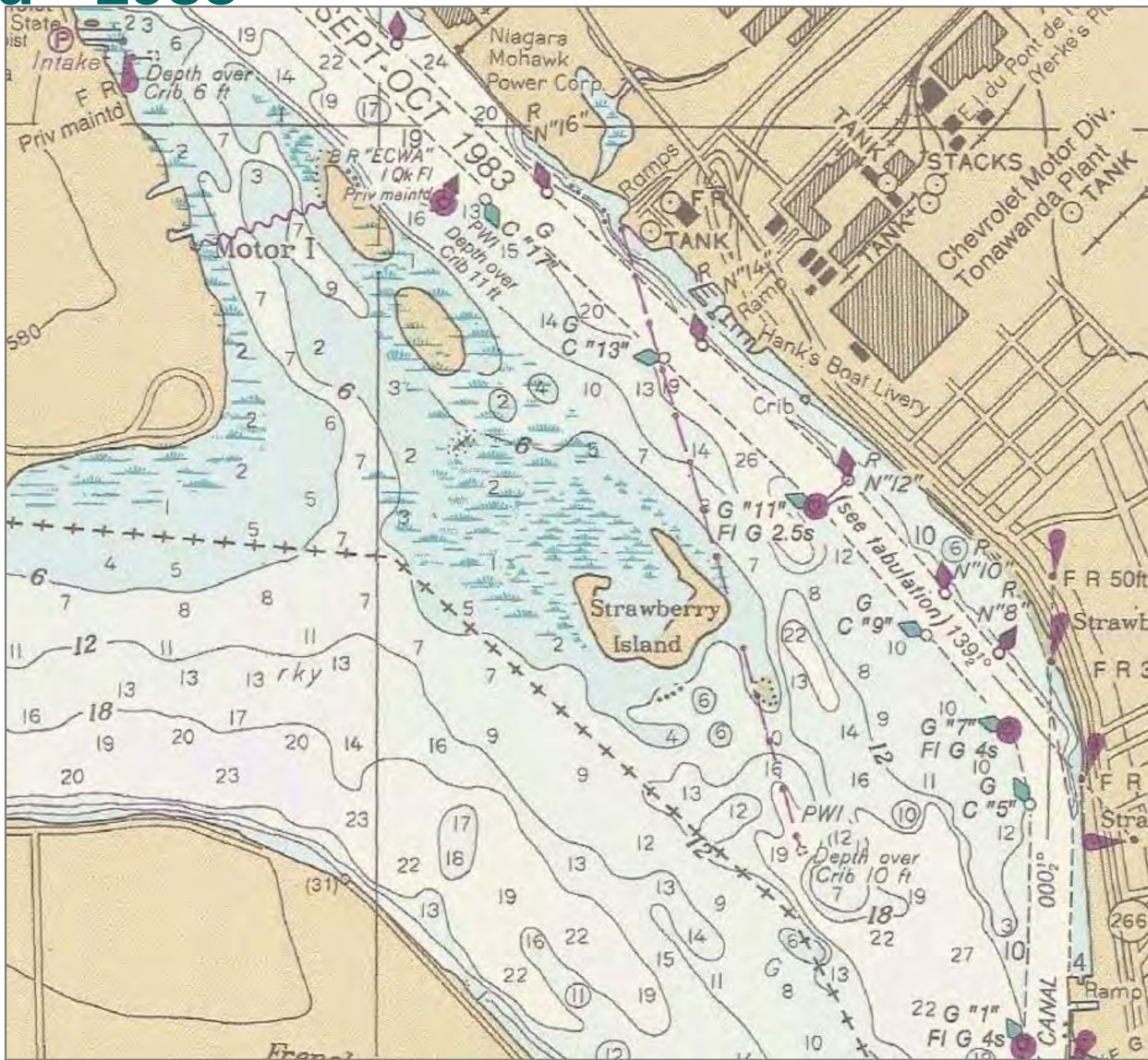
Above average water year

1981


Depth over Crib 6 ft
Niagara Mohawk Power Corp.
21 FEET (see note B)
N"16"
Ramp
B R "ECWA" 1 Qk Fl
Priv maintd
Motor I
PWI
C "17"
Depth over Crib 11 ft
TANK
STACKS
E. I. du Pont
Chevrolet Motor Div. Tonawanda Plant
N"14"
Hank's Boat Livery
C "13"
Crib
N"12"
"11" Fl 2.5sec
(see tabulation)
N"10"
N"8"
F R 50ft
Strawberry Island
C"9"
F R 30ft
"7" Fl 4sec
F R 34ft
C"5"
Depth over Crib 10 ft
"1" Fl 4sec
BLACK ROCK CANAL
Frenchman Creek
Ramp
580
600

