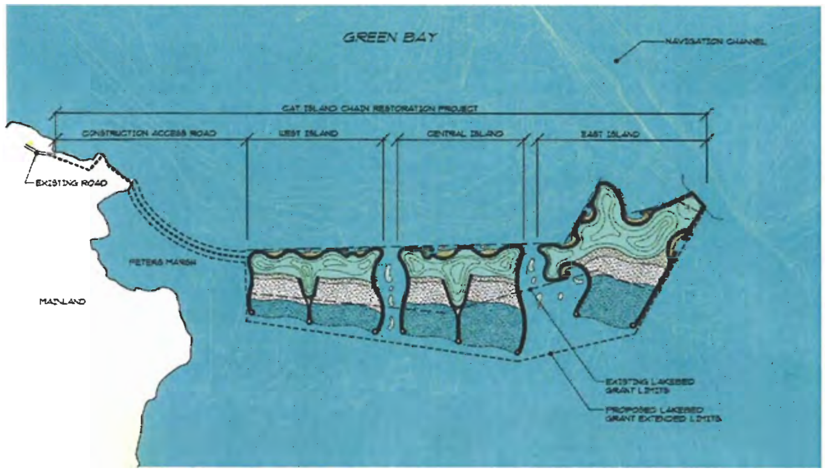
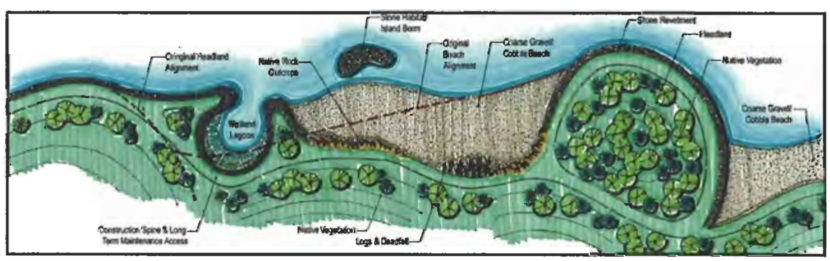
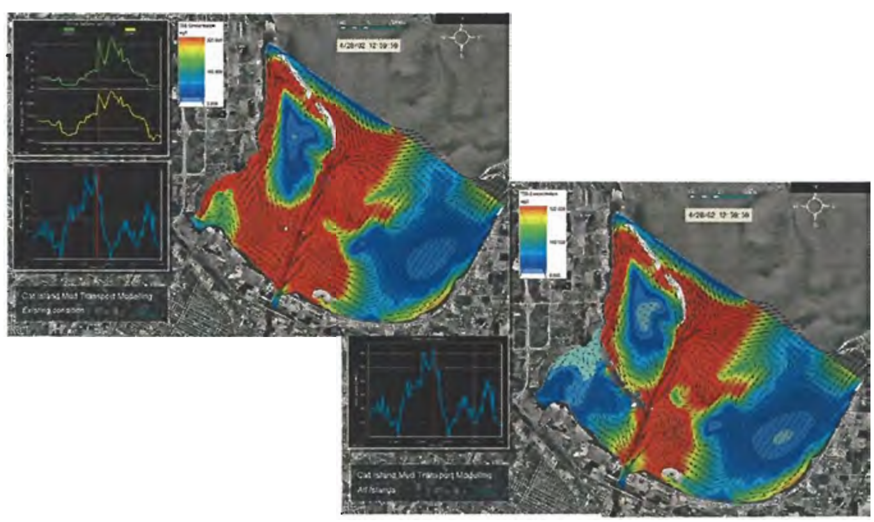
U.S. Army Corps of Engineers
Detroit District

Cat Island Chain Restoration Design Development Report







Prepared by
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April 2005

CAT ISLAND CHAIN RESTORATION
DESIGN DEVELOPMENT REPORT

Prepared for:

US ARMY CORPS OF ENGINEERS
DETROIT DISTRICT

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APRIL 28, 2005

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TABLE OF CONTENTS

EXECUTIVE SUMMARY **1**

1.0 INTRODUCTION AND BACKGROUND **5**

2.0 DATA GATHERING **6**

2.1 Bathymetry **6**

2.2 GIS Data Sets **11**

2.3 Sediment & Water Characteristics **11**

2.3.1 Green Bay Lake Bottom Sediment Samples ***11***

2.3.2 Total Suspended Sediment Samples ***11***

2.3.3 Lake Levels and Storm Surge ***12***

2.3.4 Wave Data ***13***

2.4 Vegetation Survey **16**

3.0 GEOMORPHIC ASSESSMENT **17**

4.0 PHYSICAL MODEL STUDY **33**

4.1 Model Objectives **33**

4.2 Model Facilities, Design and Construction **33**

4.3 Overview of Model Testing Program **36**

4.4 Model Material Characteristics **38**

4.5 Key Model Results **41**

4.5.1 Beaches ***41***

4.5.1.1 Profile Development 41

4.5.1.2 Wave Overtopping 46

4.5.2 Revetments ***48***

4.5.2.1 Armour Layer Stability 48

4.5.2.2 Wave Overtopping 51

4.6 Model Scale Effects and Interpretation **52**

5.0 WAVE GENERATION AND TRANSFORMATION MODELING **56**

5.1 Wave Generation Modeling **56**

5.2 Wave Transformation Modeling **60**

5.2.1 Extreme Event Simulations ***61***

5.2.3 Growing Season Event Simulations ***63***

6.0 HYDRODYNAMIC ANALYSIS **66**

6.1 MIKE 21 Hydrodynamic Model **66**

6.2 Surge Event Simulations **67**

7.0 MODELING TOTAL SUSPENDED SOLIDS 73
7.1 Introduction 73
7.2 Model Approach, Setup and Inputs 73
7.2.1 Modeling Approach 73
7.2.2 MT Model Parameters 74
7.2.3 Incoming Sediment From Rivers 75
7.3 Selection of Testing Scenarios 76
7.4 Model Testing and Calibration 77
7.5 Model Results 78
7.5.1 Individual Island Tests 79
7.5.2 All Islands 79
7.5.3 All Island with Shore Connection 80
7.6 Interpretation of Findings 80
8.0 AQUATIC VEGETATION STABILITY ANALYSIS 108
8.1 Introduction and Background 108
8.2 Analysis and Results 110
8.2.1 Secchi Disk and Potential Vegetation Growth Area 110
8.2.2 Vegetation Growth Prediction 111
8.3 Summary 112
9.0 DESIGN DEVELOPMENT 130
9.1 Island Design Layouts 130
9.2 Storage Capacity 135
9.3 Physical Model Results & Island Design Requirements 136
9.3.1 Construction Access Road 136
9.3.2 Stone Revetment/Headland Cross-Sections 137
9.3.3 Imported Material Beach Cross-Sections 140
9.3.4 Dredge Sand Beach Sections 142
9.4 Habitat Considerations for Layout & Sections 144
10.0 CONSTRUCTION ISSUES 144
10.1 Construction Access & Sequencing 144
10.1.1 Land Based Construction –Preliminary Plan 144
10.1.2 Water-Based Construction –Preliminary Plan 147
10.1.3 *Land-based and Water-based Construction – Revised Plan* **............................ 148**
10.2 Material Availability & Costs 148
10.3 Schedule 151

11.0 SUMMARY 154
12.0 CONCLUSIONS AND RECOMMENDATIONS 156
13.0 REFERENCES 158

Appendix A Sediment Samples
Appendix B USFW Vegetation Survey
Appendix C Wave Transformation Modeling
Appendix D Hydrodynamic Modeling
Appendix E Suspended Sediment Modeling
Appendix F Aquatic Vegetation Stability Modeling
Appendix G Baird Concept Plan Drawings 2002
Appendix H Baird Preliminary Plan Drawings
Appendix I Preliminary Statement of Probable Construction Costs
Appendix J U.S. Fish & Wildlife Service Comments on Report and Baird Responses

EXECUTIVE SUMMARY

The Cat Island chain of islands, located within Green Bay, was severely eroded during high water levels and extreme wave attack in the early 1970s. It is believed that the loss of the above water part of the islands was responsible in whole or part for the loss of extensive emergent and submerged aquatic vegetation between the islands and the shore to the south and west (e.g. Duck Creek Wetland, Peats Lake and Peter's Marsh). In addition to these indirect impacts, the terrestrial habitat of the islands themselves was also directly lost. The US Fish & Wildlife, Brown County and the US Army Corps of Engineers plan to restore the islands through beneficial use of clean dredged sediment from the Green Bay Federal Navigation Channel.

There are three key objectives of restoring the Cat Island Chain:

1. Creating the conditions for re-establishment of emergent and submerged aquatic vegetation southwest of the Cat Island Chain;

2. Providing capacity for placement of clean dredge spoils of Green Bay Federal Navigation Channel dredging activities;

3. Restoring terrestrial habitat associated with the islands.

Baird & Associates was commissioned by the US Army Corps of Engineers Detroit District to perform a design development investigation on the restoration of the Cat Island chain. The study tasks included:

- field investigations and measurements to define the local conditions and provide input and test data for the numerical and physical models);

- a geomorphic analysis to understand the long term historic evolution of the Cat Island chain and other neighboring and related features including but not limited to Long Tail Point, Frying Pan Shoal and Little Tail Point;

- a physical model investigation to develop an understanding of protection requirements for headlands, beach stability (from fine to coarse sediment) and overtopping characteristics;

- numerical modeling of waves, hydrodynamics (water levels and currents) and sediment transport to understand the impact of the islands on circulation patterns and turbidity levels in the lower bay and to use this information to refine the layout and construction sequencing of the islands to achieve maximum benefits in terms of promoting the recovery of aquatic vegetation in the lee of the islands;

- development of plans and cross sections based on the results of the various tasks described above to promote the primary objectives (restoring habitat and creating storage capacity for dredged sediment) while minimizing the overall costs;

- review of construction issues and recommendations to provide for future flexibility in construction approach.

Both from this study, and from previous investigations, it was determined that the large areas of aquatic vegetation that once existed in the lee of the Cat Island chain have been prevented from recovering due to two primary processes that impair water clarity: the advection and dispersion of sediment plumes discharged from Duck Creek and Fox River; and re-suspension of lake bed sediment by wave action. By sediment we refer to both the biotic and abiotic components of the Total Suspended Load (TSS). Only one of the two sources could be directly influenced by the construction of the islands to reduce turbidity levels. The investigations presented in this report showed that sediment re-suspended from the lake bed by waves (often associated with the highest levels of TSS) could be reduced to levels conducive to the recovery and survival of aquatic vegetation with the construction of the islands and, importantly, with the significant reduction in flow between the west island and the shore. The water clarity impairment associated with the plumes from the two rivers will not be significantly influenced by construction of the islands. Therefore, in order to promote the recovery of the aquatic vegetation in the lee of the islands it will also be necessary to ensure that the sediment load (TSS) from the two watersheds (and that created biologically within the bay itself) is equivalent to or less that the levels experienced prior to 1970.

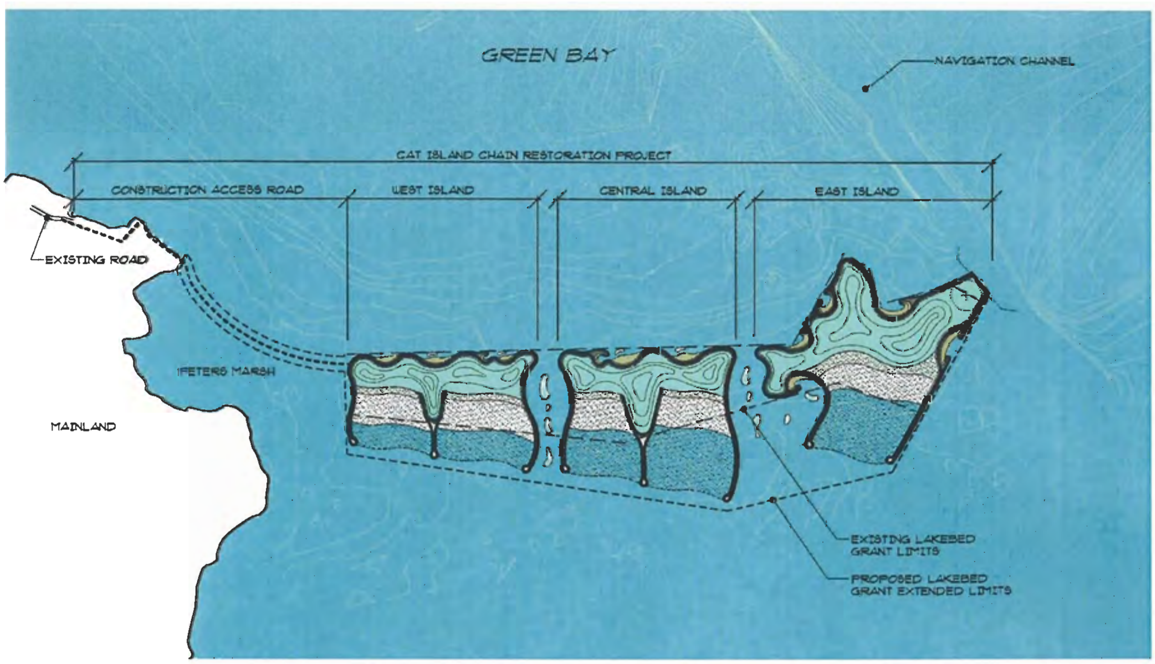


Figure A – Revised Design Development Plan

The proposed form of the islands is shown in Figure A. The islands are situated within the original footprint of the former Cat Island chain. Moving from west to east there are four main components of the project: 1) a construction access road between the shore and the west island that will eventually be converted into a series of island berms consisting of rock; 2) the west island; 3) the central island; and 4) the east island. The access road, and the islands that will be created once land-based construction access is not longer required, is an essential component of the design to prevent the flow of sediment-laden water from the exposed side of the islands into the area in the lee of the islands where recovery of aquatic vegetation is desired. The three islands consist of headlands and gravel beaches on the exposed northeast side and mild-sloping sand beaches with confining structures on the lee, southwest side. The sand beaches on the lee side will be created from the clean dredged sediment used to fill the shell of the islands created from the headlands and gravel beaches. Together, these different substrates and slopes provide for a diversity of terrestrial habitat that can be fine-tuned in the final design phase of the project. The northeast corner of the east island is configured to provide for a marine terminal for marine-based construction access. The gaps between the islands allow for circulation to be maintained between one side of the chain and the other. Flows through the gaps will be strong during periods of surges and seiches, but also persistent under fair-weather conditions due to the natural tidal fluctuation in Green Bay (that was determined from the water level measurements). Gravel berm islands and a gravel-covered lakebed are proposed for the gaps between the main islands. In addition, the gaps also serve to deter predators from migrating from one island to the next.

The form of the islands presented in Figure A was refined through feedback from US Fish & Wildlife, US Army Corps of Engineers, Brown County, Wisconsin Department of Natural Resources, University of Wisconsin – Green Bay, UW Sea Grant and others through two workshops and several video-conferences.

The storage capacity of the islands for dredged sediment has been estimated at approximately 2,350,000 cubic yards. It has also been estimated that the cost of the islands (excluding the cost to fill the islands with dredged sediment) will be in the range of $19 to $24 million. There is a need and opportunity to refine and possibly reduce the cost of the islands through design optimization in the final design phase when construction documents are developed.

It has been proposed the island construction should start with advancing a continuous spine of quarried rock extending from the mainland in the west to the northeast limit of the east island. This rock berm would provide the access road for construction of the island shells. This structure would also form the core of the exposed side of the island and could be used to protect a permanent dredge pipeline for filling the islands. Culverts would be placed between the mainland and the west island and in the locations of the proposed gaps between the islands as a temporary measure to maintain flows during the construction period. An advantage of this approach to construction sequencing is that maximum sheltering from waves (required to promote recovery of the aquatic vegetation in the lee of the islands) is achieved at the outset of the project. The cost of creating the shell for the west island and the construction access road spine across the full length of the project, as the initial phase of work, is estimated to be approximately $9 to $10 million. For an estimated $5 to $6 million the west island and the construction access road spine across the full length of the project could be built without armor stone. Some annual maintenance may be required if the project is left un-armored until final completion.

The proposed design allows for either or both marine and land-based construction. It is our opinion that this flexibility is required to facilitate the broadest possible market for stone suppliers. One of the largest cost components of the project is the supply and delivery of stone and there are two main approaches: by road and by ship.

1.0 INTRODUCTION AND BACKGROUND

The Cat Island Chain is located in Green Bay, Wisconsin. In the early 1970's the Cat Island Chain was severely eroded leaving a series of shoals mostly below low water datum. The US Army Corps of Engineers, US Fish & Wildlife and Brown County plan to restore the island chain.

The benefits of restoring the islands are threefold:

- Creating the conditions for re-establishment of emergent and submerged aquatic vegetation southwest of the Cat Island Chain;
- Providing capacity for placement of clean dredge spoils of Green Bay Federal Shipping Channel dredging activities;
- Restoring habitat associated with the islands.

A concept evaluation and initial design development report (Baird, 2002) was performed by Baird & Associates. The 2002 report documents conceptual coastal design of the islands, construction issues, and recommendations for subsequent phases. An initial report titled Cat Island Geomorphic Analysis (Baird, 2003) was also issued as part of Phase A of this study. The 2003 report included documentation regarding obtaining hydrographic survey data and a geomorphic analysis of shorelines along the southern edge of Green Bay.

The purpose of this report is to document design development activities completed since the 2003 report for the restoration of the Cat Island Chain. The information in this report supersedes that of the 2003 report. This report is divided into the following sections:

- Data Gathering
- Physical Modeling
- Numerical Modeling of Waves, Hydrodynamics and Sediment Transport
- Geomorphic Assessment
- Vegetation Stability Analysis
- Island Design Progression
- Construction Issues and Sequencing
- Summary, Conclusions and Recommendations

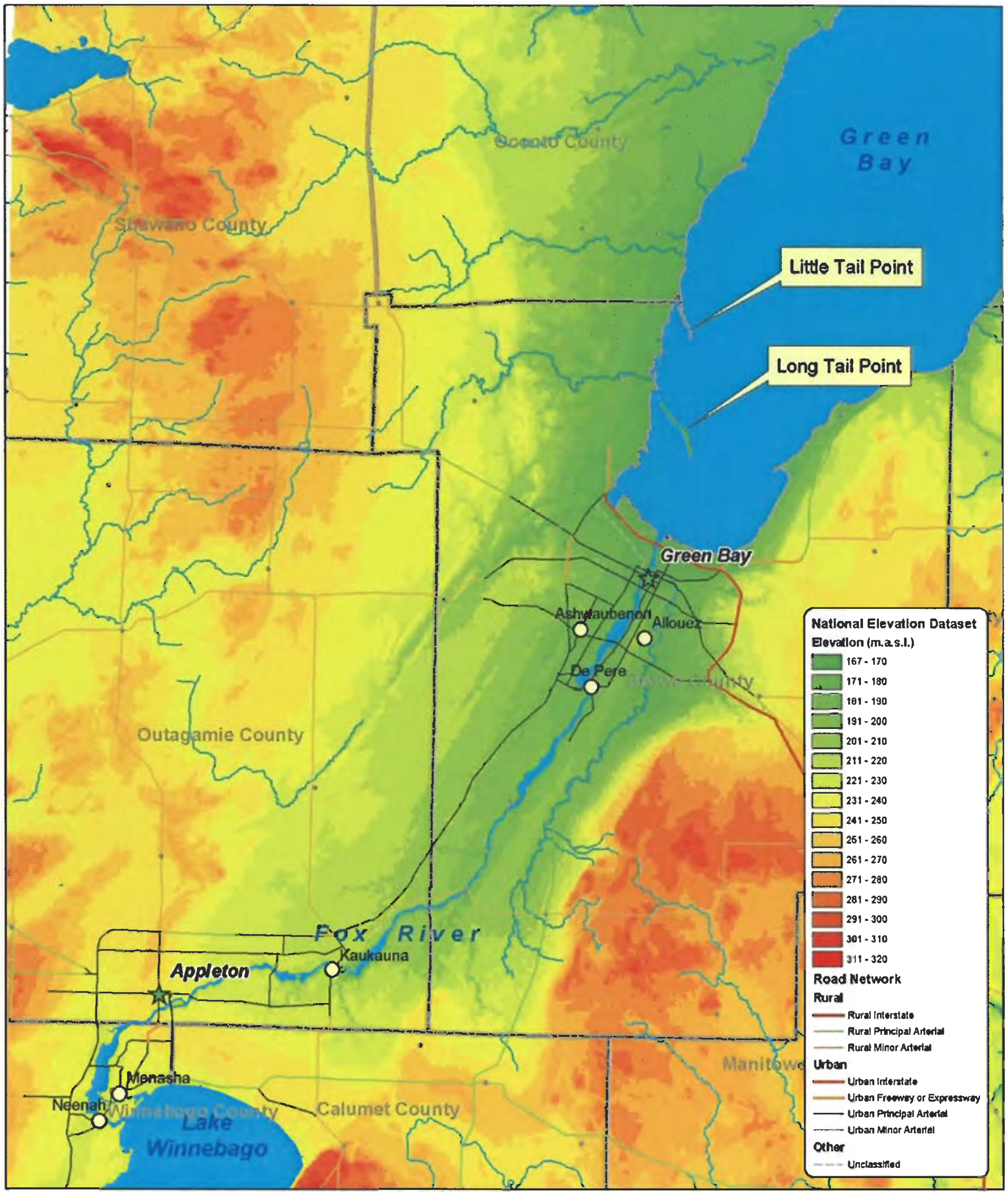
2.0 DATA GATHERING

2.1 Bathymetry

Bathymetry of the study area from 1943 was obtained from the NOAA GeoDAS digital survey DVD and also a 1997 US Army Corps of Engineers Survey. To complement the available data, Baird & Associates contracted Spatial Data Surveys, LLC, Verona, WI, to perform Topographic/bathymetric survey of the study area during September and October 2003. The survey was conducted using GPS RTK and Coastal Oceanographics' Hypack data collection survey techniques. Figure 2.1 shows a general overview and elevations of the south Green Bay area and Figure 2.2 shows the new survey data points as well as the 1943 survey data. In this figure the yellow line encompasses an overlapping area between the two surveys.

Additional topographic survey information was obtained from Brown County, WI. This information provided elevation detail for Long Tail Point.