Frog Island - 1985

Above average water year



Environmental FirstSearch

Historical Aerial

1985

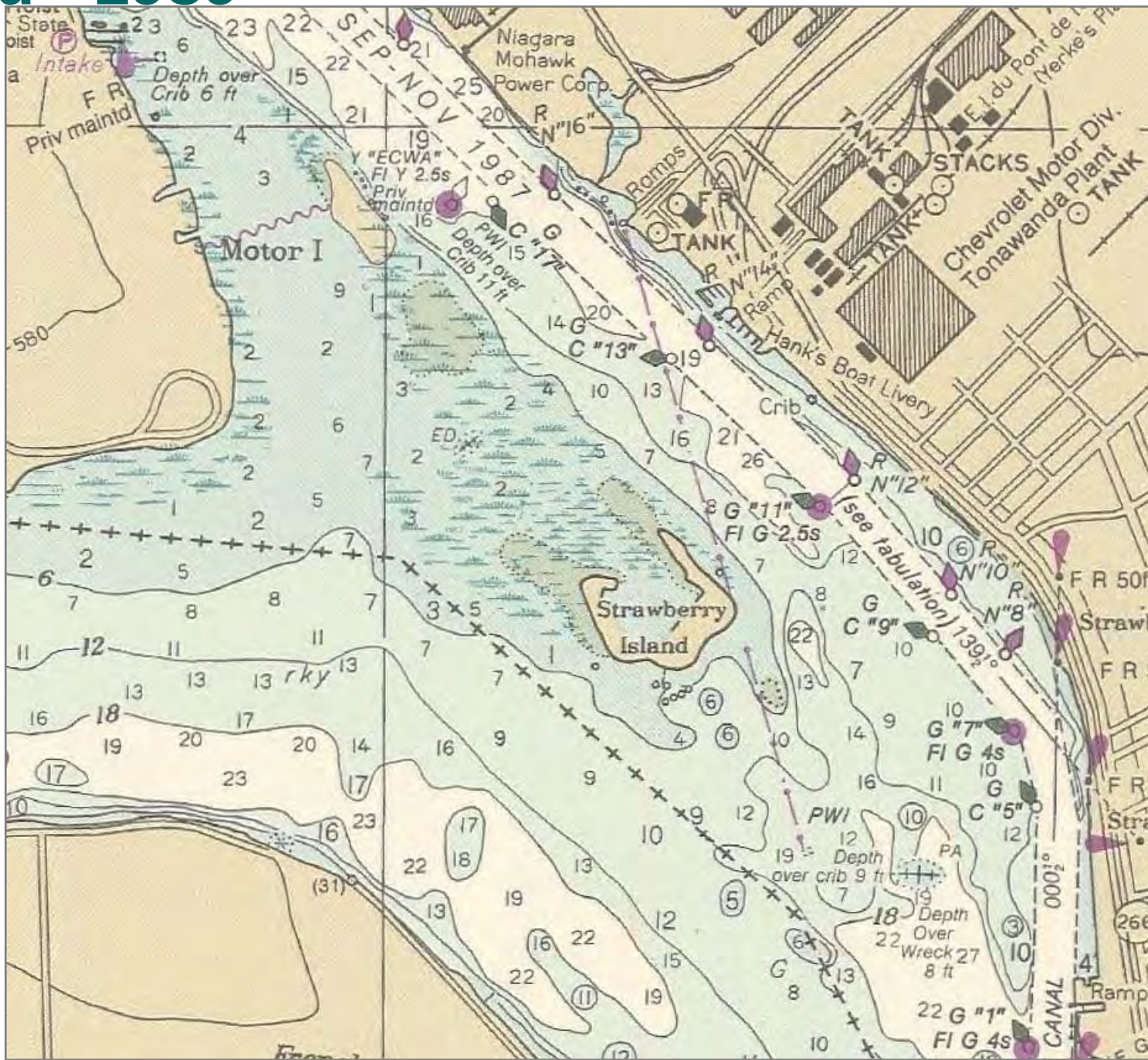
, BUFFALO NY 14207

Source:
Target Site (Latitude: 42.964365 Longitude: -78.934059)
Quad Name: Buffalo NW
Date: 1985