Figure 2.3 shows a number of selected profiles across the survey area and Figure 2.4 shows their corresponding elevations. It may be seen that Cat Island is now a submerged feature below the 0.0 ft contour (see Profiles B through H). The area between Cat Island and Long Tail Point has mostly a constant depth of about 8 ft with the exception of the old dredge spoil mounds intersected by Profile F. Profile F also skirts the edge of the navigation channel and Profile G and H cross the channel. Profiles G and H also cut across Frying Pan shoal.



0 2 4 8 km

0 1 2 4 mi

Approx. Scale 1:350,000

REGIONAL OVERVIEW MAP WITH ELEVATION DATA

Elevation data from The National Map, USGS. Elevation expressed as meters above sea level.

Baird

Figure 2.1 – Regional Overview Map with Elevation Data

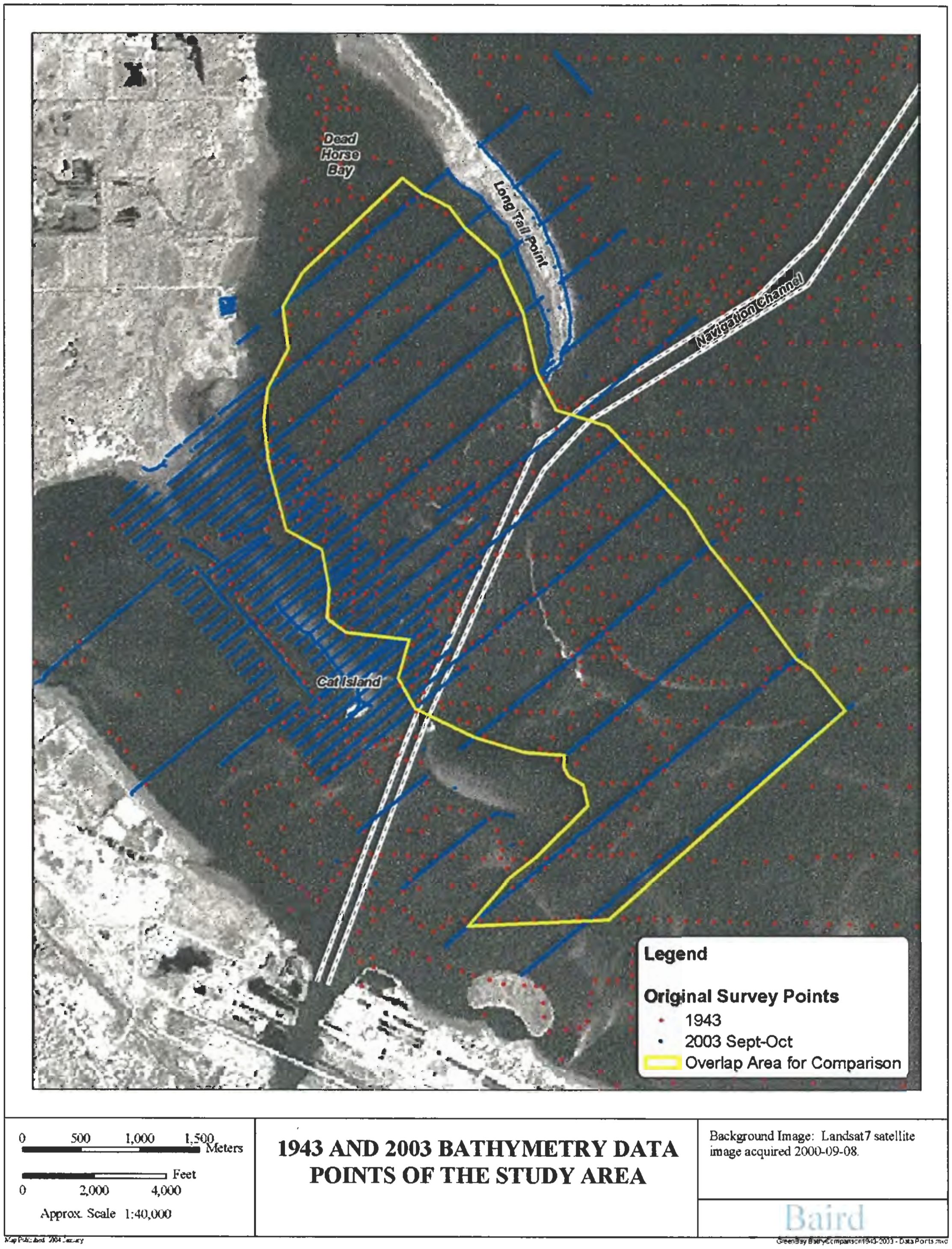


Figure 2.2 – 1943 and 2003 Bathymetry Data

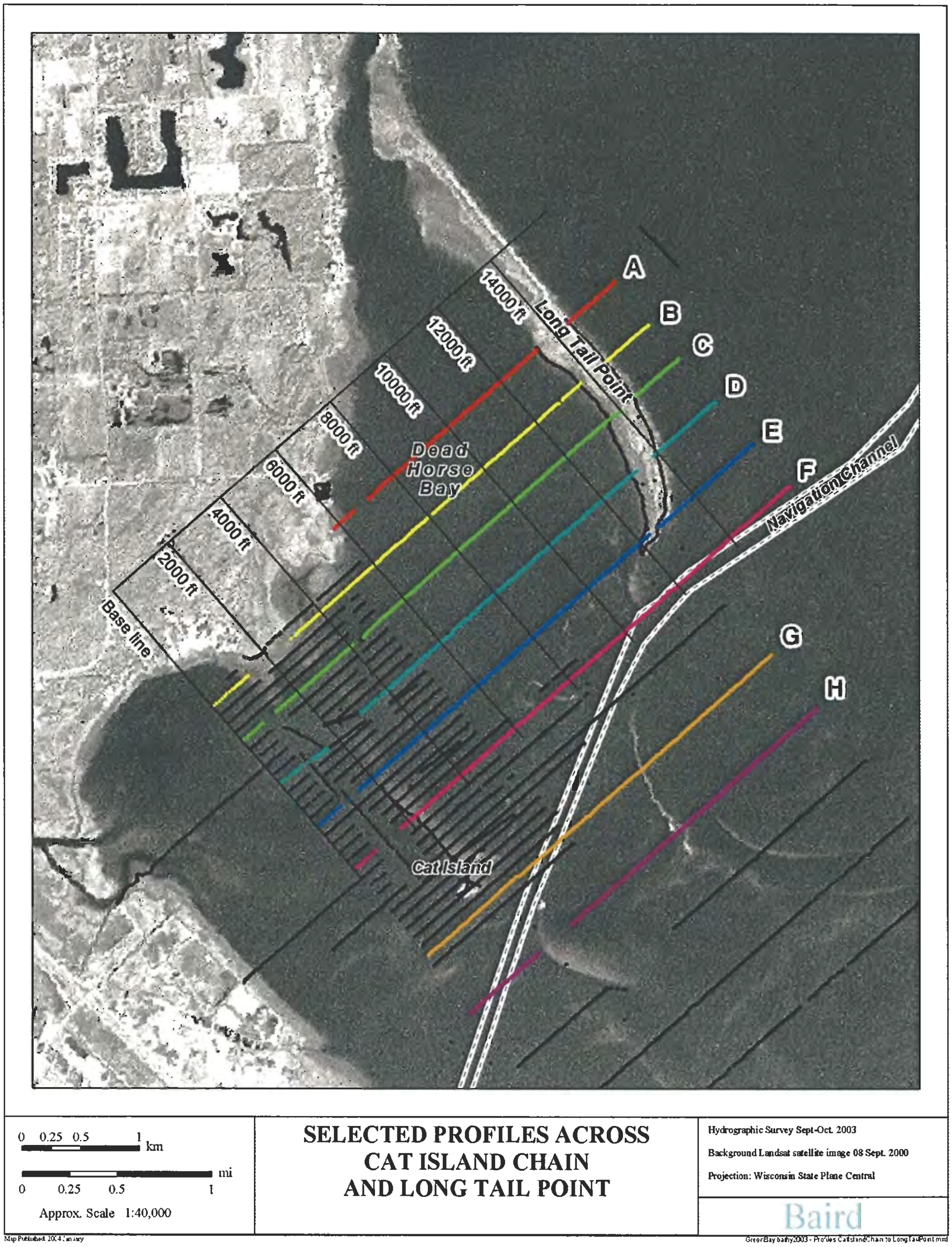


Figure 2.3 – Selected Profiles Across Cat Island Chain and Long Tail Point

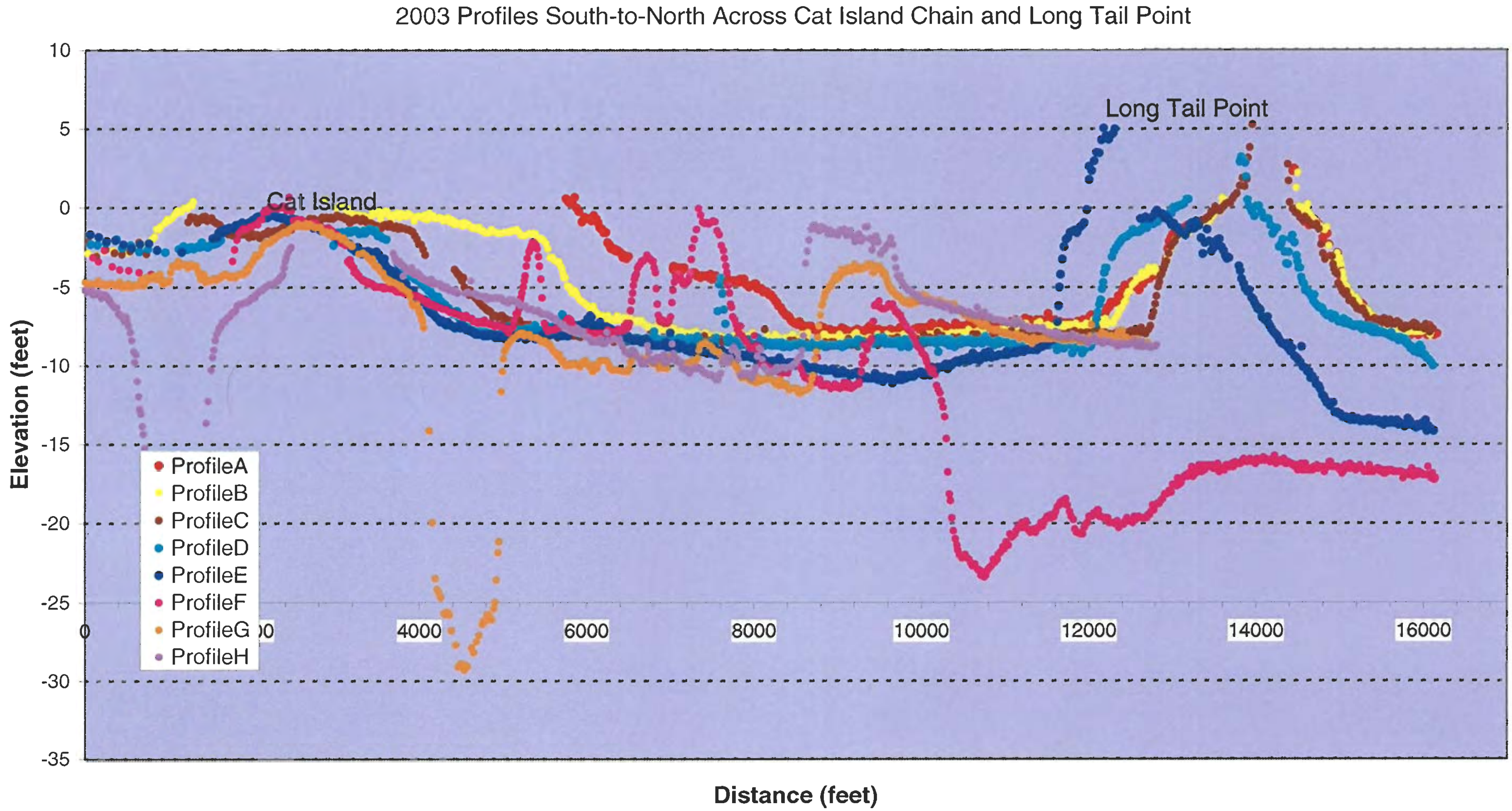


Figure 2.4 – 2003 Survey Profiles

2.2 GIS Data Sets

Historic air photos were acquired from the USGS EROS Data Center. The oldest available set was seven air photos captured on 28 June 1938 at a scale of 1:20,000. These were scanned at a resolution of 1200 dots per inch producing a nominal ground resolution of 0.5 meters. The photos were georegistered to within 10 meters using existing imagery as ground control.

Another set of historic air photos was available, captured on 11 May 1965 by the US Navy at an altitude of 20,000 feet, producing a 1:40,000 scale photo. These were scanned at a resolution of 1200 dots per inch producing a nominal ground resolution of 0.85 meters. The photos were georegistered to within 10 meters using existing imagery as ground control.

1992 Digital Orthophotos were purchased from the USGS, with a ground resolution of 1.0 meter.

Additionally, Landsat imagery was acquired from a variety of sources, including downloads from the University of Maryland's Global Land Cover archive. The imagery dates were 1988-05-17, 1989-09-18, 1999-07-27, and 2000-09-08.

2.3 Sediment & Water Characteristics

2.3.1 Green Bay Lake Bottom Sediment Samples

Acquisition and testing of sediment samples from the Green Bay Federal Channel were completed by Dodson-Stilson Inc. (DSI) between May 12 and 15, 1998. The sampling was completed to assess environmental impacts regarding possible disposal sites of the dredged material from the channel. Sampling sites and laboratory results can be found in the DSI report (DSI, 1998).

Several lake bottom samples were obtained during the hydrographic survey commissioned by Baird in 2003. Sample locations and grain size distribution curves are located in Appendix A.

2.3.2 Total Suspended Sediment Samples

Total Suspended Sediment (TSS) samples were collected by the Green Bay Metropolitan Sewerage District at several locations on the bay as part of the State of the Bay assessment. This sample information was utilized in the sediment transport analysis discussed in Section 7.0.

2.3.3 Lake Levels and Storm Surge

Water levels at Green Bay vary in response to long-term and seasonal variations in climate (as defined by monthly mean lake levels), as well as in response to specific storm events (i.e. localized, short-term storm surges associated with strong NE winds). Statistical analyses of water level data recorded by NOAA at Green Bay were undertaken in order to estimate extreme water levels by return period. This included a combined probability analysis of annual maximum (AMAX) lake levels (based on Lake Michigan gauge network data from 1918-2001) and annual maximum storm surges (based on analyses of hourly water level data at Green Bay from 1970-2002) using the HYDSTAT software package. The results of these analyses are summarized in Table 2.1.

Table 2.1
Extreme High Water Levels at Green Bay

Return Period (years)	Lake Level (ft LWD)	Storm Surge (ft)	Combined Water Level (ft LWD)
2	+2.1	2.2	+4.5
5	+3.2	2.8	+5.7
10	+3.8	3.3	+6.4
25	+4.3	4.1	**+7.1**
50	+4.6	4.7	+7.6
100	**+4.9**	**5.5**	+8.1
200	+5.1	6.3	+8.5
Max. on Record	**+4.9 (Oct. 1986)**	**5.5 (Dec. 3, 1990)**	**+7.3* (Apr. 9, 1973)**

*Note: water level gauge malfunctioned during Apr. 9, 1973 storm prior to peak surge; USGS (1976) suggests peak level of +7.3 ft LWD during this storm

The peak water level on record (estimated at +7.3 ft LWD) occurred during a severe storm event on April 9, 1973, with an estimated return period in the order of 30 years. This event caused severe flooding in Green Bay, with estimated property damage in the order of $6 million (Keillor, 1986), and resulted in severe erosion of the Cat Island chain. The mean lake level during this event was +3.6 ft LWD, with an estimated storm surge of 3.7 ft above the mean lake level for a peak elevation of 7.3 ft above LWD. Higher lake levels and larger storm surges are possible and have occurred. For example, Lake Michigan reached a record high of +4.9 ft LWD in October 1986, while a storm surge of 5.5 ft occurred at Green Bay during a storm on December 3, 1990. The estimated 100-year design water level, considering the combined occurrence of lake levels and surges, is

+8.1 ft LWD. This is almost one foot higher than the peak water level that occurred during the storm of April 9, 1973.

2.3.4 Wave Data

In order to obtain data for calibration of wave models used for design, two wave gauges were deployed. One gauge was located northeast of Long Tail Point, and the other northeast of Cat Island. A map depicting the gauge locations is shown in Figure 2.5.

Figure 2.5 - Location of Wave Gauges

The wave gauges were deployed from March 25 to May 19, 2004. They were installed before total ice breakup in the upper bay in order to capture any large NE events that may have occurred immediately after the ice breakup. Ice breakup throughout the entire bay was estimated by satellite images to occur between April 6 and April 13, 2004. The gauges used were bottom mounted pressure gauges. Pressure records were transformed into wave records by linear wave theory. Graphs depicting the results of the wave gauge records for the Long Tail Point Gauge and Cat Island Gauge are displayed respectively in Figures 2.6 and 2.7.

The largest wave height on record was approximately 0.8 m for the Long Tail Point Gauge and 0.3 m for the Cat Island Gauge. Although an extreme event was not observed during the deployment period, a better level of calibration was obtained through scaling of the winds used in the hindcast to determine design conditions. This is covered in further detail in Section 5.0.

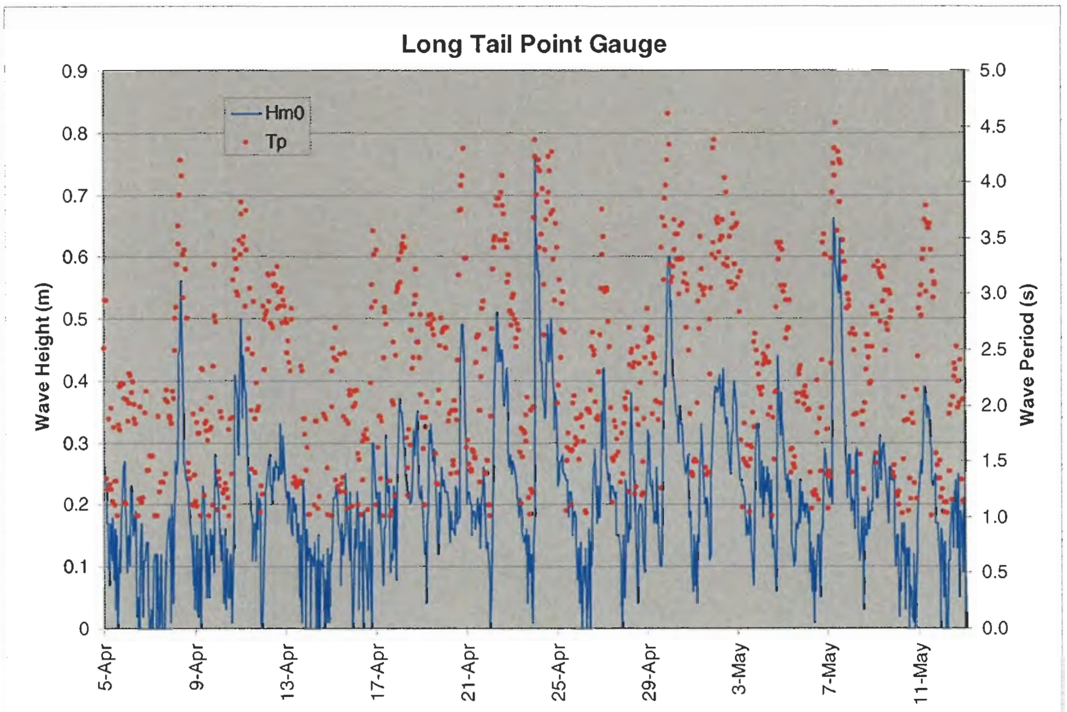


Figure 2.6 - Long Tail Point Wave Gauge Record

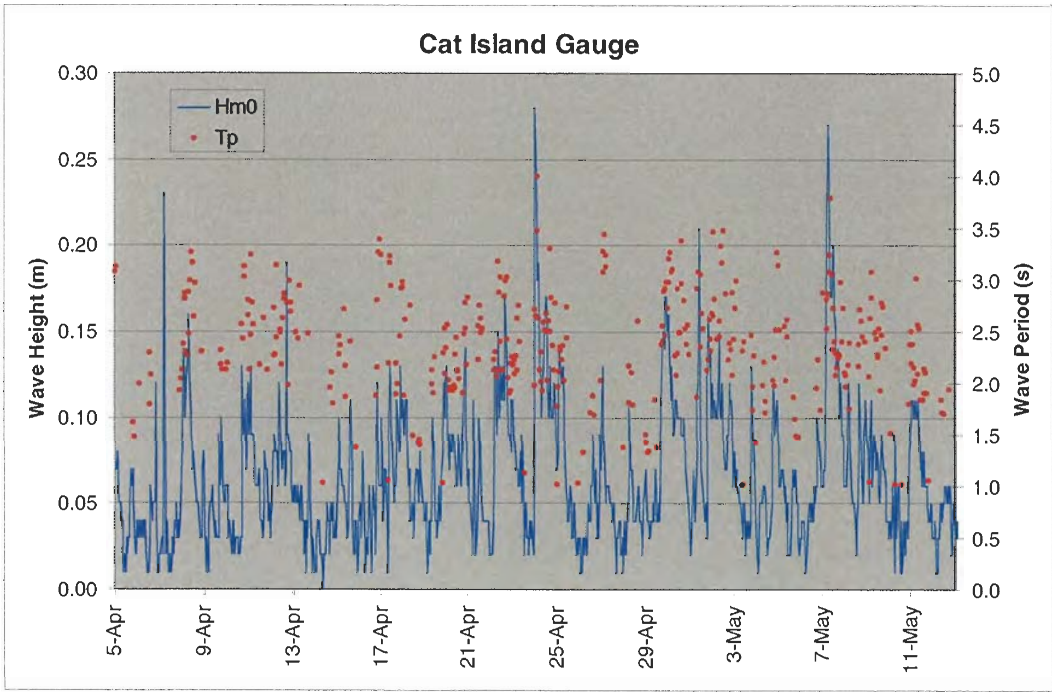


Figure 2.7 - Cat Island Wave Gauge Record

In addition to wind generated waves, ship generated waves were also observed at the site. As a ship passes by the Cat Islands through the shipping channel, the water is lowered around the islands. After the ship passes, a series of waves travel by the islands. Figure 2.8 displays a time series of a ship passing by the Cat Islands.