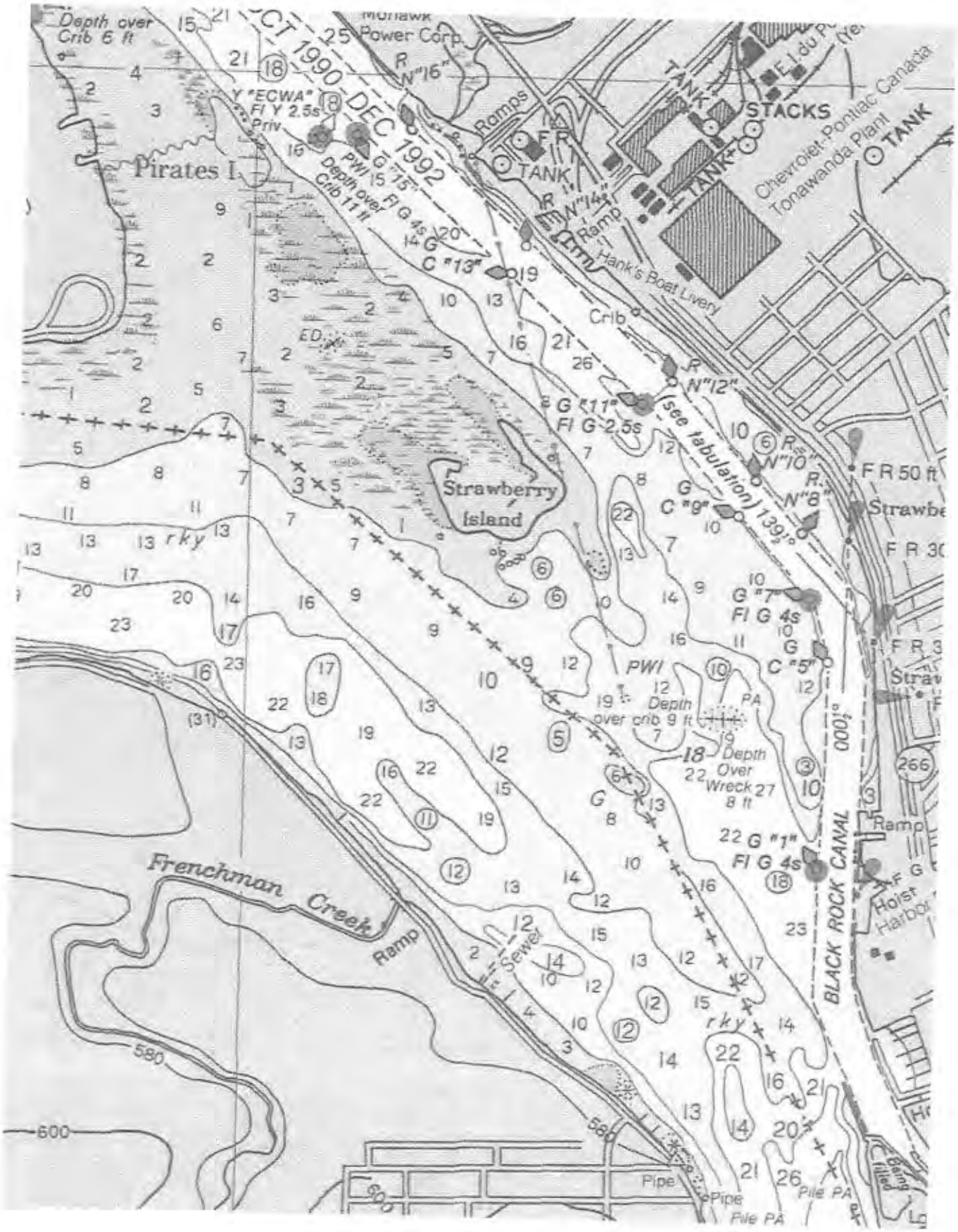
COPYRIGHT: MICRODOT, INC

Frog Island - 1989

Above average water year



1992


Depth over Crib 6 ft
Mohawk Power Corp.
OCT 1990 DEC 1992
Y "ECWA" Fl Y 2.5s Priv
Pirates I.
Depth over Crib 11 ft
Ramps
TANK
STACKS
Chevrolet-Pontiac Canada Tonawanda Plant
Hank's Boat Livery
Crib
Strawberry Island
(see tabulation) 139
Depth over crib 9 ft
Depth Over Wreck 8 ft
BLACK ROCK CANAL
Frenchman Creek
Ramp
Sewer
Pipe
Pile PA
Hoist Harbor

Environmental FirstSearch

Historical Aerial

1995

, BUFFALO NY 14207

Source:
Target Site (Latitude: 42.964365 Longitude: -78.934059)
Quad Name: Buffalo NW
Date: 1995

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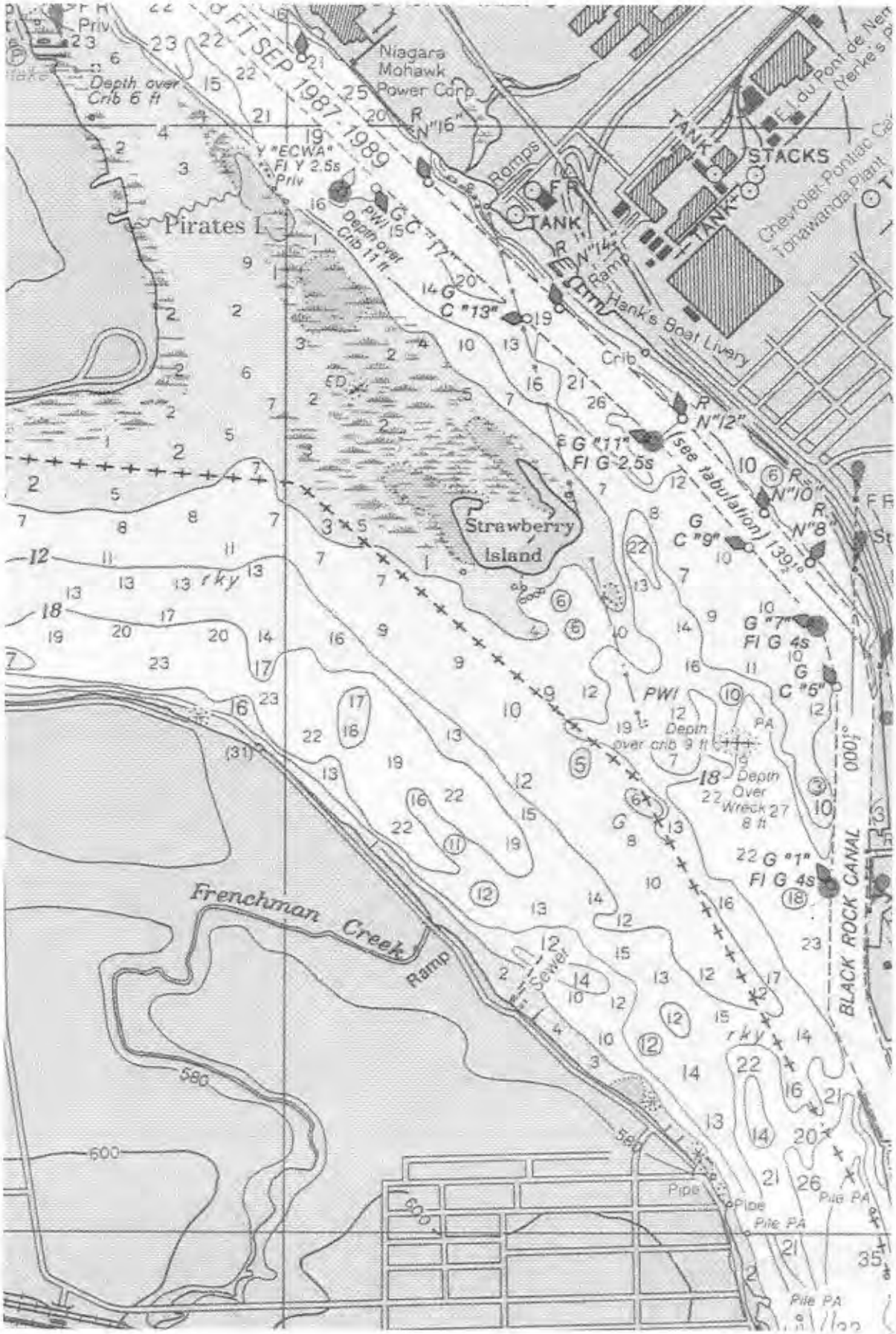
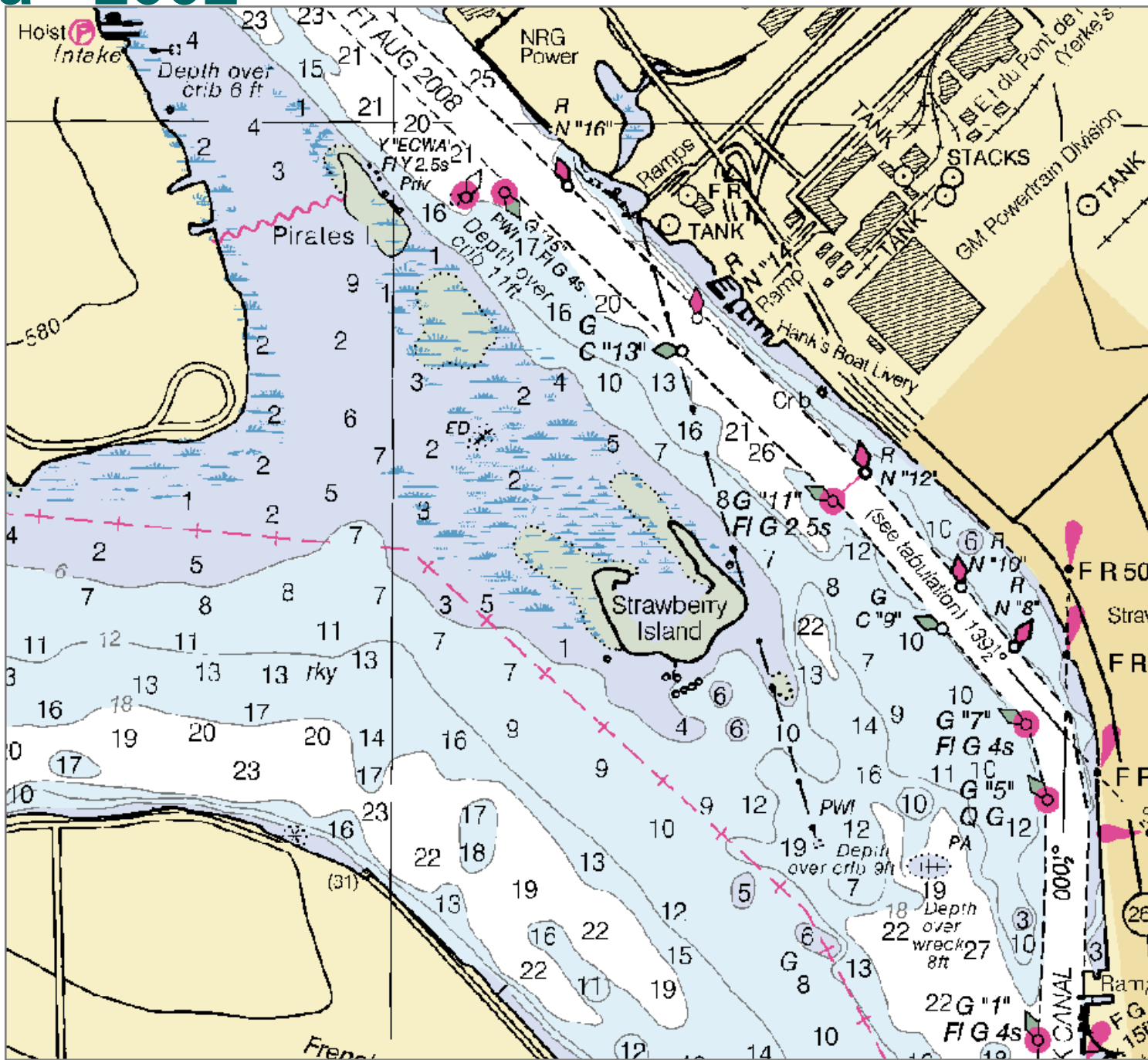
1995