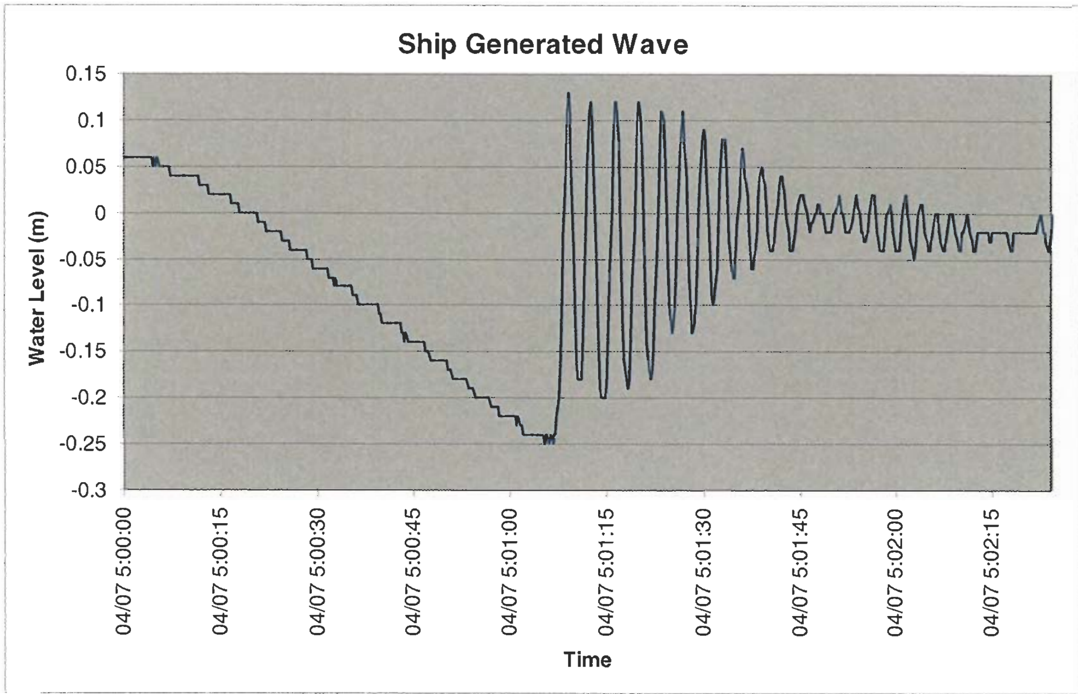


Figure 2.8 – Ship Wave at Cat Island

2.4 Vegetation Survey

USFW staff completed a reconnaissance survey of the vegetation communities on Long Tail Point to provide an indication of the role of wave exposure (see US exposed side) and land elevation on type of vegetation. The photos and their locations are provided in Appendix B.

3.0 GEOMORPHIC ASSESSMENT

Three sets of air photos from June 28, 1938, May 11, 1965 and May 6, 1992 together with a Landsat 7 image from September 8, 2000 (15m resolution, Panchromatic Band 8) were georegistered in GIS to investigate the morphologic change on the lower part of Green Bay over past 60 years. Four series of shorelines were traced from the above photos in ArcMap. If the shoreline was not distinctive, it was not digitized.

Brown County contracted with Aerometric, Inc. of Sheboygan, WI to produce on orthophoto dataset, derived from 1" = 840' scale aerial photography that was flown in the spring of 2000. It was flown to provide six-inch ground resolution (or pixel) digital orthophotography coverage. This photo data were obtained subsequent to the completion of the geomorphic analysis and therefore have only be used as backdrop for various analyses and figures and not in the shoreline change assessment. The development of the orthophotography also resulted in the production of spot elevations and 2-foot elevation contours that were used along Long Tail Point to understand the Point's profile shape as part of the vegetation analysis (see Section 8 of this report).

Figure 3.1 shows the four digitized shorelines overlaid on the 1938 air photo. There are three distinct morphological features to consider in south Green Bay area: 1) Little Tail Point, 2) Long Tail Point and 3) Cat Island chain. The geomorphic history of these features has a geologic time scale. The fact that each feature is associated with a river (Little Suamico River, Suamico River and Duck Creek, respectively) suggests the possibility that they have been formed in part from the sediments delivered to the bay by these rivers. On the other hand, there is a smaller mirror image of Long Tail Point on the west side of the bay (Frying Pan Shoal) which indicates that these features might be the remnants of old coastal dunes/berms. Combined with isostatic rebound (in this area the land/lake bed is actually sinking at about 6 cm/century – see Baedke et al, 2004), rising or static levels on Lake Michigan over the past 5,000 years has resulted in gradual shifting of south shore of Green Bay towards the south due to gradual inundation. Figure 3.2 is the satellite image of Green Bay and indicates that similar features also exist on the west shores of the bay further north of the study area. As all the sediment is expected to move along the west and east shorelines of the bay and deposit at its south end, it is possible that coastal dunes were established and then washed out at different stages of this long-term relative water level rise.

The area around Little Tail Point is shown in Figure 3.3. A number of longshore bars are observed around Little Tail Point indicating the sandy nature of this feature. Comparison of the four traced shorelines indicates that Little Tail Point has been relatively stable over the past 60 years. It should be mentioned that the location of each shoreline should be interpreted considering its corresponding lake level. The monthly mean level in Lake Michigan for June 1938, May 1965 and September 2000 was 176.28 m, 175.94 m and 176.09 m, respectively. The 1938, 1965 and 2000 shorelines therefore correspond to relatively low lake levels and can be compared relatively well without the need for water level correction. The mean lake level reached 176.53 m in May 1992 and explains why the Little Tail feature is narrow in the 1992 air photo. The 2003 hydrographic survey around Long Tail Point indicates a bottom slope of 1/100 on the north side and 1/200 on the south side of Long Tail. The corresponding information for Little Tail Point is not available but it is reasonable to assume they are similarly mild. Therefore, every 10 cm change in the water level roughly results in 30 m change in the dry (out of water) width of these spit features.

Figure 3.4 shows the traced shorelines on 1965 air photo. This is at the time of historic low water levels in Lake Michigan and therefore the three features are very prominent. Figures 3.5 and 3.6 show Cat Island and Long Tail Point in detail, respectively. It may be seen that there was little change in Cat Island between 1938 and 1965. The remnants of Cat Island in 1992 and 2000 images also do not indicate any change in their position. This may be attributed to the relatively calm wave climate in the area derived from the sheltering effect of Long Tail Point. Figure 3.5 also shows the dramatic demise of the Duck Creek wetland area after 1965 and most likely linked to the disappearance of the Cat Island chain in 1973.

Figure 3.6 shows the historic shorelines of Long Tail Point superimposed on the 1965 air photo. Again the 1938, 1965 and 2000 shorelines indicate that this area has experienced only minor changes over past 60 years. This is contrary to the findings of the previous report of October 31, 2002 in which, based on comparison between 1992 air photo and 1943 NOAA navigation chart, it was concluded that Long Tail Point has migrated inshore at a rate of 4 m/year in the last 60 years. The NOAA chart was compared to the present air photos in GIS and it was found that the boundaries of Long Tail Point shown in this chart are fairly rough and inaccurate (it is a navigation chart mostly concerned with the alignment of the navigation channel, which was indeed accurate).

In Figure 3.6 the shoreline of May 1992 reveals a gap between Long Tail Point and the shore (see also Figure 3.9). This is because of the higher water level at this time (176.53 m) when a section of the middle of the Tail was also submerged. This is very interesting, because the monthly mean water level in April 1973, when a storm is believed to have destroyed Cat Island, was 177.1 m, i.e. about 60 cm above the May 1992 level. Adding the wave setup and surge to this high water level, it is likely that most of Long Tail Point was also submerged during this storm.

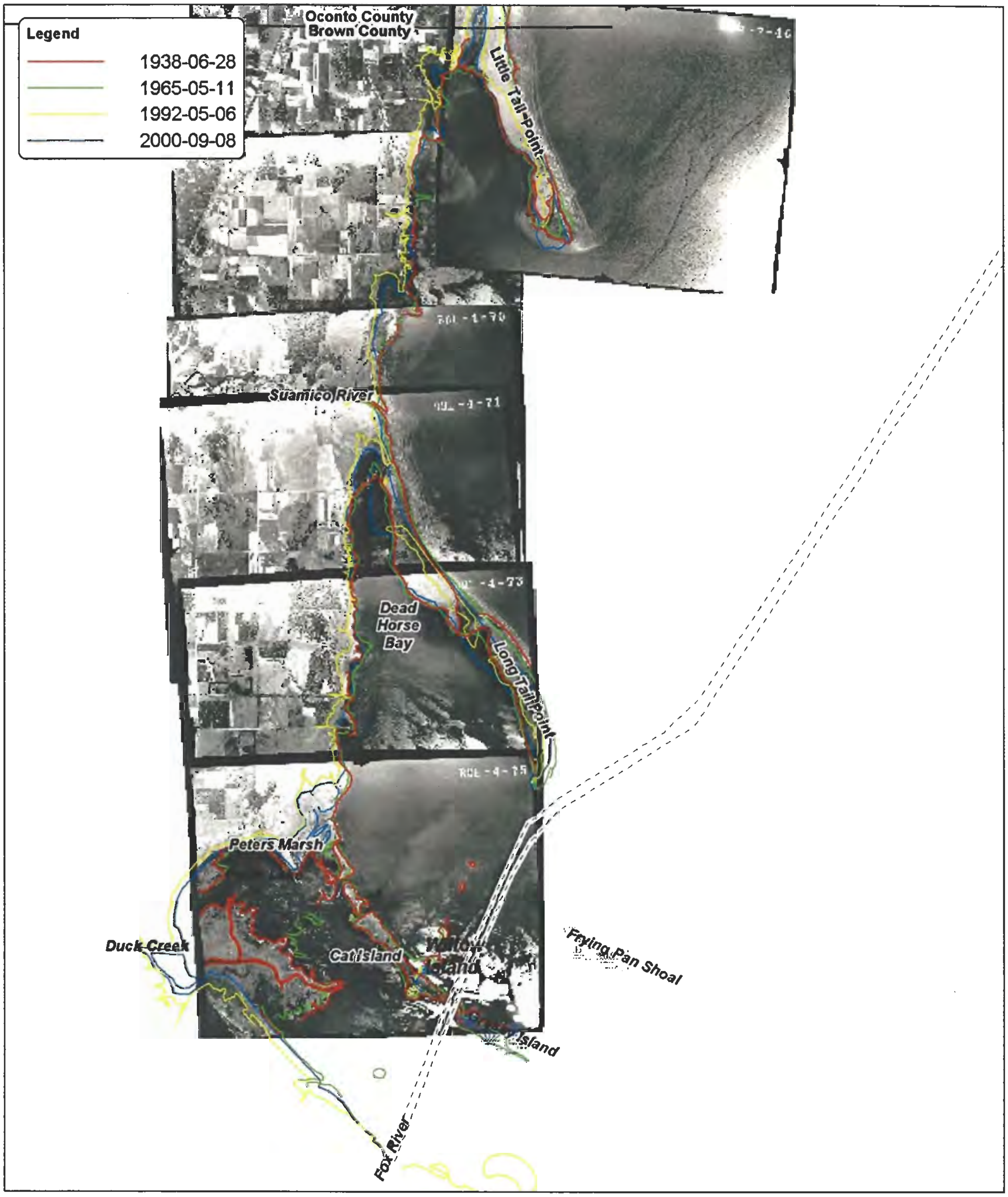
Figures 3.7 and 3.8 show the traced shorelines at Little Tail Point and Long Tail Point, respectively, on a Landsat 7 image taken in July 1999. The mean water level in this month was 176.41 m, which is very close to that of May 1992. It may be seen that the shoreline of 1992 (yellow line) closely follows the 1999 image in both figures indicating that the two features were fairly stable during the seven-year period of 1992 to 1999. Figure 3.8 shows Long Tail Point area shorelines on 1992 air photo, while Figure 3.10 shows the complete traced shorelines on Landsat image of September 2000.

The change in lakebed elevations determined by comparing bathymetry data of 1943 and 2003 is shown in Figure 3.11. The comparison is limited in accuracy because of the coarse grid spacing. Therefore, local areas of large erosion/deposition may be inaccurate and misleading. It may be seen that apart from areas along the navigation channel (related to small shifts in the channel alignment) there have not been any well-defined and significant changes in the bathymetry of the area. Most of the values are in the range of 1 to 2 feet, which is the expected accuracy of the present analysis, and therefore not very conclusive. In the lee of Long Tail Point there is a clear trend of deposition, presumably from sediment that is transported southward past the distant end of Long Tail Point. Also, between Cat Island and Long Tail Point there is a series of rises probably related to dredge spoil mounds from channel dredging. In general, it may be concluded that the area between Long Tail Point and Cat Island has been relatively stable over the past 60 years. The lakebed to the east of the navigation channel shows an overall erosion trend, possibly due to the channel intercepting a net westerly/southwesterly transport.

Figure 3.12 shows the lakebed change in the immediate vicinity of the former Cat Island Chain between the 1997 US Army Corps of Engineers hydrographic survey and the recent 2003 survey completed by Baird. It is evident that there has been very little change in the lakebed and that it may be considered relatively stable for this six-year period. A review of the two isolated areas of erosion and deposition revealed that these are probably not real and instead related the fact the lines for the two surveys were not coincident (i.e. one survey caught the hole between the old central and west islands and the other did not, and similarly one caught the edge of the remnant Cat Island and the other did not).

The stability of Long and Little Tail Points implies that there is a balance between incoming and outgoing sediment transport resulting in no change in morphology. In other words, the spit features are in dynamic equilibrium. This dynamic equilibrium will be maintained only as long as the incoming sediment supply matches the outgoing transport beyond the distal ends of the Points. In turn, this requires that supplies from local rivers and shoreline erosion be maintained. The stability of these features also implies that wave overwash and related transgression of the features is a relatively infrequent.

In the previous report (October 2002) part of the dredge volumes from the navigation channel (adjacent to Long Tail Point) was linked to a southeastwardly longshore transport along Long Tail Point. The observation of a large area of deposition in the lee of the distal end of the Point would appear to confirm this hypothesis. Also, although it is not so evident for Long Tail Point (primarily because the 1938 air photo does not cover the distal end of the point and the water level during the 1965 photo was low), it is evident that the distal end of Little Tail Point is extending with time as one might expect. Certainly, the position of the old lighthouse at the end of Long Tail Point (located well north of the current distal end of the Point), the geomorphic similarity of this feature, and the fact that there is lake bed sedimentation (and significant dredging in this area of the navigation channel) all point to the ongoing extension of Long Tail Point towards the southeast. With time this is likely to lead to increased dredging requirements for the navigation channel in this area (providing no additional mitigative measures are undertaken).



Scale 1:72,000 (0–2.5 km; 0–1.5 mi)	**HISTORIC SHORELINE COMPARISON SOUTH GREEN BAY OVERVIEW 1938 JUNE 28**	Monthly Mean Water Level June 1938 - 176.28m

Figure 3.1

0 2 4 8 km

0 1 2 4 mi

Approx. Scale 1:300,000

SATELLITE IMAGE OF GREEN BAY AND THE STUDY AREA

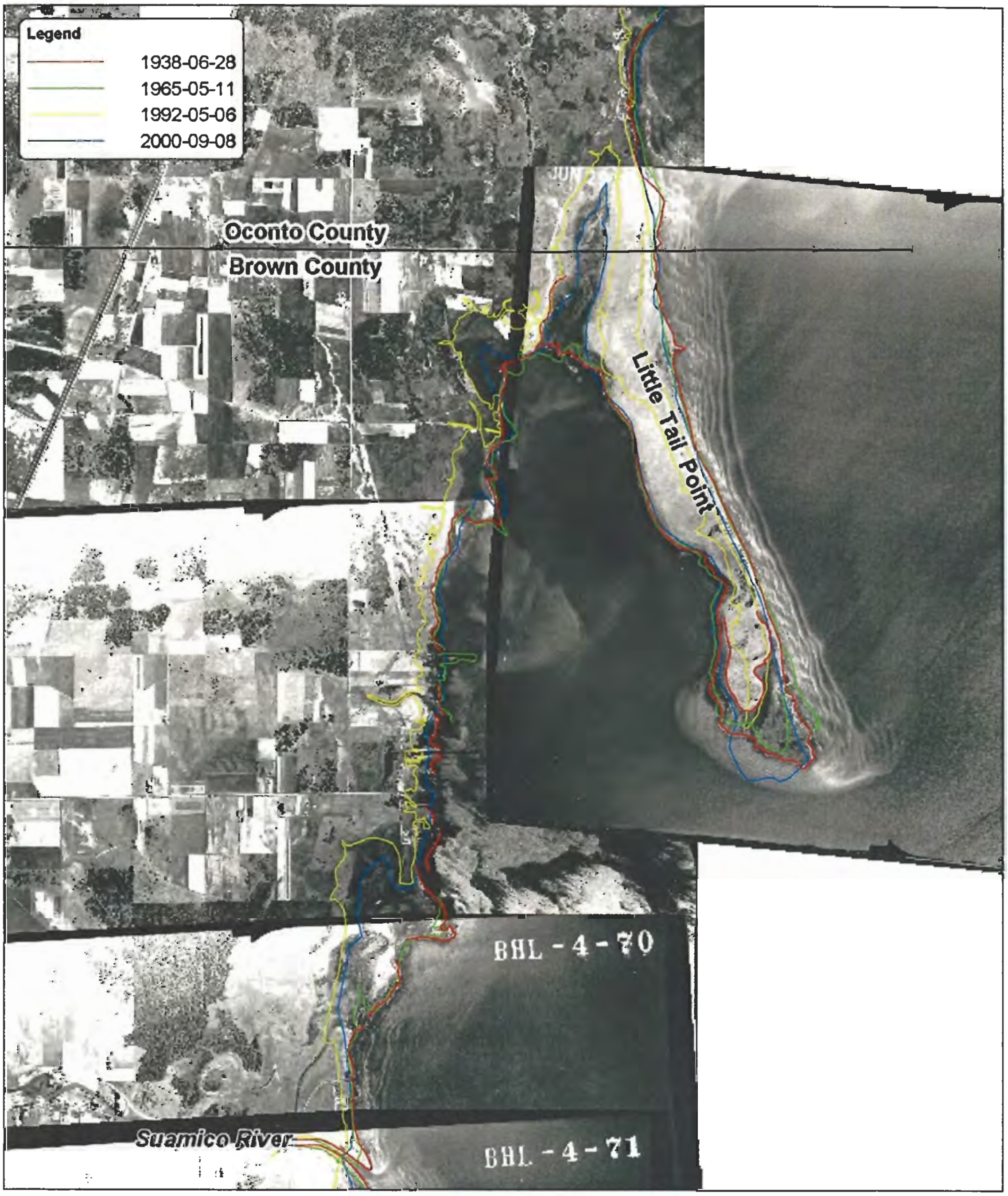
Landsat 7 Satellite:
08 September 2000,
True Color (Bands 3-2-1),
Histogram Equalize, 2 Std. Dev.