Niagara Mohawk Power Corp.
Depth over Crib 6 ft
Y "ECWA" Fl Y 2.5s Priv
Pirates I.
Depth over Crib 11 ft
Ramps
TANK
STACKS
Chevrolet-Pontiac Tonawanda Plant
Hank's Boat Livery
Crib
G C "13"
G "11" Fl G 2.5s
(see tabulation) 139
Strawberry Island
G C "9"
G "7" Fl G 4s
G C "5"
Depth over crib 9 ft
Depth Over Wreck 8 ft
G "1" Fl G 4s
BLACK ROCK CANAL
Frenchman Creek
Ramp
Sewer
Pipe
Pile PA

Frog Island - 2002

Below average water year

Frog Island no longer exposed during low water periods – erosion?



Frog Island - 2005

Average water year

Frog Island – 2006-2007

Frog Island – 2009

APPENDIX B

WAVE CALCULATIONS

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MEMORANDUM

TO: Design Team

FROM: Jonathan Quebbeman, Kleinschmidt

DATE: March, 2009

RE: Frog Island Wave Height and Runup

Reference: EM1110-2-1100 Part II, Chapter 2, Coastal Engineering Manual (CEM) "Meteorology & Wave Climate"

Check required wind duration:

$$t_{x,u} = 77.23 \frac{X^{0.67}}{u^{0.34} g^{0.33}}$$

X = Wind Fetch (km) = 2.4km or 2400m (SW direction)
U10 or u = 10m wind speed = 40mph = 18 m/s
g = gravity = 9.81 m/s2
T(x,u)=2503 seconds = ~42 minutes
*Wind speed assumed for sample calculations
Therefore:
*One-hour winds would be fetch limited, one-mile (minute) winds would not.
*Use one-hour wind values

Estimate Friction Velocity (u*)

$$C_D = 0.001(1.1 + 0.035\, U_{10})$$

U10 = 18 m/s
C_D = .00173

$$C_D = \frac{u_*^2}{U_{10}^2}$$

Therefore:
u*=0.7487 m/s

Estimate Zeroth-Moment Significant Wave Height (H_{mo})

$$\frac{gH_{m_0}}{u_*^2} = 4.13 \times 10^{-2} * \left(\frac{gX}{u_*^2}\right)^{\frac{1}{2}}$$

Solve for H_{mo}
Hmo = 0.48m = 1.6 ft

Wave Period (T_p)
*Check deep-water Tp first:

$$\frac{gT_p}{u_*} = 0.751\left(\frac{gX}{u_*^2}\right)^{\frac{1}{3}}$$

Tp = 2.0 sec

Check wave period against shallow water limiting wave period – cannot exceed this calculated Tp:

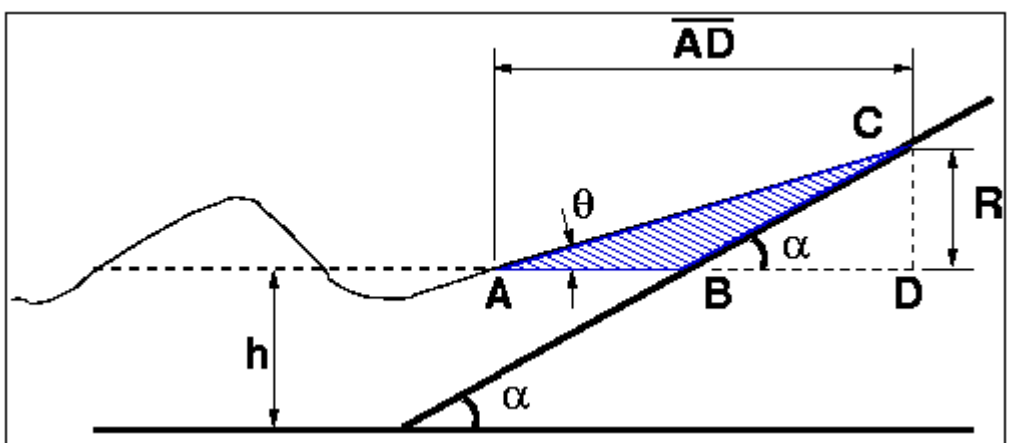
$$T_p \approx 9.78\left(\frac{d}{g}\right)^{\frac{1}{2}}$$

d=2m (assumed average channel depth during storms)
Tp=4.42 sec

*This wave period is not limiting to shallow waters, and the fetch/wind calculated wave period of 2.0 seconds will be utilized for runup calculations.

Check Wave Runup
Reference: ERDC/CHL CHETN-III-70, ACOE
"Estimating Irregular Wave Runup on Rough Impermeable Slopes", July, 2005

α=3:1
tan α =0.333



Irregular Wave Runup on Rough Impermeable Slopes:

$$\frac{R_{u2\%}}{h} = 4.4\ (\tan\alpha)^{0.7}\left(\frac{M_F}{\rho g h^2}\right)^{1/2}(0.505) \qquad \text{for} \qquad 2.0 \le \cot\alpha \le 4.0$$

Where the Dimensionless Wave Momentum Flux M_F is given by:

$$\left(\frac{M_F}{\rho g h^2}\right)_{max} = A_0 \left(\frac{h}{gT^2}\right)^{-A_1}$$

where

$$A_0 = 0.639 \left(\frac{H}{h}\right)^{2.026}$$

$$A_1 = 0.180 \left(\frac{H}{h}\right)^{-0.391}$$

H=Wave Height = 0.48m
h=Depth = ~2m
A_0=0.0355
A_1=0.3145
T = 2.0 sec

$$\left(\frac{M_F}{\rho g h^2}\right)_{max} = A_0 \left(\frac{h}{gT^2}\right)^{-A_1} = .0905$$

Therefore:

$$\frac{R_{u2\%}}{h} = 4.4(0.333)^{\wedge 0.7}(0.0905)^{\wedge 0.5}(0.505)$$
$$= 0.310$$

Or:

$R_{u2\%}$=0.620m (2.0ft)

Checked by: MCS 4-1-09

APPENDIX C

ROCK SIZING CALCULATIONS

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May 8, 2009
Frog Island Design Memo, NYPA (#1210-002)