Baird

Map Published 2004 January

GreenBay Landsat Images - 2000-09-08.mxd

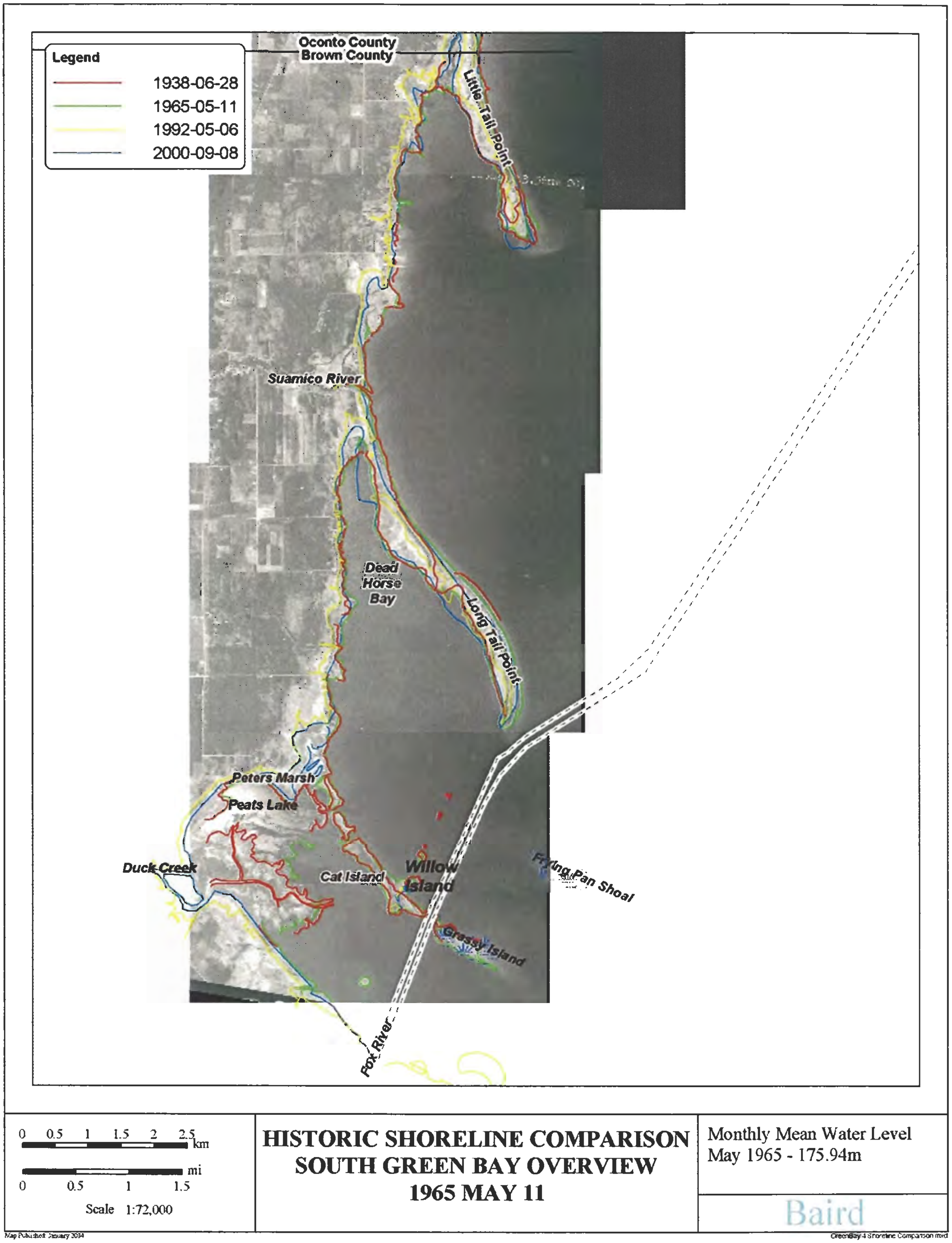
Figure 3.2



0 0.5 1 km 0 0.2 0.4 0.6 mi Scale 1:30,000	**HISTORIC SHORELINE COMPARISON LITTLE TAIL POINT 1938 JUNE 28**	Monthly Mean Water Level June 1938 - 176.28m Baird

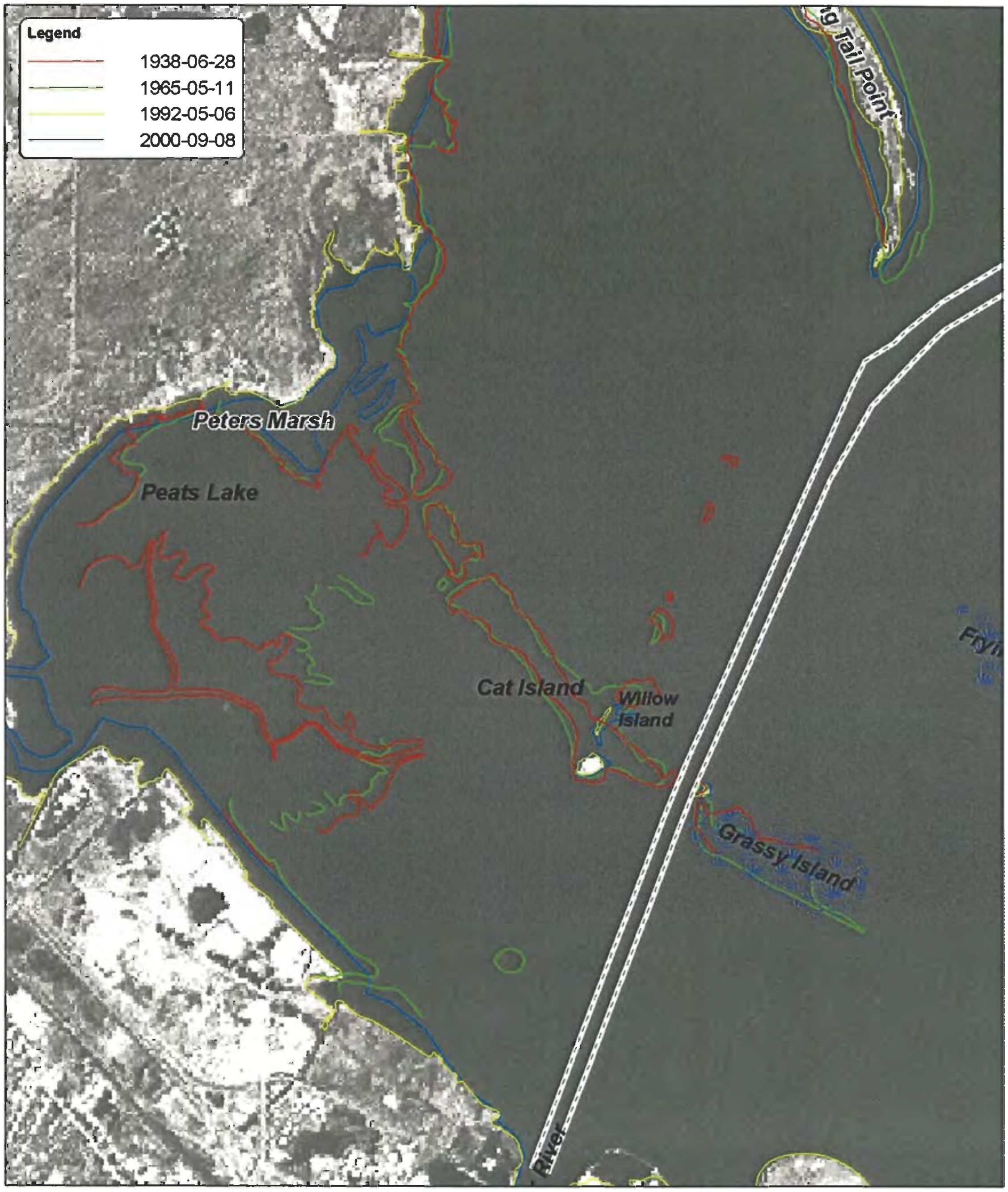
Map Published: January 2004 GreenBay 4 Shoreline Comparison.mxd

Figure 3.3



Legend
1938-06-28
1965-05-11
1992-05-06
2000-09-08
Oconto County
Brown County
Little Tail Point
Suamico River
Dead Horse Bay
Long Tail Point
Peters Marsh
Peats Lake
Duck Creek
Cat Island
Willow Island
Frying Pan Shoal
Grassy Island
Fox River
0 0.5 1 1.5 2 2.5 km
mi
0 0.5 1 1.5
Scale 1:72,000
HISTORIC SHORELINE COMPARISON
SOUTH GREEN BAY OVERVIEW
1965 MAY 11
Monthly Mean Water Level
May 1965 - 175.94m
Baird

Figure 3.4



0 0.5 1 km

0 0.2 0.4 0.6 mi

Scale 1:30,000

HISTORIC SHORELINE COMPARISON
CAT ISLAND CHAIN
1965 MAY 11

Monthly Mean Water Level
May 1965 - 175.94m

Baird

Map Published: January 2004

GreenBay 4 Shoreline Comparison.mxd

Figure 3.5

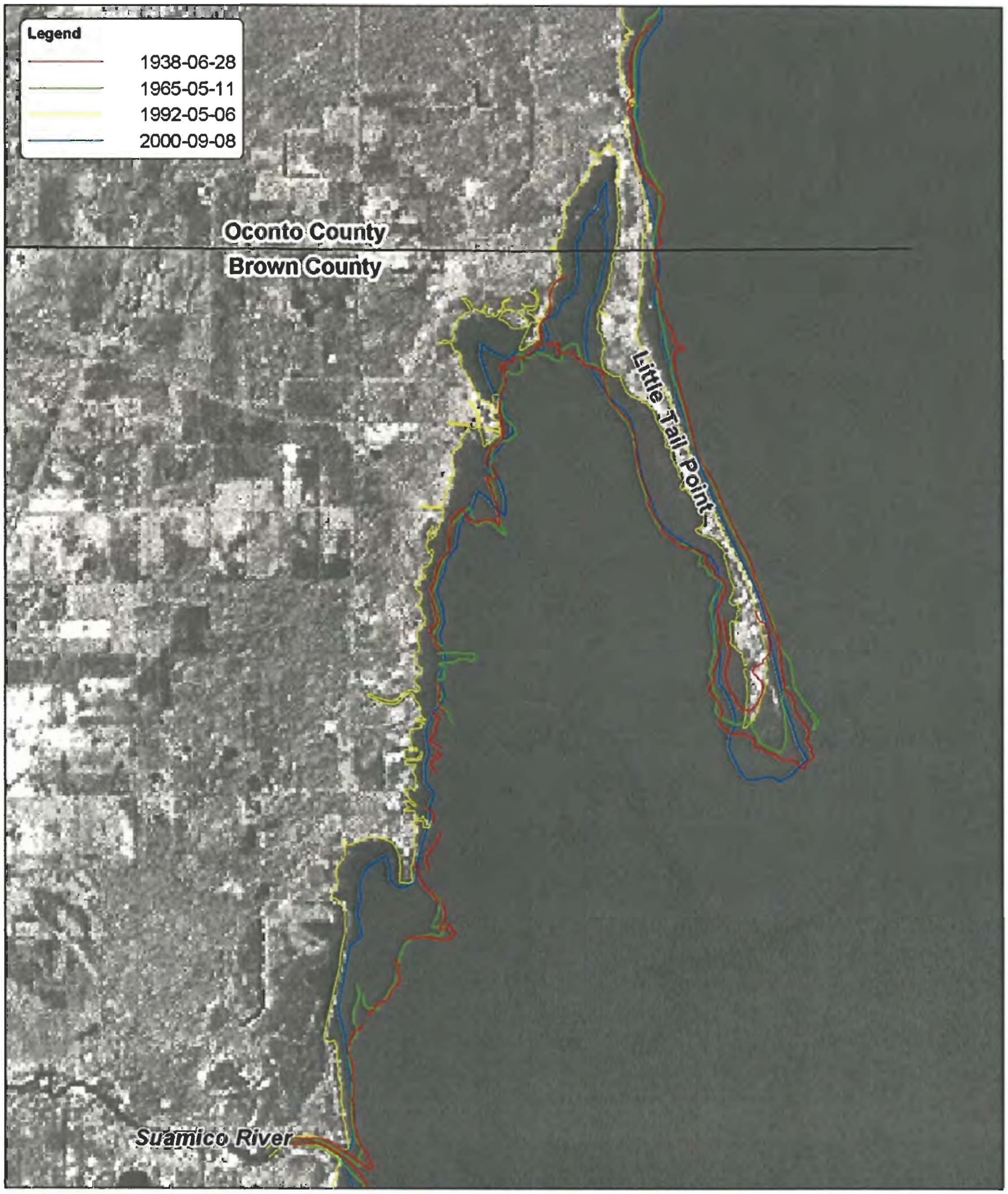
0 0.5 1 km
mi
0 0.2 0.4 0.6
Scale 1:30,000

HISTORIC SHORELINE COMPARISON
LONG TAIL POINT
1965 MAY 11

Monthly Mean Water Level
May 1965 - 175.94m

Baird

Figure 3.6



0 0.5 1 km
0 0.2 0.4 0.6 mi
Scale 1:30,000

HISTORIC SHORELINE COMPARISON
LITTLE TAIL POINT
LANDSAT - 1999 JULY 27

Monthly Mean Water Level
July 1999 - 176.41m

Baird

Map Published: January 2004

Figure 3.7

0 0.5 1 km

0 0.2 0.4 0.6 mi

Scale 1:30,000

HISTORIC SHORELINE COMPARISON
LONG TAIL POINT
LANDSAT - 1999 JULY 27

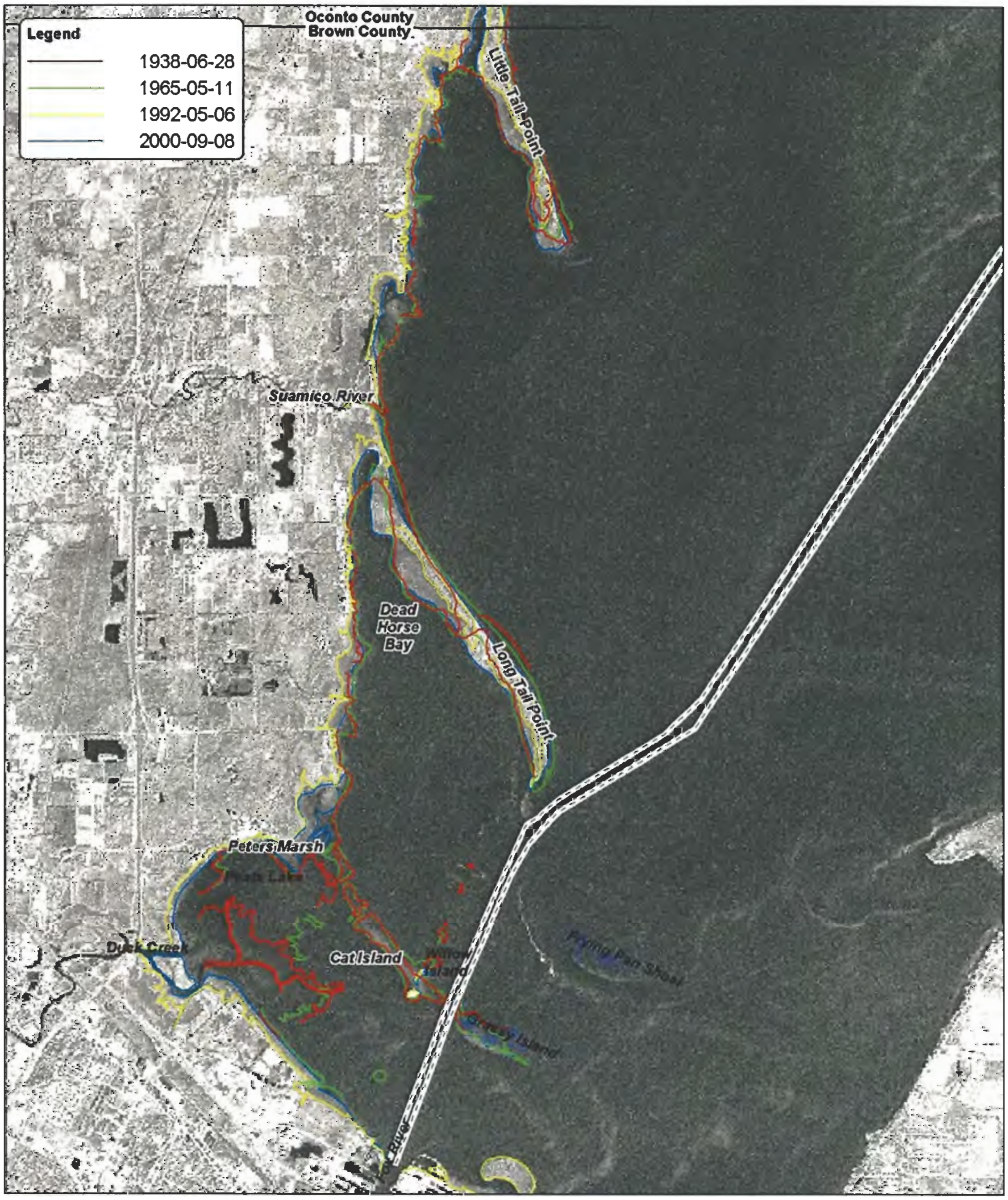
Monthly Mean Water Level
July 1999 - 176.41m

Baird

Figure 3.8

0 0.5 1 km 0 0.2 0.4 0.6 mi Scale 1:30,000	**HISTORIC SHORELINE COMPARISON LONG TAIL POINT 1992 MAY 06**	Monthly Mean Water Level May 1992 - 176.53m Baird

Figure 3.9



0 0.5 1 1.5 2 2.5 km 0 0.5 1 1.5 mi Scale 1:72,000	**HISTORIC SHORELINE COMPARISON SOUTH GREEN BAY OVERVIEW LANDSAT - 2000 SEPT. 08**	Monthly Mean Water Level Sept. 2000 - 176.09m Baird

Map Published January 2004

Figure 3.10

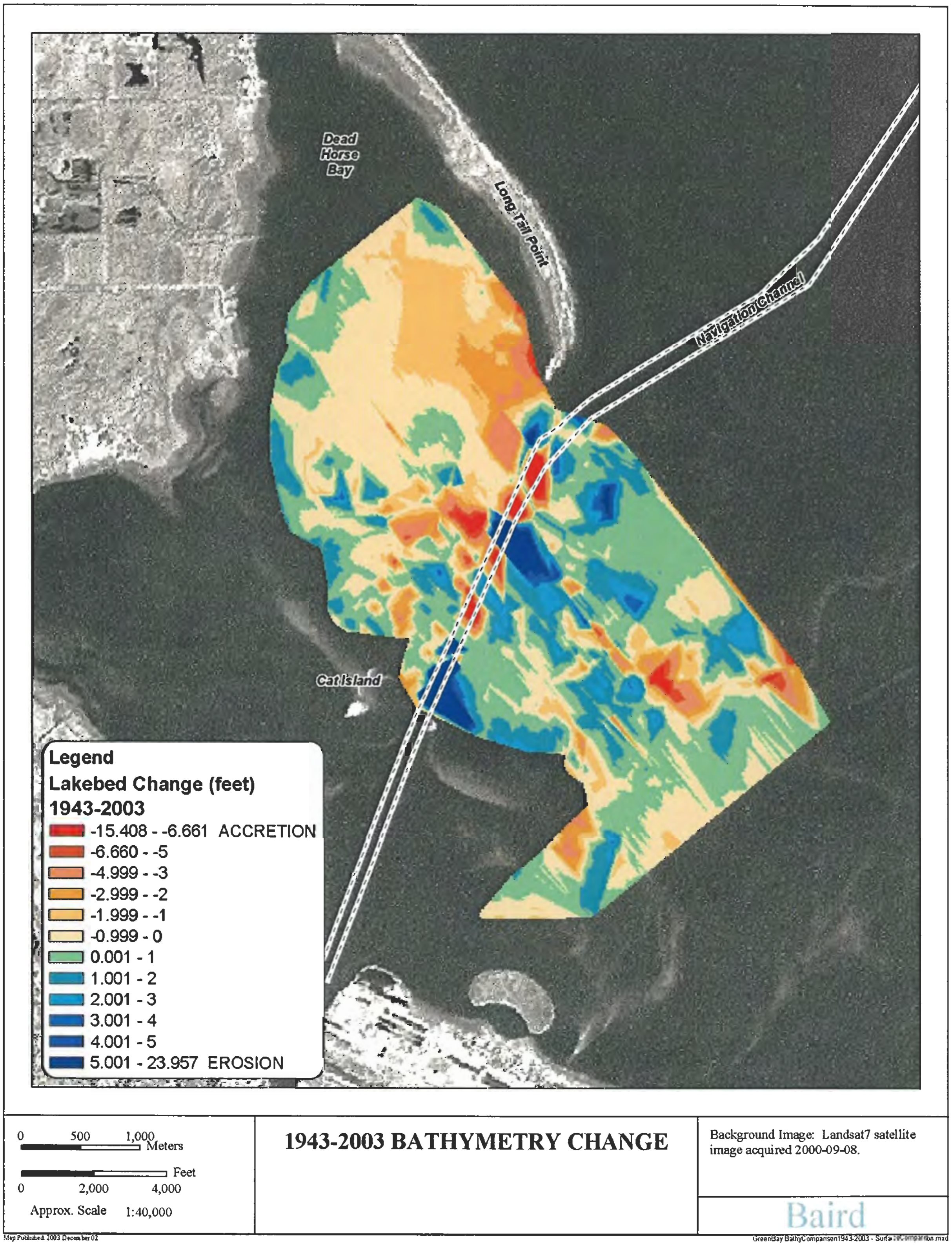

Dead Horse Bay
Long Tail Point
Navigation Channel
Cat Island
Legend
Lakebed Change (feet)
1943-2003
-15.408 - -6.661 ACCRETION
-6.660 - -5
-4.999 - -3
-2.999 - -2
-1.999 - -1
-0.999 - 0
0.001 - 1
1.001 - 2
2.001 - 3
3.001 - 4
4.001 - 5
5.001 - 23.957 EROSION
0 500 1,000 Meters
Feet
0 2,000 4,000
Approx. Scale 1:40,000
1943-2003 BATHYMETRY CHANGE
Background Image: Landsat7 satellite image acquired 2000-09-08.
Baird

Figure 3.11

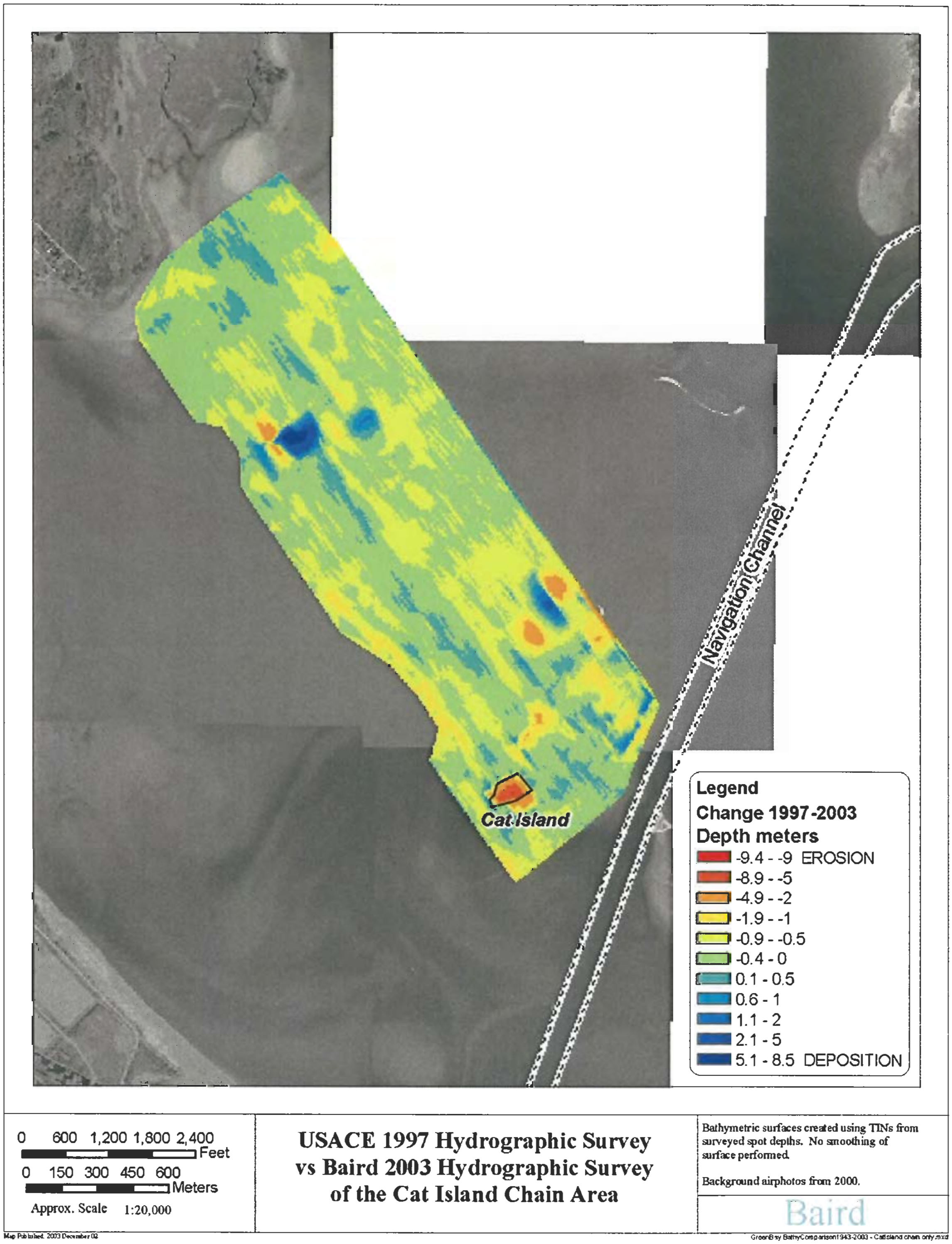

Navigation Channel
Cat Island
Legend
Change 1997-2003
Depth meters
-9.4 - -9 EROSION
-8.9 - -5
-4.9 - -2
-1.9 - -1
-0.9 - -0.5
-0.4 - 0
0.1 - 0.5
0.6 - 1
1.1 - 2
2.1 - 5
5.1 - 8.5 DEPOSITION
0 600 1,200 1,800 2,400 Feet
0 150 300 450 600 Meters
Approx. Scale 1:20,000
USACE 1997 Hydrographic Survey vs Baird 2003 Hydrographic Survey of the Cat Island Chain Area
Bathymetric surfaces created using TINs from surveyed spot depths. No smoothing of surface performed.
Background airphotos from 2000.
Baird

Figure 3.12

4.0 PHYSICAL MODEL STUDY

4.1 Model Objectives

The primary objective of the physical model investigation was to provide detailed information to support the development and optimization of designs for the island perimeter/containment structures considering the range in exposure to wave action around the islands, as well as the characteristics of locally available construction materials (sands, gravels and rock). In particular, the model investigation focused on the following processes:

- Revetment stability and overtopping;
- Beach profile response and overtopping.

4.2 Model Facilities, Design and Construction

The model was undertaken in the 47 by 200 ft Coastal Wave Basin (CWB) at the Canadian Hydraulics Centre of the National Research Council in Ottawa, Canada. The CWB is equipped with a computer controlled wave generator (WM14) that can simulate irregular wave conditions with significant wave heights (Hs) of up to 0.5 to 1 ft depending on the water depth and wave period.

The geometric scale of the Cat Island model was set at 1:10 based on consideration of several factors, including:

- Model wave generation capabilities versus design wave conditions (refer to Section 4.0);
- Availability of model materials (sands, gravels and crushed rock) to simulate anticipated construction materials (refer to Section 9.0);
- Desire to simulate a number of different beach materials and revetment designs;
- Desire to work at as large a scale as possible (to minimize model scale effects).

The adopted model layout is shown in Figures 4.1 and 4.2, and included five different test sections, including three beaches and two revetments. The model test sections were constructed on existing bathymetry in the CWB, which provided a reasonable representation of the flat lakebed slope to the NE of the proposed Cat Island chain. The depth at the toe of the beach and revetment sections was –2 ft CD, which is similar to the average lakebed elevation along the NE limit of the proposed island chain. A range in beach fill materials and revetment designs were tested under a range in water levels and wave conditions, as summarized in Section 4.3.

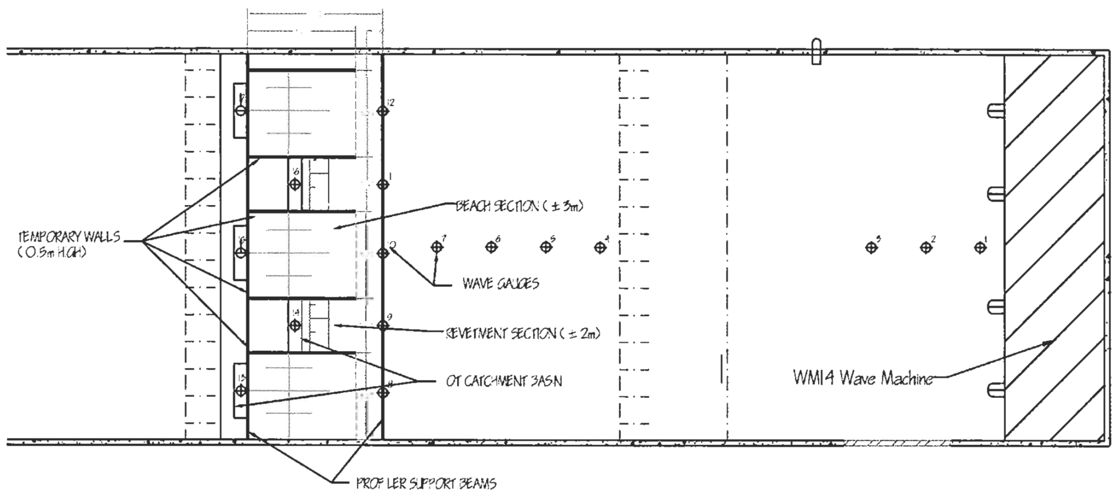


Figure 4.1 – Model Layout

Figure 4.2 – Overview of Model Beaches, Revetments and Instrumentation

The model instrumentation included 12 wave gauges; five wave overtopping catchments/gauges and an electro-mechanical profiler. The wave gauges provide a measure of wave conditions at selected locations in the model (refer to Figures 4.1 and 4.2), while the wave overtopping catchments/gauges provide a measure of the volume/rate of water overtopping the crest of each beach and revetment section (refer to Figure 4.3). Samples were measured at each wave and overtopping gauge for every model test condition, with a 20 minute (prototype) sample duration and a 25 Hz (model) sampling frequency. CHC's GEDAP software was used to reduce and analyze these data. Standard zero crossing and spectral analyses were undertaken to define representative wave parameters at each wave gauge (including Havg, $H_{1/3}$, $H_{1/10}$, H_{max}, T_{avg}, $T_{1/3}$, H_{mo}, T_p, etc.), while customized analyses procedures were developed and utilized to define representative wave overtopping rates.

Figure 4.3 – Wave Overtopping Catchments/Gauges

The profiler (refer to Figure 4.4) was used to measure profile development on the beaches throughout each test series. Profiles were measured at two locations across each test section, with various graphical presentations used to assess ongoing profile development and to compare the profile response of different beach fill materials. The profiler was also used in some tests to measure the profile response of the revetment structures. In addition, visual observations of revetment armor layer stability were made throughout the testing program in order to define damage patterns/levels.

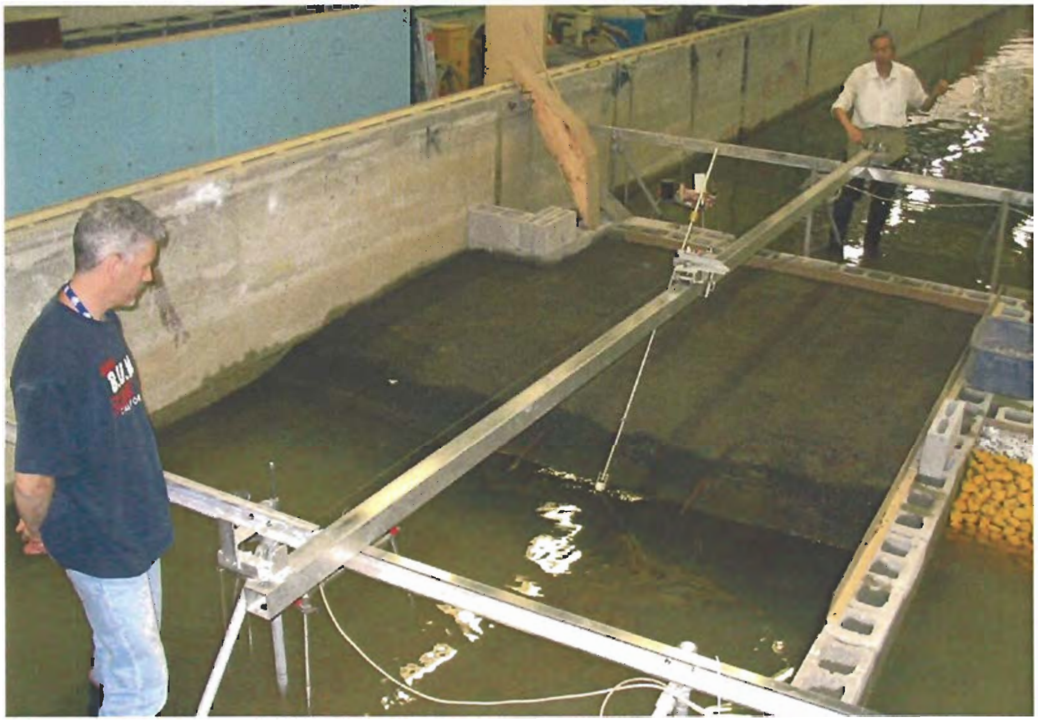


Figure 4.4 – Electro-Mechanical Profiler

4.3 Overview of Model Testing Program

Four separate test series were run in order to assess the performance of different beach fill materials and revetment designs. Tables 4.1 provides a summary of the basic design parameters for the five test sections in each test series, while Table 4.2 provides a summary of the range in test conditions in each test series. In general, beach fill materials were placed to an elevation of +8 to +9 ft CD with a front slope of 6:1 (horizontal:vertical), while the revetments were constructed with various riprap armor layers placed to an elevation of +9 to +10.5 ft CD with a front slope of 1.5:1 (specific exceptions are noted in Table 4.1).

Table 4.1 – Details of Model Test Sections

Test Series	Beach 1	Revetment 1	Beach 2	Revetment 2	Beach 3
A	Stone Dust	Conventional (16-20" riprap, +10.0 ft CD)	Pea Gravel	Conventional (25-32" riprap, +10.5 ft CD)	Silica Sand
B	Stone Dust	Conventional (16-20" riprap, +10.0 ft CD, 2:1 slope)	Pea Gravel	Conventional (25-32" riprap, +10.5 ft CD)	Silica Sand
C	Stone Chip	Conventional (9-18" riprap, +9.5 ft CD)	Pea Gravel (with sand berm at toe)	Conventional (14-20" riprap, +9.0 ft CD	Concrete Sand
D	Stone Chip (1.5:1 slope)	Berm (9-18" riprap, +10 ft CD)	Pea Gravel (1.5:1 slope)	Berm (9-11" riprap, +10.0 ft CD)	Filter Sand

Table 4.2 – Model Test Conditions

Test Series	Water Levels (ft CD)	Wave Conditions		No. of Beach Profile Sets	No. of Revetment Profile Sets	Overtopping Measurements
		Hs/Tp	Total Duration			
A	+4, +5	1.8ft/4s to 3.7ft/6s	15 hrs (model)	8	As-built only	Revetments only
B	+7	1.0ft/2s to 4.6ft/6s	5 hrs (model)	5	None	Beaches & revetments
C	+4, +6	1.8ft/4s to 4.3ft/7s	11 hrs (model)	5	4	Beaches & revetments
D	+4, +6, +7	1.9ft/4s to 4.7ft/7s	15 hrs (model)	7	7	Beaches & revetments

The characteristics of the different beach fill and revetment armor materials tested are presented in the following section of this report.

4.4 Model Material Characteristics

Most of the beach fill materials used in the Cat Island tests were aggregates (natural or crushed) available from local quarries. Two commercial/industrial grade silica sands (a fine sand used extensively at CHC for mobile bed model tests, and a coarse "filter" sand available from a local pool supply store) were also used.

Stone materials for the revetment filter and armor layers were mixed from pre-sorted stockpiles available at CHC (in 1/8" size increments from 1 to 2"), as well as crushed "clear" stone products available from local quarries.

Grain size distributions (GSDs) were measured on samples of each beach fill and revetment armor material. Standard sieve tests were used to define the GSDs for the model beach fill materials (refer to Figure 4.5), while individual stone weights were measured to define the GSDs for the model armor materials (refer to Figure 4.6).

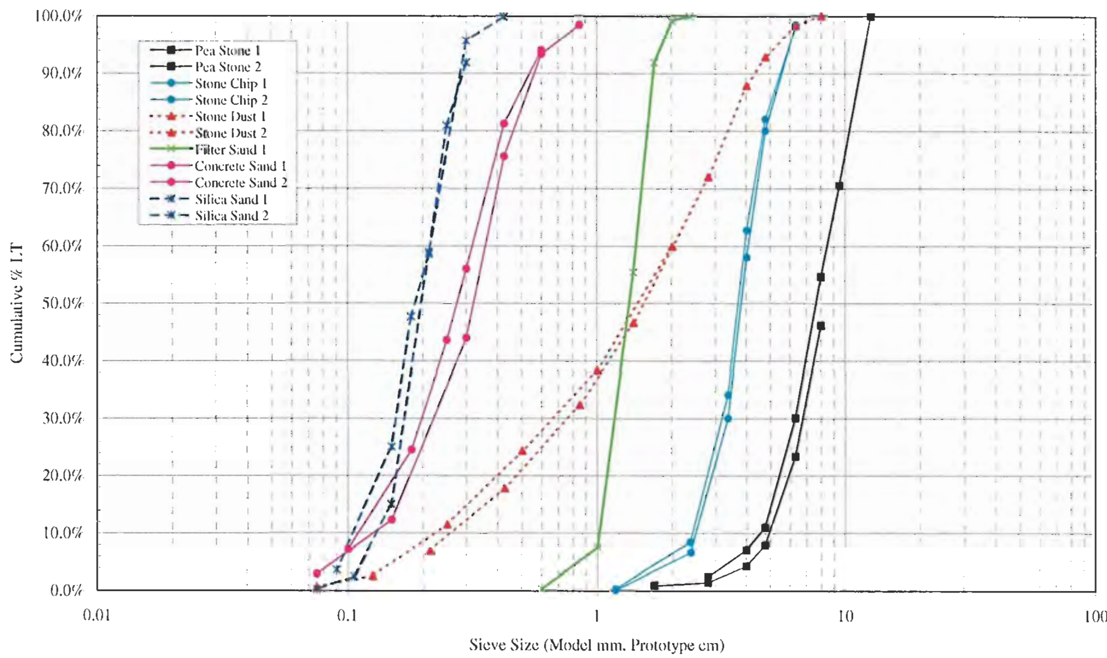


Figure 4.5 – Model Beach Fill Materials – Sample GSDs

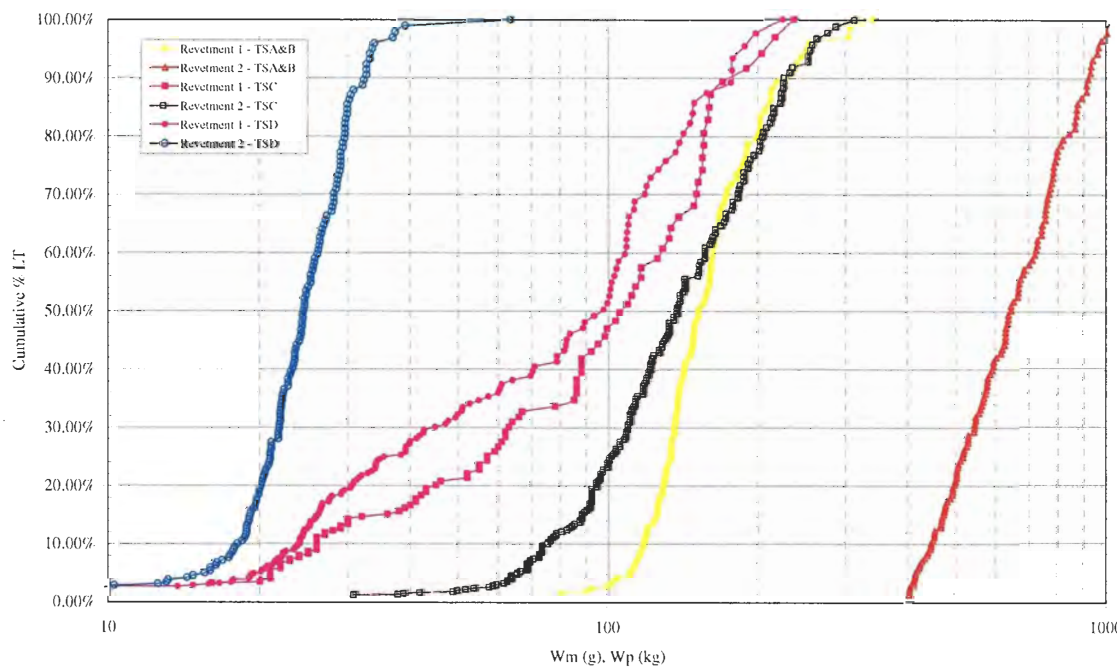


Figure 4.6 – Model Armor Stone Materials – Sample GSDs

The beach fill and armor stone gradation characteristics are also summarized in Tables 4.3 and 4.4 respectively. The armor stone gradations were measured by stone weight (Table 4.4a), but are also presented by "equivalent" stone size (Table 4.4b).

Table 4.3 – Beach Fill Material Characteristics

Material Description	Sieve Size (Model mm, Prototype cm)			D90/D10
	D10	D50	D90	
Silica Sand	0.12	0.19	0.29	2.4
Concrete Sand	0.13	0.30	0.55	4.2
Filter Sand	1.0	1.3	1.7	1.7
Stone Dust	0.25	1.5	4.25	17
Stone Chip	2.5	3.8	5.5	2.2
Pea Gravel	4.8	8.0	11.5	2.4

Table 4.4a – Armor Stone Characteristics by Weight

Material Description	Stone Weight (Model g, Prototype kg)			W90/W10
	W10	W50	W90	
Revetment 1 – TS A&B	120	150	230	1.9
Revetment 2 – TS A&B	445	640	920	2.1
Revetment 1 – TS C & D	25	100	175	7.0
Revetment 2 – TS C	75	140	225	3.0
Revetment 2 – TS D	18	25	33	1.8

Table 4.4b – Armor Stone Characteristics by Equivalent Size

Material Description	Equivalent Stone Size* (Prototype inches)			D90/D10
	D10	D50	D90	
Revetment 1 – TS A&B	16	17.5	20	1.2
Revetment 2 – TS A&B	25	28	32	1.3
Revetment 1 – TS C & D	9.5	15	18.5	1.8
Revetment 2 – TS C	14	17	20	1.4
Revetment 2 – TS D	8.5	9.5	10.5	1.2

*Note: equivalent stone size assumes stone density = 165 lbs/ft^3, shape factor = 1.15 (angular)

The model materials generally exhibit narrow grading, with the exception of the stone dust beach fill (Beach 1 in TSA & B) and one widely graded armor (Revetment 1 in TS C & D). In general, the model materials are representative of prototype materials that are

readily available, or can be easily produced, by quarries in the vicinity of Green Bay (and trucked to the site) or around the north end of Lake Michigan (and shipped to the site on self-unloaders). For example, the filter sand, stone chip and pea gravel beach fills represent 3/8-3/4", 1-2.5" and 2-4" materials respectively, which roughly correspond to Michigan Limestone's G-1, E-1 and 2B products (refer to Section W, and Figure W.1). Considering riprap and armor stone, at least one local quarry stocks a 6-12" product. However, larger materials would likely be specifically produced for this project.
As noted earlier, it may be possible to process shot rock or quarry run materials to produce suitable beach fill and riprap materials for this project. For example, the material could be passed over an 8" grizzly, with material smaller than 8" being used as beach fill (additional processing to remove fines might be required) and material larger than 8" being used as riprap. The feasibility of this approach requires more detailed information on the characteristics of shot rock and quarry run materials produced at local quarries.

4.5 Key Model Results

4.5.1 Beaches

4.5.1.1 Profile Development

As noted earlier, a detailed understanding of beach profile development was one of the key objectives of the Cat Island physical model. Beach profile development was measured for six different beach fill materials under wave conditions up to Hs/Tp = 4.7 ft/7 at water levels ranging from +4 to +7 ft CD. The model beach fill materials had median grain sizes ranging from 0.2 to 8 mm (0.2 to 8 cm, or 1/16 to 3", prototype), with all but one being narrowly graded (refer to GSDs presented in Figure 3.5 and Table 4.3).

As noted earlier, the model beaches were constructed to an initial elevation of +8 to +9 ft CD, with a 6:1 front slope, and were then exposed to progressively increasing wave conditions at a water level of +4 ft CD, followed by similar tests at one or more higher water levels (up to +7 ft CD). For example, the profile development test sequences used in Test Series C and D are presented in Table 4.5, with corresponding profiles measured on the concrete sand (TSC), filter sand (TSD), stone chip (TSD) and pea gravel beaches (TSC and D) presented in Figures 4.7 to 4.10. It is noted a berm of silica sand was placed in front of the toe of the pea stone beach in TSC to simulate the deposition of fine sediment that might naturally occur at the site. In addition, it is noted that the stone chip and pea gravel beaches were placed at a steep slope (angle of repose ~1.5:1) in TSD; all other tests were done with an initial beach slope of ~6:1.