Re: Design of Rock Slope Material Sizing, Open Water Waves

Source: EM1110-2-1100 Part VI, Chapter 5, Part I

From Table VI-5-23, find ξ_m and ξ_{mc}:

$$\xi_m = s_m^{-0.5} \tan\alpha \qquad \xi_{mc} = \left(6.2\, P^{0.31} (\tan\alpha)^{0.5}\right)^{1/(P+0.5)}$$

Where:
tan α = 0.5
P = 0.1 (Table VI-5-11 for mostly impermeable core)
$s_m = H_s/L_{om}$ (Wave Steepness)
H_s = 0.6m (Previously Determined)
L_{om} = 7m (Previously Determined)

Therefore:
ξ_m = 1.71
ξ_{mc} = 3.57

Since $\xi_m < \xi_{mc}$, they are considered plunging waves.

$$\frac{H_s}{\Delta D_{n50}} = 6.2 \cdot S^{0.2}\, P^{0.18}\, N_z^{-0.1}\, \xi_m^{-0.5} \qquad \text{Plunging waves}: \ \xi_m < \xi_{mc}$$

$$\frac{H_s}{\Delta D_{n50}} = 1.0 \cdot S^{0.2}\, P^{-0.13}\, N_z^{-0.1} (\cot\alpha)^{0.5}\, \xi_m^{P} \qquad \text{Surging waves}: \ \xi_m > \xi_{mc}$$

For rock slopes, at 2:1, allow for initial damage of S=2 according to the table below:

Damage level by S for two-layer armor (van der Meer 1988)

Unit	Slope	Initial damage	Intermediate damage	Failure
Rock	1 : 1.5	2	3–5	8
Rock	1 : 2	2	4–6	8
Rock	1 : 3	2	6–9	12
Rock	1 : 4 – 1 : 6	3	8–12	17

N_z = 7500 (maximum value for number of waves, equilibrium damage)

$\frac{H_s}{\Delta D_{n50}}$ = 1.47 (Stability Number)

Where:
$\Delta = (SG_{rock} - 1) = (2.65-1)$
Thus, Dn50 = 0.25m (0.8 ft)

Use Dn50 minimum of 10 inches (poorly graded)

Notes:
-Does not consider Ice Loading
-Ho assumed equal to Hs

By: JAQ, 5-8-09 / Checked by: MCS, 5-8-09

APPENDIX D

WETLAND PLANT MATRIX FROM NYPA (2009)

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Wetland Species Observed in the Vicinity of the HIPs