Table 4.5 – Test Sequence for Test Series C and D

WL (ft CD)	Hso* (ft)	Tp (s)	Hs* (ft)	Duration (hrs)	TS C Profile #	TS D Profile #
As-Built Profiles					001	001
+4	2.0	4	1.9	~6	002	002
+4	3.9	6	3.1	~12	003	003
+6	3.2	6	3.2	~6	004	004
+6	4.2	6	4.0	~6	Not tested	005
+6	6.0	6	4.1	~6	005	006
+7	6.2	6	4.7	~6	Not tested	007

*Note: Hso at wave generator (d = -9 ft CD), Hs at test section (d = -2 ft CD)

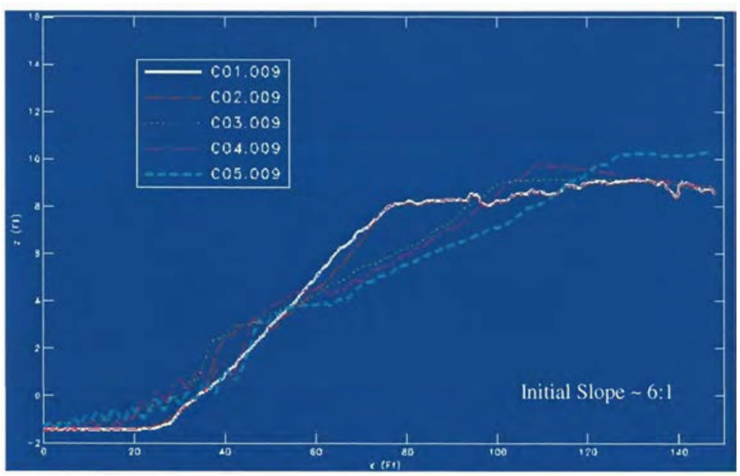


Figure 4.7 – Concrete Sand Beach – Sequential Profiles through TSC

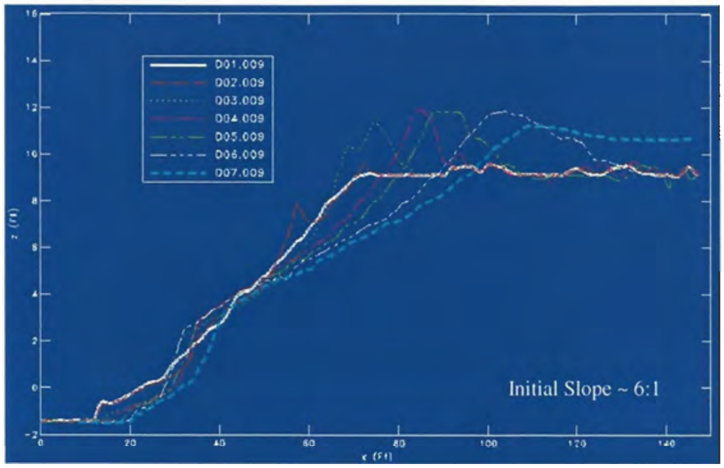


Figure 4.8 - Filter Sand Beach – Sequential Profiles through TSD

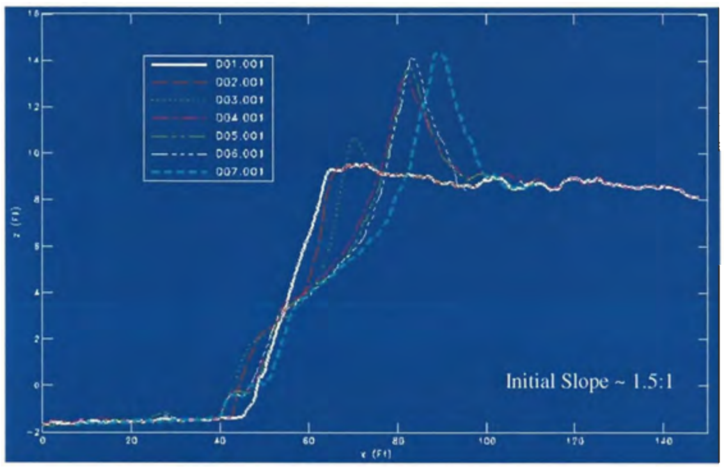


Figure 4.9 – Stone Chip Beach – Sequential Profiles through TSD

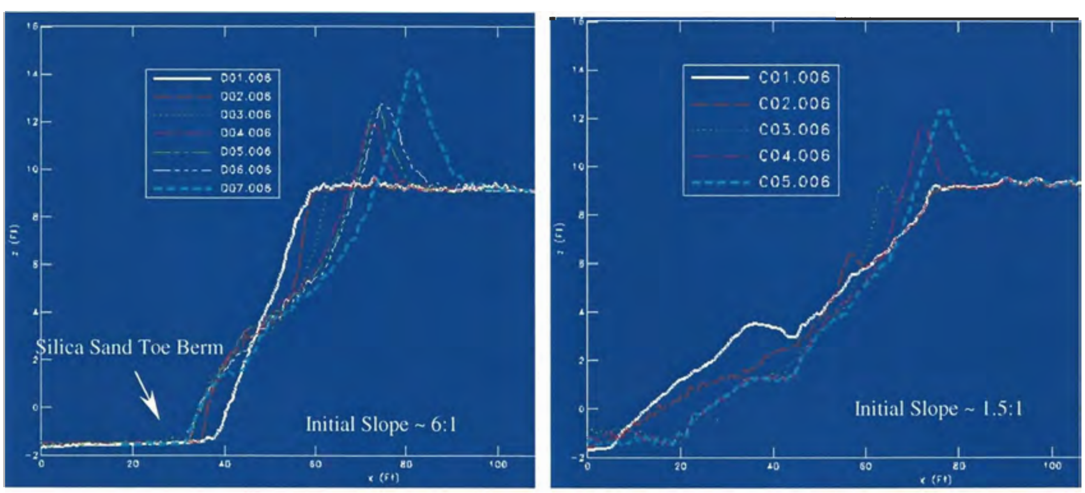


Figure 4.10 – Pea Stone Beach – Sequential Profiles through TSC and TSD

These results show progressive recession of the beach face in response to increasing wave action, and the development of a significant storm berms on the coarser beach fill materials (up to an elevation as high as +14 ft CD). The profile response of the silica sand and stone dust beaches tested in TSA/B was generally similar to that of the concrete sand shown in Figure 4.7, with flatter slopes and less pronounced berm development than the coarser materials.

Figure 4.11 presents a comparison of beach profiles measured for all six beach fill materials following exposure to storm wave conditions (approximately 12 hours at Hs ~ 3.1 ft, Tp ~ 6 s) at a moderately high water level (+4 ft CD). Results for three of the beach fill materials following a shorter duration (6 hrs) of more severe storm waves (Hs ~ 4 ft, Tp ~ 6 s) at a higher water level (+6 ft CD) are presented in Figure 4.12.

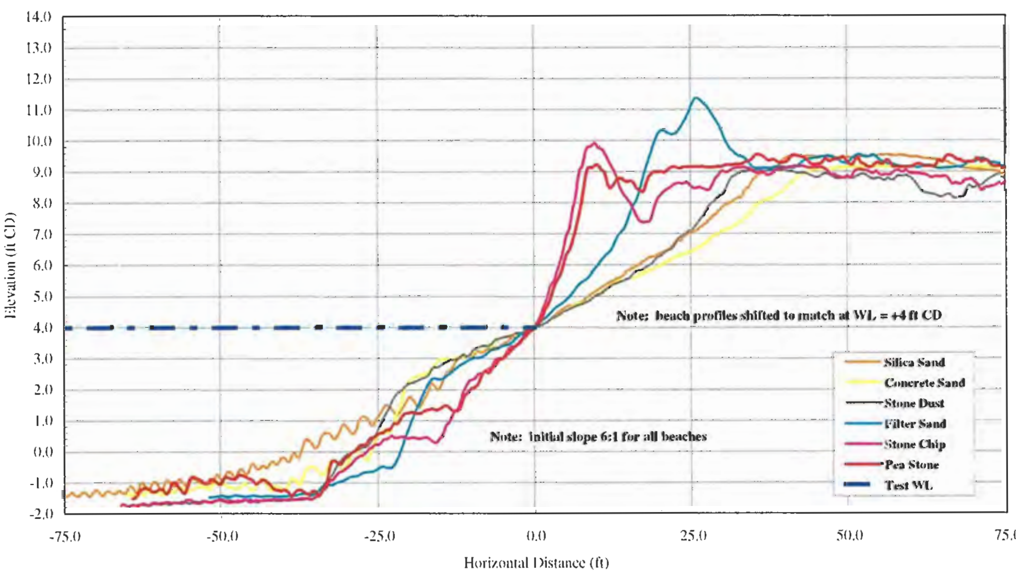


Figure 4.11 – Comparison of Model Beach Profiles
(after ~ 12 hours at Hs/Tp ~ 3.1 ft/6s at WL = +4 ft CD)

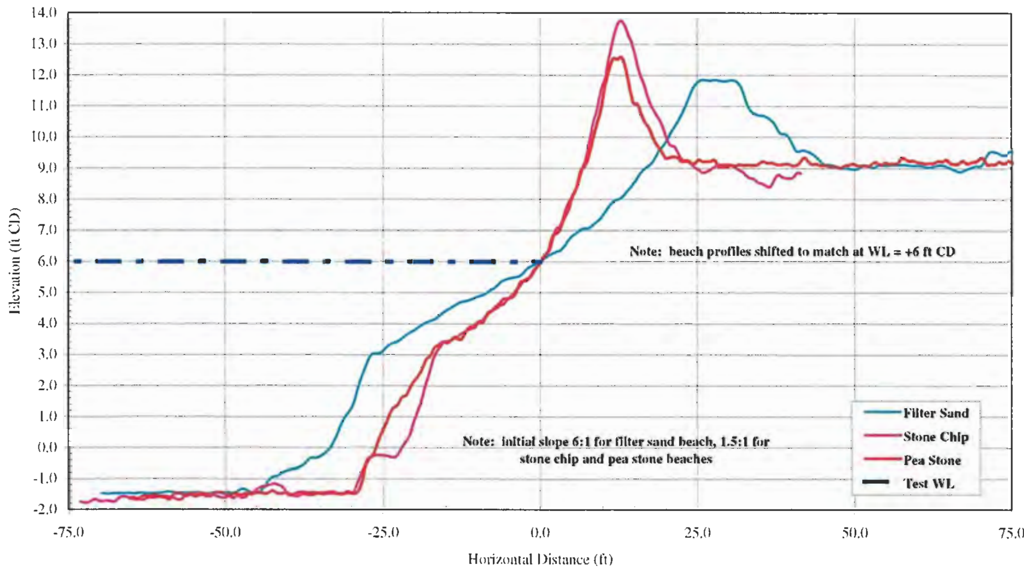


Figure 4.12 – Comparison of Model Beach Profiles
(after ~ 6 hours at Hs/Tp ~ 4 ft/6s at WL = +6 ft CD)

It is noted that there was some variation in beach profile across the width of each test section following any given test condition. For example, the peak berm elevations varied by up to +/-1 ft across the width of each test section following any given test condition. The stone dust beach profile showed considerable variability, likely due to the wide gradation of this material and spatial variability in the material characteristics. It is interesting to note that similar variations were noted by Bradbury and McCabe (2003) in their tests of mixed sand/gravel beaches.

In any event, the model beach profile measurements generally show two characteristic profile types. The first profile type is characterized by a relatively flat slope, without a significant "storm berm", and was exhibited by the two model sands (silica sand and concrete sand) and stone dust beaches. The second profile type is characterized by a relatively steep slope, with a significant storm berm, and was exhibited by the two coarsest materials (stone chip and pea stone). This is a classic gravel beach profile, as previously schematized by van der Meer (1988) and Powell (1990). The filter sand beach profile falls in between these two profile types.

The difference between these two profile types is attributed to the beach fill material characteristics. Specifically, the silica sand, concrete sand and stone dust materials include a significant proportion of fine material (<1 mm) and have relatively low porosity/permeability, while the stone chip and pea stone materials have no fines and high porosity/permeability. Not surprisingly, the first group of materials exhibits a profile shape typical of sandy beaches, while the second group of model materials exhibits a profile shapes typical of gravel/shingle/cobble beaches. The filter sand appears to fall within a transition zone between these two profile types, with an intermediate slope and moderate berm development.

Repeat tests were done with the stone chip and pea stone beaches with initial front slopes of 6:1 and 1.5:1. In addition, repeat tests were done with the pea stone beach without and with a wedge of fine sand placed in front of the toe of the beach to simulate the impact of contamination of a gravel beach with sand. No significant differences were noted in the resulting beach profiles following an extended exposure to storm wave conditions.

4.5.1.2 Wave Overtopping

Wave overtopping of the beaches (and revetments) was measured throughout TSB through D using an overtopping catchment channel and basin (refer to Figure 3.3), with the water level in the catchment basin measured by a capacitance gauge continuously through each one hour (prototype) duration sample. Figure 3.13 presents a typical time series of overtopping data (catchment basin water level versus time) for the three beaches and two revetments under a particular test condition. These data show a number of overtopping "events" (rapid rise in water level) associated with the arrival of "groups" of larger waves at each structure.

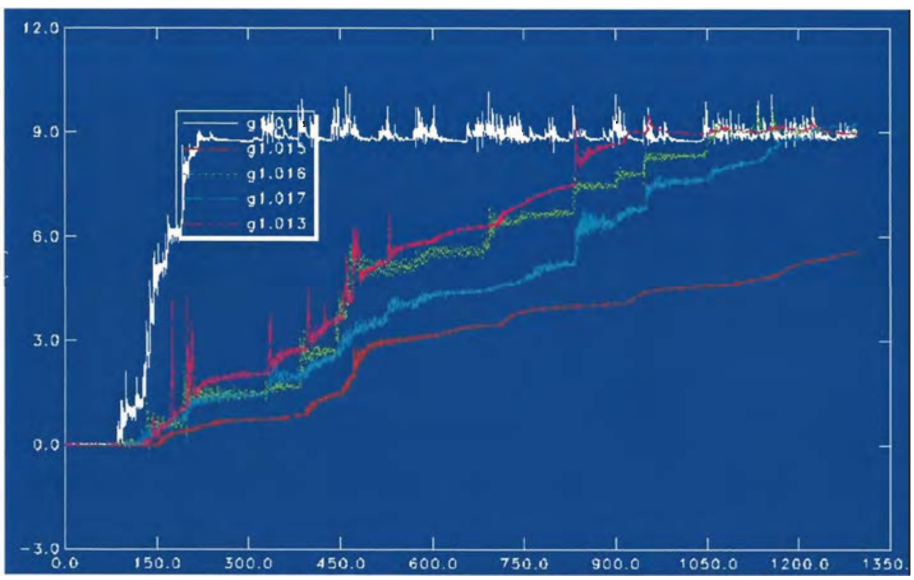


Figure 4.13 – Typical Time Series of Overtopping Data
(Water Level in Catchment Basin versus Time)

These data were subsequently analyzed in order to estimate the mean wave-overtopping rate over each 1-hour (prototype) duration sample, as well as the peak "instantaneous" overtopping rates within each sample (maximum values averaged over durations of 1*Tp and 3*Tp, where Tp is the peak wave period of the test wave condition). Figure 4.14

presents the overtopping data for the different model beaches, with the mean wave overtopping rate ($m^3/s/m$) plotted as a function of the relative freeboard, F/Hs (F = beach crest height above still water level, Hs = significant wave height at structure toe).

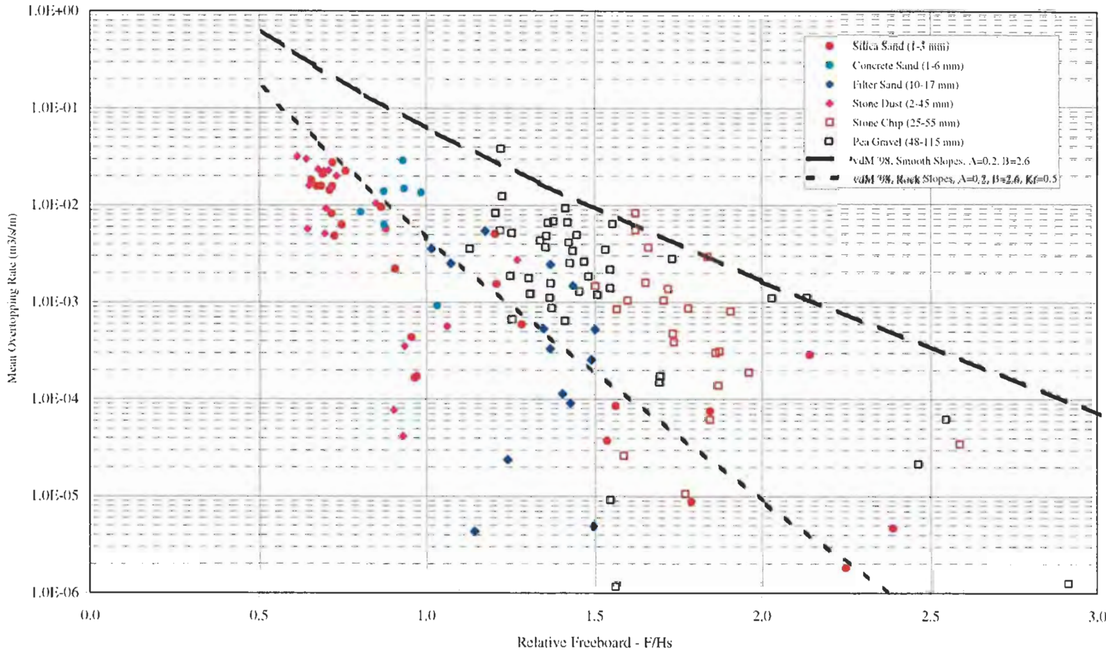


Figure 4.14 - Beach Overtopping Data – Mean OT Rate vs. F/Hs

The model results show considerable scatter, which is typical of model overtopping measurements, as noted by Goda (1985). However, some trends are apparent in the data, with the coarser (and more porous) beach fill materials (stone chip and pea gravel - open symbols in Figure 4.14) generally having higher overtopping rates at any particular value of the relative freeboard parameter. The dashed lines shown in the figure are based on the empirical prediction model of van der Meer (1998) for non-breaking waves on smooth and rock slopes. The higher smooth slope prediction provides an upper bound limit for the model results, as defined by the measurements on the coarser beach fill materials. The lower rock slope prediction provides a mid-range estimate of the results for the other beach fill materials.

The higher overtopping rates noted above for the coarser beach fill materials is somewhat misleading, in that these materials develop a higher storm berm, and therefore have a higher relative freeboard, than the finer materials under any given test condition. Figure 4.15 presents a subset of the beach overtopping data (extreme waves at WL = +6 ft CD), with the mean overtopping rate plotted as a function of the incident wave height at the toe of the beach.

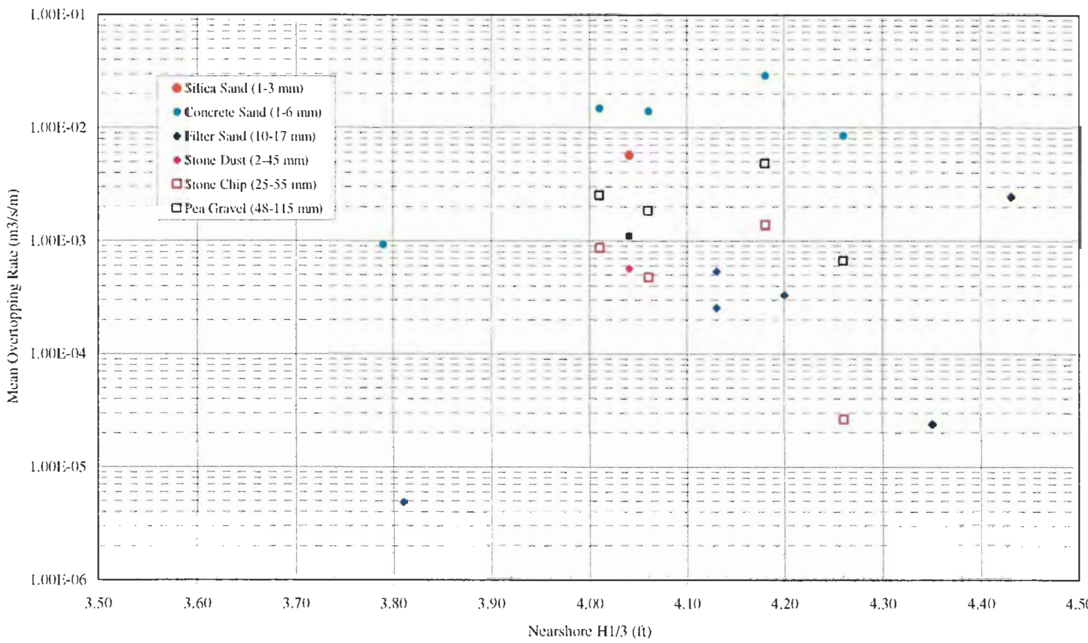


Figure 4.15 – Beach Overtopping Data - Mean OT Rate vs. Hs

This plot demonstrates that the mean wave-overtopping rate is higher for the finer sand beaches than for the coarser gravel beaches under similar wave and water level conditions. This trend is attributed to the combination of the reduced permeability, flatter slope and lower crest of the sand beaches.

4.5.2 Revetments

4.5.2.1 Armour Layer Stability

The revetments in Test Series A and B were "conventional" design concepts, with two layers of armor stone placed over a filter layer and core. The structures were constructed with a crest elevation of approximately +10 ft CD, with the fill behind the crest of the structure protected by a filter stone "splash pad" (nominally 10"). Two different armor stone gradations were tested, including 16-20" and 24-32" size ranges (refer to Figure 4.6 and Table 4.4). For comparison purposes, Hudson equation calculations (refer to USACE, 2001) for the 20 and 100 year design wave heights (Hs = 3.3 and 3.9 ft respectively) give armor stone sizes (D50) of 16" and 19" respectively.

The larger armor gradation was stable under all test conditions (up to and exceeding the 100 year design wave at a water level of +7 ft CD), with the exception of one stone that was displaced landward from the crest by severe wave overtopping. Figure 4.16 shows this revetment following TSB.

Figure 4.16 - Conventional Revetment with 24-32" Armor Layer after TSB

The smaller armor gradation suffered minor damage during the 20-year design wave condition with structure slopes of 1.5:1 (TSA) and 2:1 (TSB), with increasing damage under more severe conditions. Figure 4.17 shows the revetment following TSB.

Figure 4.17 - Conventional Revetment with 16-20" Armor Stone After TSB

Severe wave overtopping was observed/measured on both structures during tests at high water levels (+6 to +7 ft CD), but no significant damage to the crest was noted due to the protection provided by the splash pad. Overtopping is discussed in more detail in the following section.

"Berm" type design concepts were assessed in Test Series C and D, with a wider layer of riprap placed directly over the core (i.e. no filter layer). Two graded ripraps were tested, including 9-18" and 14-20", as well as a smaller, more narrowly graded, riprap (8-10"). These structures were constructed with berm widths of 7 to 20 ft at an elevation of +9 to +10 ft CD. The core stone fill material behind the berm crests was left unprotected.

Sequential profiles were measured to document changes in the profile under progressively more severe waves and water levels. Figures 4.18 to 4.20 show the measured profile response for the three riprap gradations (refer to Table 4.5 for a summary of test conditions).

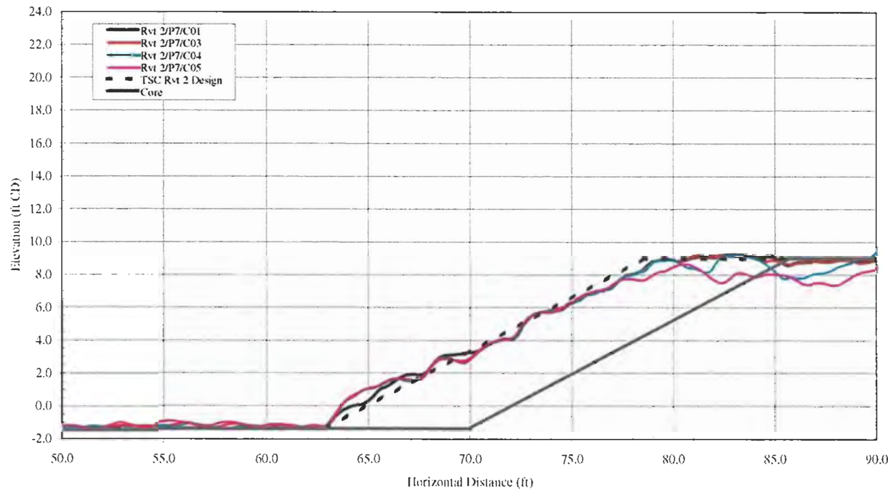


Figure 4.18 – Berm Revetment Profile Response - 14-20" Riprap, TSC

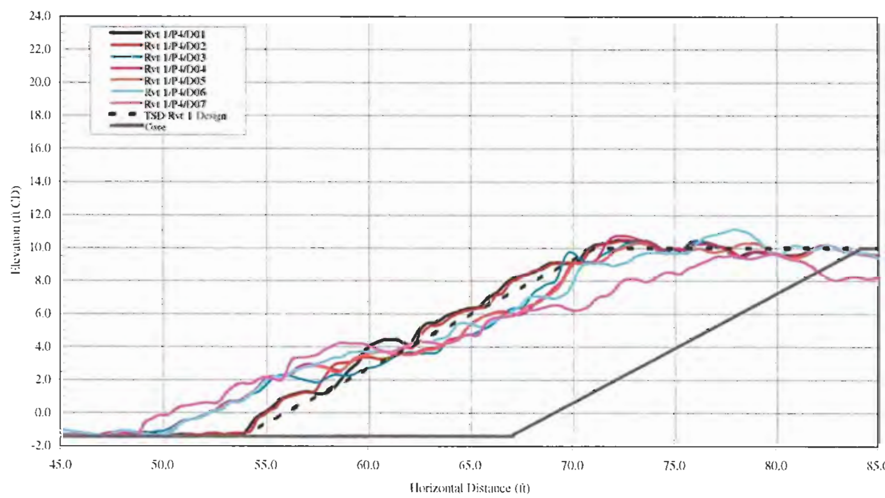


Figure 4.19 – Berm Revetment Profile Response - 9-18" Riprap, TSD

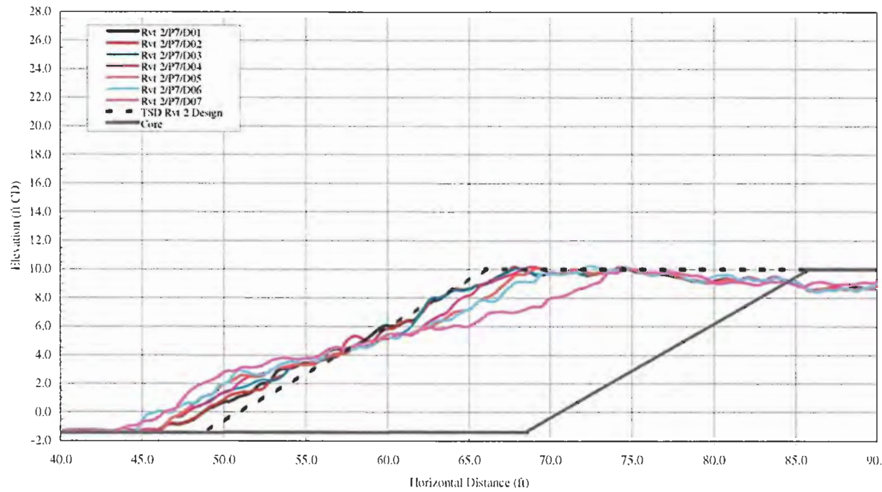


Figure 4.20 – Berm Revetment Profile Response – 8-10" Riprap in TSD

No significant profile development was noted on the largest riprap material (14-20") under wave conditions up to and exceeding the 100-year design event. However, severe overtopping during storm waves at water levels of +6 ft CD and higher caused erosion of the unprotected fill material behind the riprap berm, with subsequent landward displacement of stone from the berm crest. The onset of profile development in the two smaller riprap materials occurred at Hs ~ 3 ft, which is similar to the 20 year design condition. In general, these results show the initial stages of development of an "S-shaped" profile that is similar to, but less pronounced than, that of the gravel beach profiles presented earlier. As noted above, severe overtopping during storm waves at high water levels caused erosion of the fill material behind the riprap berms, with subsequent landward displacement of stone from the berm crest in some cases. This damage mechanism was not observed on the revetment with the widest berm (20 ft). Wave overtopping of the revetment structures is discussed in more detail below.

4.5.2.2 Wave Overtopping

Wave overtopping of the revetments was measured throughout TSA through D using an overtopping catchment channel and basin (refer to Figure 4.3), with the water level in the catchment basin measured by a capacitance gauge continuously through each one-hour (prototype) duration sample (refer to Figure 4.13 for example). Data reduction and analyses procedures were similar to those described earlier for the beach overtopping data. Figure 4.21 presents the mean wave-overtopping rate ($m^3/s/m$) plotted as a function of the relative freeboard, F/Hs (F = structure height above still water level, Hs = significant wave height at structure toe) for the different revetment structures.

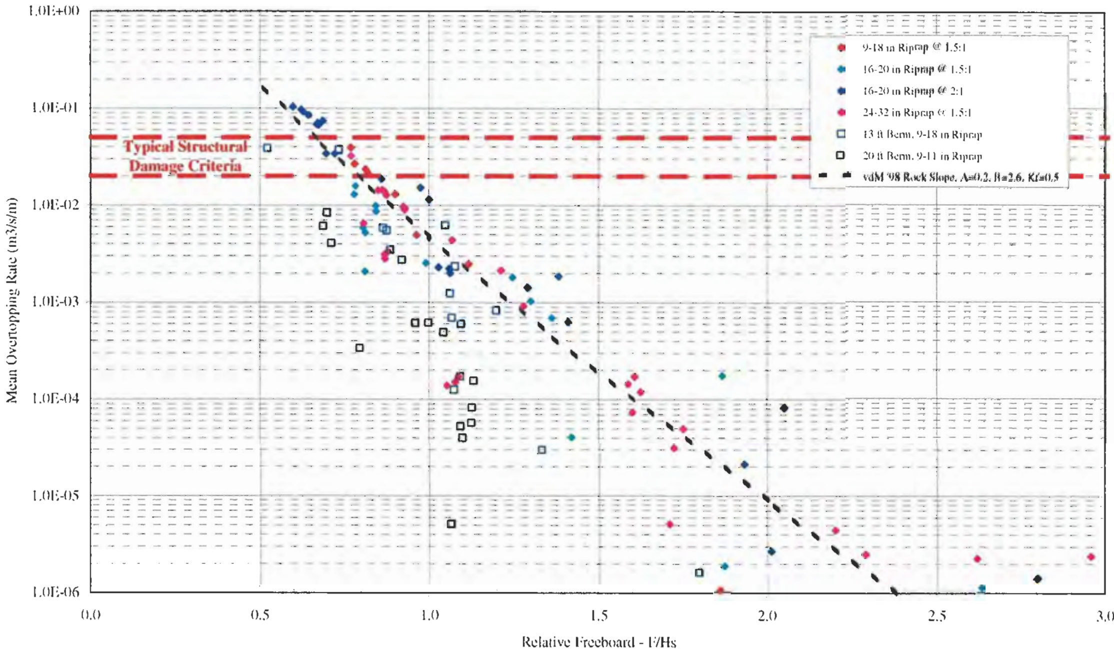


Figure 4.21 – Revetment Overtopping Data – Mean OT Rate vs. F/Hs

Again, there is considerable scatter in the overtopping data. However, the empirical approach of van der Meer (1998) for rock slopes provides a reasonable mid-range estimate of the model measurements on the conventional revetment designs. Further, the test results indicate that the berm structures (open symbols in figure) have lower overtopping rates than the conventional structures; this is attributed to the increased width and porosity of the berms.

Published information (for example, Besley/HRW, 1999; USACE, 2001; OCDI, 2002) suggests that structural damage due to wave overtopping can be expected for mean wave overtopping rates in the order of 0.02 to 0.05 $m^3/s/m$ (0.2 to 0.5 $ft^3/s/ft$ or greater). This range is highlighted by the red dashed lines in Figure 4.21. The model results (measured overtopping rates, as well as visual observations) indicate that damage (to the crest and adjacent fill) due to wave overtopping can be expected for F/Hs > ~ 0.75 to 1.0. This result is generally consistent with Baird's experience with physical model investigations of other coastal structures.

4.6 Model Scale Effects and Interpretation

As noted earlier, "scale effects" are inherent in any physical model, as the viscosity (and surface tension) of the water is not scaled properly (there is no practical alternative to water as the model fluid), thereby leading to exaggerated viscous (and surface tension) forces in the model. In addition, other model effects, such as the absence of wind, must be considered in the interpretation/application of model results. The following paragraphs provide a brief summary of these issues with respect to revetment stability, wave runup/overtopping and beach profile response.

Considering the stability of rubblemound structures such as revetments and breakwaters, Dai and Kamel (1969) indicate that viscous scale effects (due to a change in wave-induced flow characteristics within the core from turbulent in prototype to laminar in the model) may be significant for Reynolds Numbers (Re) of less than 30,000 ($Re = D^*\sqrt{gH}/v$, where D = armor size, g = gravitational acceleration, H = wave height and v = kinematic viscosity of water). However, more recent research (Owen and Briggs, 1986) suggests that this limit may be as low as 3,000 to 8,000. In any event, it is generally agreed that these scale effects result in conservative results, with damage to the armor layer being exaggerated in the model. Considering the revetment structures modeled in this study, the armor layer Reynolds Number is 20,000 or greater under the design wave conditions, so no significant scale effects are anticipated with respect to stability.

Considering wave runup and overtopping, a literature review indicates considerable differences in opinion regarding scale effects in physical models. For example, de Wall et al (1996) suggest that model scale effects (due to incorrectly scaled viscosity and surface tension, as well as the absence of wind in the model) may be significant at low overtopping rates (i.e. models underestimate spray/splash overtopping), but insignificant at high overtopping rates (i.e. models accurately simulate green water/sheet flow overtopping). More recently, Pearson et al (2002) found no significant difference between small and large-scale measurements of wave overtopping on vertical walls. On the other hand, the OPTICREST project (see de Rouck et al, 2001) indicates that actual wave runup levels on prototype sloping structures are underestimated by small-scale model results, which infers that wave overtopping may be underestimated as well. However, at this time, given the large scatter in the model overtopping results (typical of such tests, as noted by Goda, 1985), the uncertainty related to scale effects, and the relatively large model scale, no adjustment to the overtopping rates has been applied.

Considering the beaches, it is noted that "mobile bed" models of coastal processes (i.e. sediment transport, beach profile response, etc.) may be subject to significant scale effects, as the flow and sediment transport regimes may be different in model and prototype. The development of model scaling relationships for mobile bed models (and the quantification of model scale effects) has been (and continues to be) the subject of extensive research by international hydraulics laboratories, with various sediment scaling relationships having been proposed by different researchers. However, there is no generally accepted sediment scaling methodology in widespread use at this time.

In general, fine-grained sediments cannot be scaled down geometrically, as the required model sediment would be cohesive (i.e. silt or clay), with a completely different response to hydrodynamic flows than the cohesionless prototype sediment (for example, a 1:10 scale model of 0.3 mm (medium) sand would require 0.03 mm silt). Rather, very fine sand (and/or lightweight sediment) is generally used in mobile bed models, with characteristic response parameters for the model sediment (such as fall velocity, critical shear stress or some other sediment "mobility" parameter) scaled to prototype and used to estimate the corresponding prototype grain size. Clearly, larger scale models result in reduced scale effects, but even the large scale (1:10) model used for Cat Island cannot simulate the response of sand beaches without some scale effects. Table 4.6 below presents estimated prototype sediment sizes (D50) for the Cat Island model beach fill materials based on several scaling approaches, including geometric (i.e. 1:10 model scale), fall velocity (based on Hallermeier, 1981), critical shear stress (based on Shields curve, after van Rijn, 1984) and flow regime (laminar/turbulent) within porous media (based on Jensen and Klinting, 1983).

Table 4.6 – Model Beach Fill Scaling – Various Methods

Model Material	Model D50 (mm)	Scaled D50 (Prototype mm)			
		Geometric	Fall Vel.	Shear Vel.	Flow Regime*
Silica Sand	0.19	1.9	0.6	1.8	0.5-1.7
Concrete Sand	0.30	3.0	0.9	2.1	0.9-2.6
Filter Sand	1.3	13	13	8.4	6-12
Stone Dust	1.5	15	15	10	7-14
Stone Chip	3.8	38	38	34	25-38
Pea Gravel	8.0	80	80	80	60-80

*Note: flow regime estimate depends on assumed flow velocity within beach fill material

These results generally suggest the potential for significant scale effects (i.e. scaled prototype size is significantly different from that given by geometric scaling) for the finer grained model sediments, but limited to none for the coarser-grained model sediments. Given the presence of a significant proportion of fines in the model stone dust material, and the fact that the profile response of such a "mixed beach" is generally controlled by these fines, it too would be subject to scale effects.

For this project, the most important scale effect is related to the beach profile, with the actual beaches anticipated to have a flatter slope than the model beaches. Baird's extensive experience in beach modeling, design and monitoring, in particular comparisons of model and prototype beach profiles for several completed projects, indicates that prototype sand beaches will have swash zone slopes up to two to three times flatter than model sand beaches depending on model and prototype grain sizes, model scale, etc. Considering the Cat Island model, a factor of two is suggested to convert the model sand beach profiles into prototype sand or mixed (sand-gravel) beach profiles. However, the coarsest model beaches (stone chip and pea gravel) are believed to provide an accurate representation of actual profiles expected for geometrically scaled materials (i.e. clean gravel and cobble beaches).

In summary, no significant scale effects are anticipated with respect to revetment stability, wave overtopping or gravel/cobble beach profiles. However, actual sand beach profiles at Cat Island are likely to be significantly flatter than the sand beach profiles measured in the model. A factor of two adjustments has been applied to the model sand beach profiles based on comparisons of model and prototype beach profiles available from previous studies.

5.0 WAVE GENERATION AND TRANSFORMATION MODELING

5.1 Wave Generation Modeling

A preliminary assessment of the wave conditions in the vicinity of the project site was made during the initial phases of the study. The complexity of the generation process in a narrow fetch region and the wave transformation in the vicinity of the site required that additional analyses be carried out for final design. These analyses included the installation of wave recorders, as described in Section 2.2.4.

Following retrieval of the wave data from the pressure recorders, a numerical wave hindcast was carried out for the period of deployment. This hindcast, which used the numerical model WAVAD, included all of Green Bay and used winds recorded from the Green Bay Airport. WAVAD is a second generation, two-dimensional wave generation and propagation model, similar to the WISWAVE model used by the U.S. Army Corps of Engineers. The model was run at a 15-minute time step on a bathymetric grid with a 2 km grid spacing, as shown in Figure 5.1 (depths in meters).

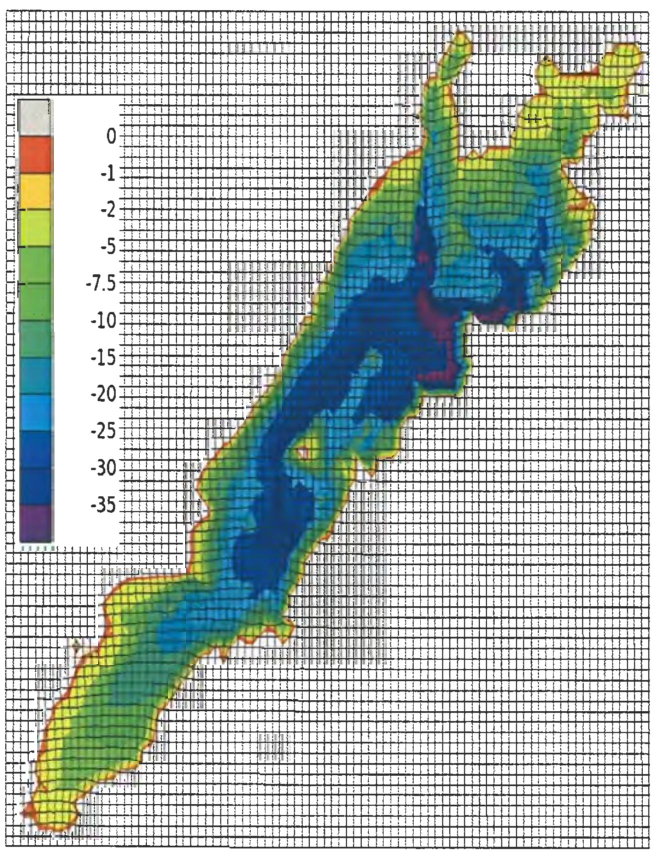


Figure 5.1 - Bathymetric Grid Used for the WAVAD Model.

Comparisons were first made between the gauge at Long Tail Point since this gauge has less influence from sheltering and other bathymetric effects compared to the inner gauge. The initial comparison showed a poor relationship between the hindcast data and the measured data. While there was typically some over-estimation of the waves, occasionally an underestimation occurred. This inconsistency lead to investigation of the wind data used for the study.

To better represent winds over Green Bay, a comparison was made between winds recorded at the airport and those recorded over the water at NOAA Buoy 45002. This comparison was carried out only for winds from the NE sector, since it is these winds that create significant waves at the site and these winds pass over the city of Green Bay before being measured at the airport. The analysis examined statistical wind trends during different thermal gradients over the lake (i.e. the air-water temperature difference measured at the buoy). Based on this analysis it was concluded that winds recorded at the airport during warm air and cold-water conditions (typical of the spring) were significantly higher than those that occurred over the lake. Conversely, warm water and cold air (typical of the fall or during sub-freezing air conditions in the spring) resulted in winds that are higher over the lake than those measured at the airport. Figure 5.2 shows the relationship between winds at the airport and winds over the lake for two air-water temperature difference scenarios. These plots present the relationship between quantile levels (for instance 90 per cent, 99 per cent, etc.) for winds at the airport and the buoy that were measured concurrently.

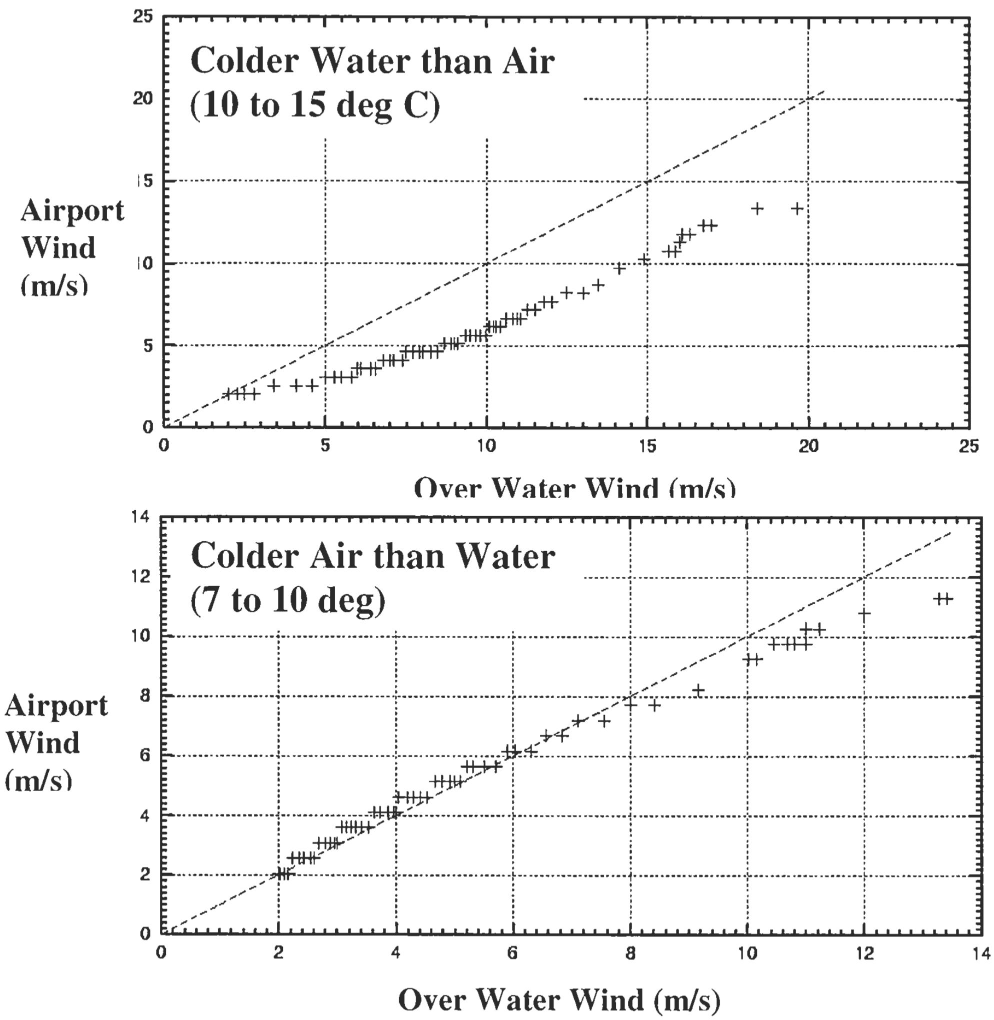


Figure 5.2 - Wind Speed Relationships for Different Air-Water Temperature Differences

From the relationship depicted in Figure 5.2 (and others not shown for other temperature gradients), correction factors were generated and these were applied to the wind conditions measured at the airport. The resulting Temperature Difference Scaled (TDS) winds then provided a set of wind data that were statistically similar to the winds recorded on the surface of Lake Michigan.