Common Name	Scientific Name	Growth Habit	Preferred Hydrologic Regime	Marsh Zone	Soil Texture Tolerance (USDA)	Erosion Control Potential	High Wildlife Value	Benefitting Wildlife Species
American Water Plantain	*Alisma subcordatum*	H	Regular to Permanent Inundation	B,C	F, M			WF
Speckled Alder	*Alnus incana*	S	Regular Saturation to Irregular Inundation	A	F, M, C	Yes	Yes	MB, WF, MM
Swamp Milkweed	*Asclepias incarnata*	H	Irregular to Regular Inundation	A	F, M			MM
Bluejoint Grass	*Calamagrostis canadensis*	G	Regular Saturation to Irregeular Inundation	A	F, M	Yes		
Fringed Sedge	*Carex crinita*	G	Regular Saturation to Irregeular Inundation	A	F, M			WF, MB, MM
Hairy Sedge	*Carex lacustris*	G	Regular Saturation	A, B	F, M			WF, MB, MM
Shallow Sedge	*Carex lurida*	G	Regular Saturation to Irregeular Inundation	A	F, M, C			WF, MB, MM
Tussock Sedge	*Carex stricta*	G	Regular Saturation to Intermittent Inundation	A, B	F, M, C			WF, MB, MM
Fox Sedge	*Carex vulpinoidea*	G	Regular Saturation to Irregeular Inundation	A, B	F, M		Yes	WF, MB, MM
Coontail	*Ceratophyllum demersum*	H	Permant Inundation	C, D	F, M, C			MM
Silky Dogwood	*Cornus amomum*	S	Irregular to Regular Inundation	A	F, M, C	Yes	Yes	WF, MB, MM
Gray Dogwood	*Cornus racemosa*	S	Seasonal Inundation	A	F, M	Yes	Yes	WF, MB, MM
Red Osier Dogwood	*Cornus sericea*	S	Seasonal Inundation	A	F, M	Yes		WF, MB, MM
Yellow Nutsedge	*Cyperus esculentus*	G	Irregular to Regular Inundation	A, B	F, M, C		Yes	WF, MB, MM
Spotted Joe-pye Weed	*Eupatoriadelphus maculatus*	H	Regular Saturation	A				MB
White Boneset	*Eupatorium perfoliatum*	H	Regular Saturation	A				MM
Swamp Rose Mallow	*Hibiscus moscheutos*	H	Irregular to Regular Inundation	A	F, M			HB
Soft Rush	*Juncus effusus*	G	Seasonal Inundation	A, B	F, M, C	Yes		WF, MB, MM, FH
Bugleweed	*Lycopus uniflorus*	H	Irregular to Regular Inundation	A				
White Water Lilly	*Nymphaea odorata*	H	Permant Inundation	C, D				WF, MM
Marsh Knotweed	*Polygonum hydropiperoides*	H	Regular to Permanent Inundation	A, B	F, M			WF, MB
Pennsylvania Smartweed	*Polygonum pensylvanicum*	H	Regular to Permanent Inundation	A, B	F, M, C	Yes	Yes	WF, MB, MM
Pickerel Weed	*Pontederia cordata*	H	Regular to Permanent Inundation	C	F, M, C			WF, MM
Pondweeds	*Potamogeton spp.*	H	Permant Inundation	C, D				WF, MB, MM
Swamp Dock	*Rumex verticillatus*	H	Regular to Permanent Inundation	A				WF, MB, MM
Arrowhead	*Sagittaria latifolia*	H	Regular to Permanent Inundation	B, C,D	F, M			WF, MM
Black Willow	*Salix nigra*	T	Irregular to Regular Inundation	A	F, M, C	Yes	Yes	MB, MM
River Bulrush	*Schoenoplectus fluviatilis*	G	Regular Inundation	A, B	F, M	Yes	Yes	WF, MB, MM, FH
Three-square	*Schoenoplectus pungens*	G	Regular to Permanent Inundation	B, C	F, M, C	Yes	Yes	WF, MB, MM, FH
Soft-stemmed Bulrush	*Schoenoplectus tabernaemontani*	G	Regular to Permanent Inundation	B, C	F, M, C	Yes	Yes	WF, MB, MM, FH
Dark Green Bulrush	*Scirpus atrovirens*	G	Regular to Permanent Inundation	A, B	F, M	Yes	Yes	WF, MB, MM
Woolgrass	*Scirpus cyperinus*	G	Regular to Irregular Inundation	A, B	F, M, C	Yes	Yes	WF, MB, MM, FH
Giant Burreed	*Sparganium eurycarpum*	H	Regular to Permanent Inundation	B, C	F, M, C			WF, MM
Freshwater Cordgrass	*Spartina pectinata*	G	Regular to Permanent Inundation	A, B	M, C	Yes		WF, MB
Broad-leaf Cattail*	*Typha latifolia*	H	Irregular to Regular Inundation	A, B, C	F, M, C	Yes		WF, MM, FH
Wild Celery	*Vallisneria americana*	H	Permant Inundation	C,D	F, M, C			WF, MM, FH
Blue Vervain	*Verbena hastata*	H	Irregular Innundation	A				WF, MB, MM
Arrowwood	*Viburnum dentatum*	S	Seasonal Inundation	A	F, M, C	Yes	Yes	MB, MM
Other Plants not Observed in Study Area, but Known to Historically Exist Within the Project Area								
Buttonbush	*Cephalanthus occidentalis*	S	Irregular to Permanent Inundated	A, B	F, M, C	Yes	Yes	WF, MB, MM
Creeping Spikerush	*Eleocharis palustris*	G	Regular or Permanent Saturation	A	F, C	Yes		WF, MB, MM
Blue Flag	*Iris versicolor*	H	Regular or Permanent Inundation	A,B				WF, MB, MM
Torreyi's Rush	*Juncus torreyi*	G	Irregular to Seasonal Inundation or Saturation	A	M, C			WF, MB, MM, FH
Cardinal Flower	*Lobelia cardinalis*	H	Regular or Permanent Saturation	A	M			HB
Lizard Tail	*Saururus cernuus*	H	Regular to Permanent Inundation	A, B				WF
Hard-Stem Bulrush	*Schoenoplectus acutus*	G	Regular to Permanently Inundation	B, C	F, M	Yes	Yes	WF, MB, MM, FH

Marsh Zones (Based on Survey elevation):
- A (Wet Meadow)
- B (Shallow Emergent)
- C (Deep Emergent)
- D (Submerged Aquatic Vegetation-SAV)

Wildlife Species:
- WF = Waterfowl
- MB = Marsh Birds
- MM = Mammals
- FH = Fish
- HB = Hummingbird

Soil Texture:
- C=Coarse
- M=Medium
- F=Fine

Growth Habit
- G = Graminoid
- H = Herbaceous
- S = Shrub
- T = Tree

*Do not include in planting plan since this species may readily colonize on it's own