The hindcast was then re-run with the TDS winds and the results were substantially different. Figure 5.3 shows a comparison of the hindcast waves, using both sets of wind data as well as the measured data at Long Tail Point.

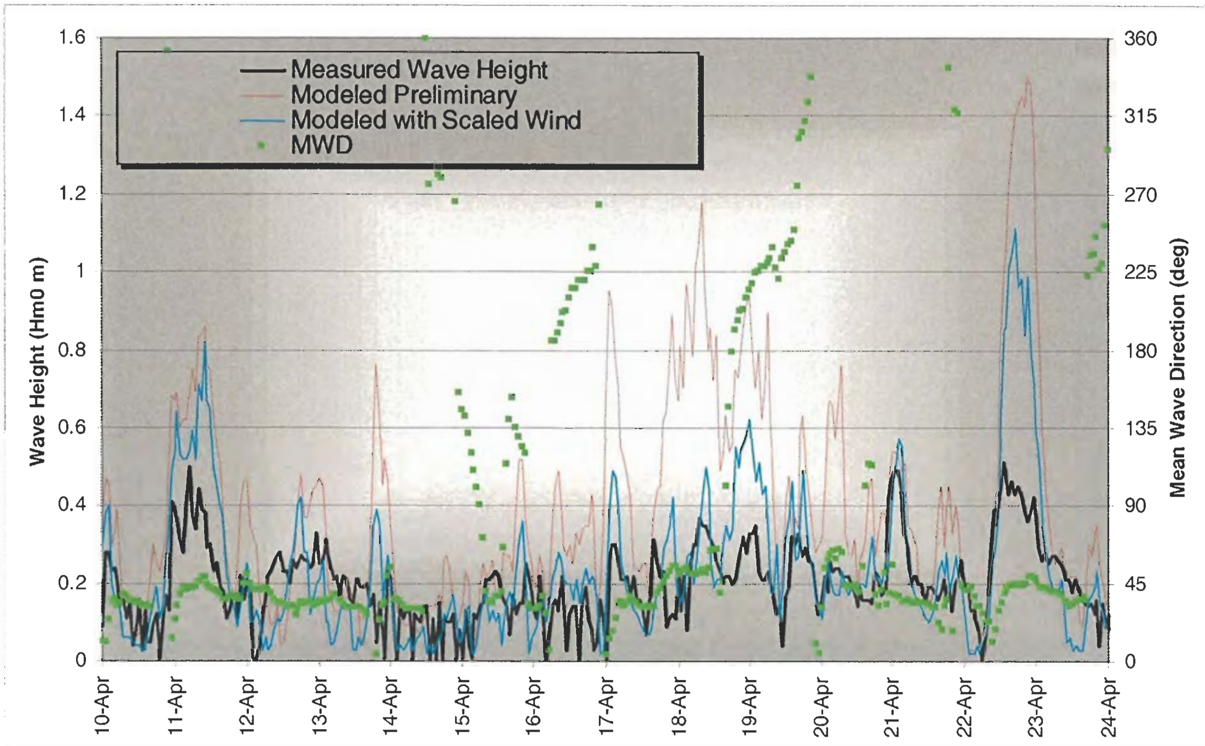


Figure 5.3 - Comparison of Hindcast Waves and Recorded Waves

A slight over-prediction of the waves at Long Tail Point remained after correction of the winds. Examination of a number of the larger events indicated that much of this over-prediction was due to refraction of the waves along the edge of the dredge channel as it transitioned towards the tip of the point. However, this wave transformation did not entirely explain the over prediction of the wave conditions. One approach to rectify this would have been to apply some sort of scale factor to the winds or waves in order to achieve a better match between the modeled and recorded waves. However, due to the fact that the field deployment did not measure any particularly large wave events, it was decided that reducing waves based on a scale factor was non-conservative and inappropriate since there was no assurance that the over-predicting seen for smaller wave events was consistent for larger wave events.

Following the adjustments to the winds during the calibration period (spring 2004), the same wind transformations were applied to the historical wind data and the hindcast was re-run for the period of record of the winds. This was done initially using Baird's parametric hindcast model and the listing of storm events was re-generated. From this list of events, the top 15 events were identified for further study and were then simulated in WAVAD.

Following the determination of the wave height at the offshore location, wave transformation modeling was required in order to determine the wave conditions at the position of the proposed islands

5.2 Wave Transformation Modeling

To determine detailed wave conditions at the site, the wave model STWAVE was implemented. STWAVE is a steady-state wave transformation model developed by the US Army Corps of Engineers capable of quantifying the effects of wave generation, shoaling, breaking, refraction and diffraction.

Bathymetry data as documented in Section 2, wind and wave conditions defined by the modeling in Section 4.1 are all used as input to the STWAVE model. A bathymetry grid was created with the parameters assigned in Table 5.1 was utilized in all of the STWAVE runs. Figure 5.4 displays a color map of the STWAVE bathymetry grid.

Table 5.1 - STWAVE Bathymetry Grid Parameters

Parameter	Value
Nx	329
Ny	335
Δx	50 m
Δy	50 m

Figure 5.4 – Color Map of STWAVE Bathymetry Grid

5.2.1 Extreme Event Simulations

A series of extreme events were simulated using STWAVE to determine design conditions for the proposed Cat Island restoration plan. The top 20 events of record were used as input to the wave model. The results for the top event are displayed in Figure 5.5. All extreme event STWAVE model results are included in Appendix C.

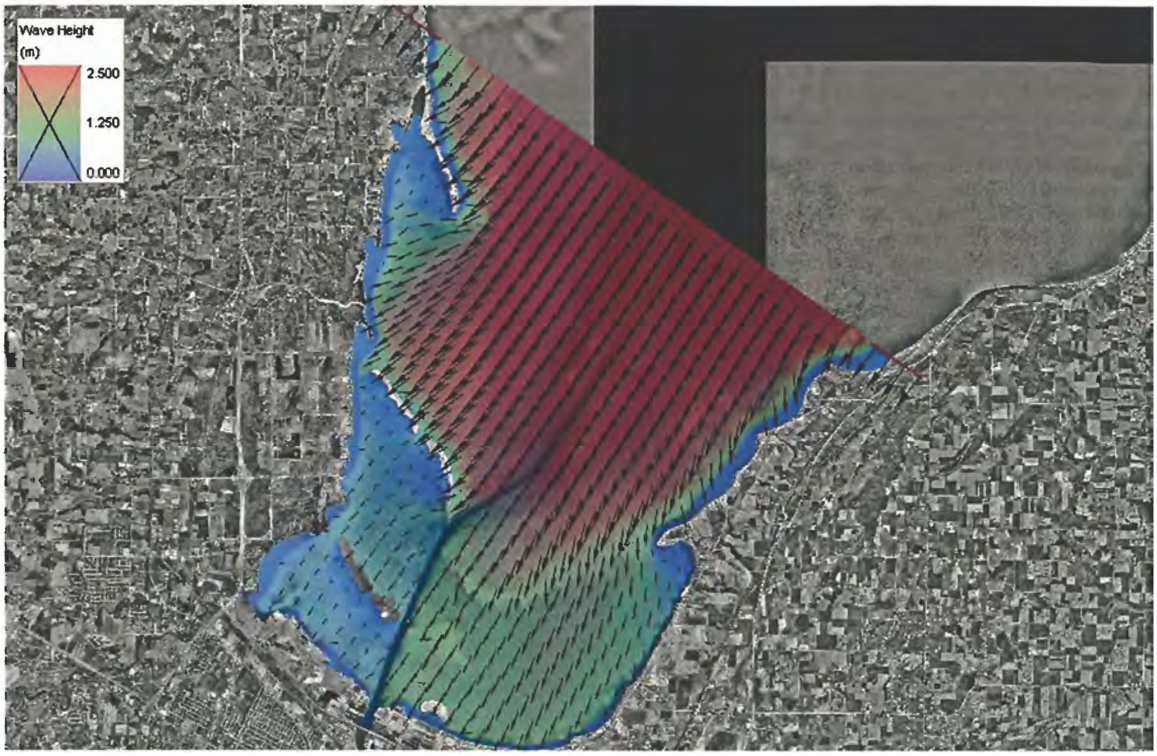


Figure 5.5 - STWAVE Results for NE Event (Ho = 2.7 m, Tp = 8.5 sec)

The results of the model for the extreme events were extracted and input into an extreme value analysis to obtain wave heights for various return periods for the islands. Table 5.2 documents the results of the analysis.

Table 5.2 - Wave Conditions by Return Period for Cat Island

Return Period (yrs)	Wave Height (m)
2	0.8
5	0.9
10	1.0
20	1.0
25	1.0
50	1.1
100	1.2
500	1.3

The 20-year event was chosen for design in the design development study. This relates to a 3.3 ft (1.0 m) wave, with a 6 second period.

On the southwest side of the islands, the SMB equation as documented in the 1977 Shore Protection Manual (USACE, 1977) was applied to determine a maximum wave height & period. Inputs to the calculation include a wind speed of 60 miles per hour, depth of 8 ft (lake bed elevation of –3 ft, LWD and high water of +5 ft, LWD), and a fetch of 2 miles. A design wave height and period of 2 ft and 4 seconds, respectively, was determined from the calculation.

5.2.3 Growing Season Event Simulations

A series of typical annual events were also simulated using the STWAVE model. The purpose of these runs was for use in the vegetation analysis documented in Section 8. The events approximated a range of average annual events that may occur in a typical growing season. Using the model output of wave heights, a grid of wave orbital velocities was calculated using linear wave theory. Figure 5.6 displays a typical growing season event simulation. Figures 5.7 and 5.8 show orbital velocities for existing and proposed conditions, respectively.

Figure 5.6 - STWAVE Results for Typical Growing Season Event (Ho = 1.3 m, Tp = 5.5 sec)

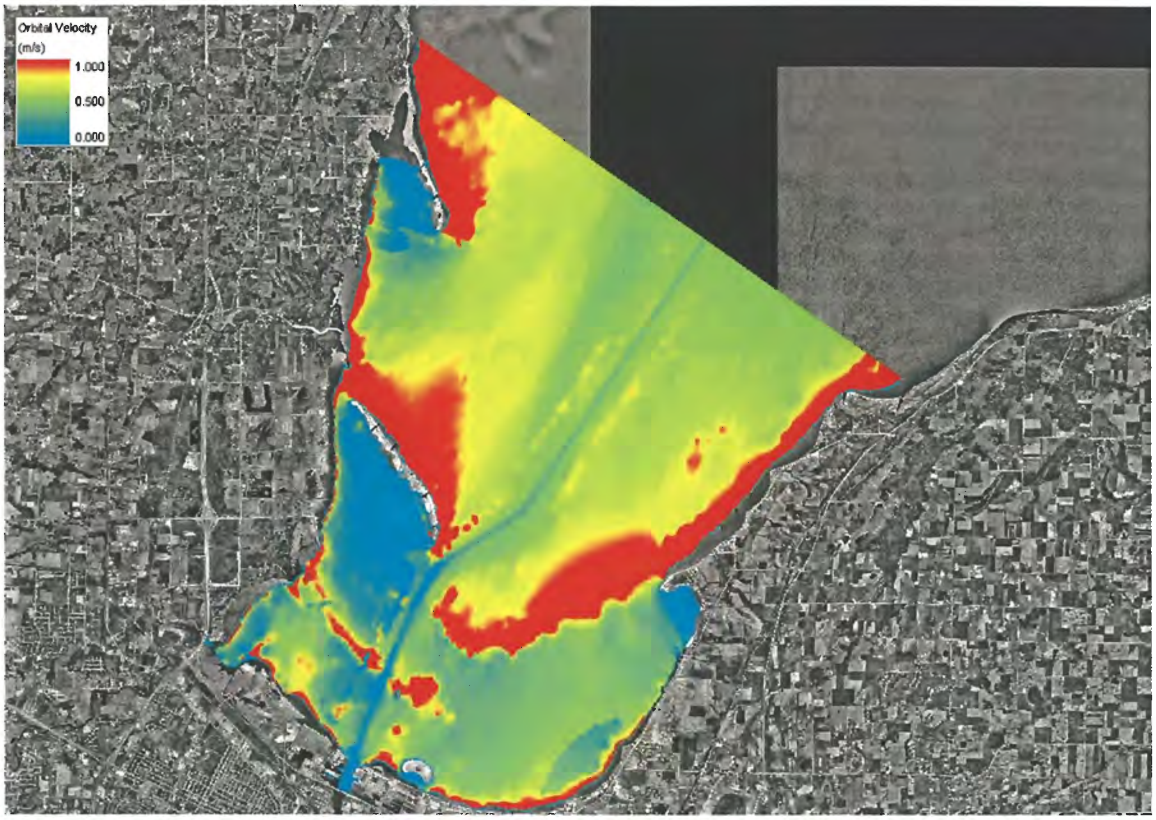


Figure 5.7 – Orbital Velocities - Existing Conditions (Ho = 1.3 m, Tp = 5.5 sec)

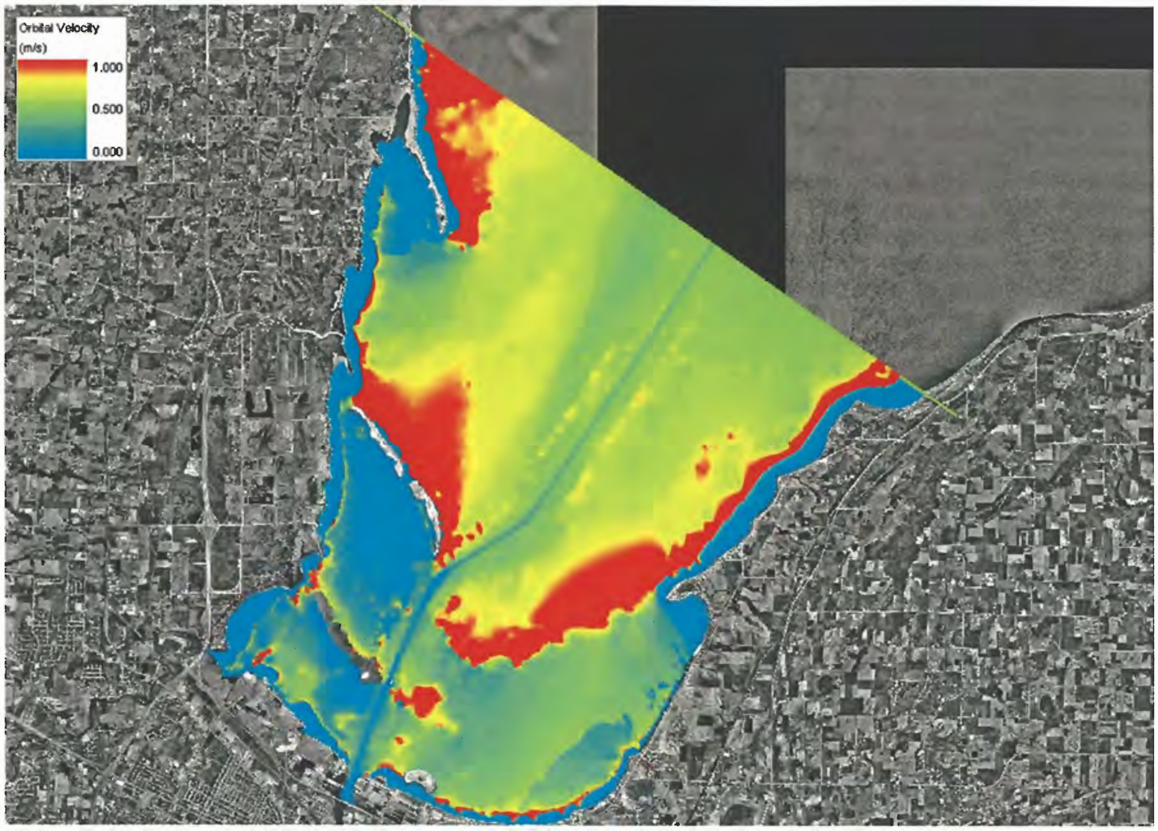


Figure 5.8 – Orbital Velocities - Proposed Conditions (Ho = 1.3 m, Tp = 5.5 sec)

6.0 HYDRODYNAMIC ANALYSIS

6.1 MIKE 21 Hydrodynamic Model

A hydrodynamic analysis was performed to evaluate velocities around the proposed islands due to storm surge by wind. The hydrodynamic model was also used as the basis for TSS modeling (both river plume and local re-suspension by waves) as described in Section 7. Due to the orientation and geometry of the bay, the worst condition for storm surge at the Cat Islands is a strong northeasterly wind. The water level near the Cat Islands builds up and as the wind stops the water level seiches back down to the level before the storm. This phenomena is observed in the water level data obtained from NOAA gauge 9087079 Green Bay, Lake Michigan, WI. As the water level rises up and seiches downwards, water is pushed into and around the proposed layout of the Cat Islands. The analysis was performed to quantify the velocities around the proposed islands that may be observed during extreme events.

The HD module of the MIKE 21 modeling system was used for this analysis. Used as inputs to the model are the following:

- Detailed Bathymetry data for the entire Green Bay
- Wind Conditions from Green Bay, WI (NOAA Gauge 14898)
- Water Levels from Sturgeon Bay, WI (NOAA Gauge 9087072) and Port Inland, MI (NOAA Gauge 9087096)

The grids were created using a nesting system, to both cover a large area and cover the Cat Island area in great detail. The grids used had a range of mesh sizing of 500 m, 180 m, 60 m and 20 m. Details for each grid are displayed in Table 6.1. The grids are displayed in Appendix D.

Table 6.1 – Grid Parameters for Hydrodynamic Analysis

Grid Spacing	Nx	Ny
500 m	98	299
180 m	115	111
60 m	220	166
20 m	259	202

6.2 Surge Event Simulations

The NOAA Green Bay water level gauge was probed to find extreme and typical surge events. Four events were identified for use in analysis. The events chosen are displayed in Table 6.2.

Table 6.2 – Events chosen for Hydrodynamic Analysis

Date	Surge Height (ft)
December 3, 1990	5.5
April 15, 1993	3.8
April 20, 2000	3.5
May 18, 2000	2.0

The Green Bay NOAA water level gauge was used for calibration of the model. Each event compared to the gauge very well. Figures 6.1 through 6.4 display the results of the calibration analysis.

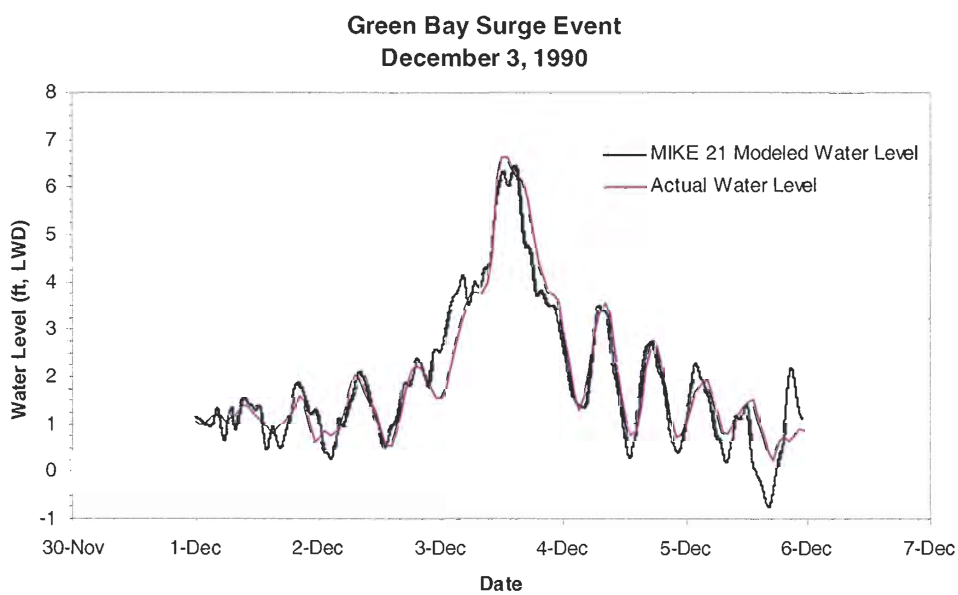


Figure 6.1 – December 3, 1990 Surge Model Results

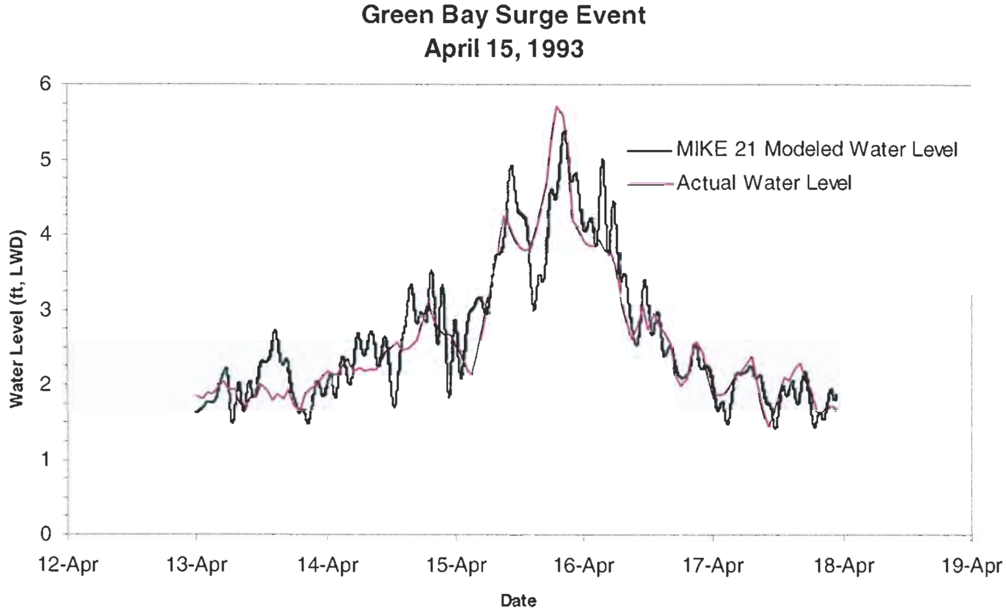


Figure 6.2 – April 15, 1993 Surge Model Results

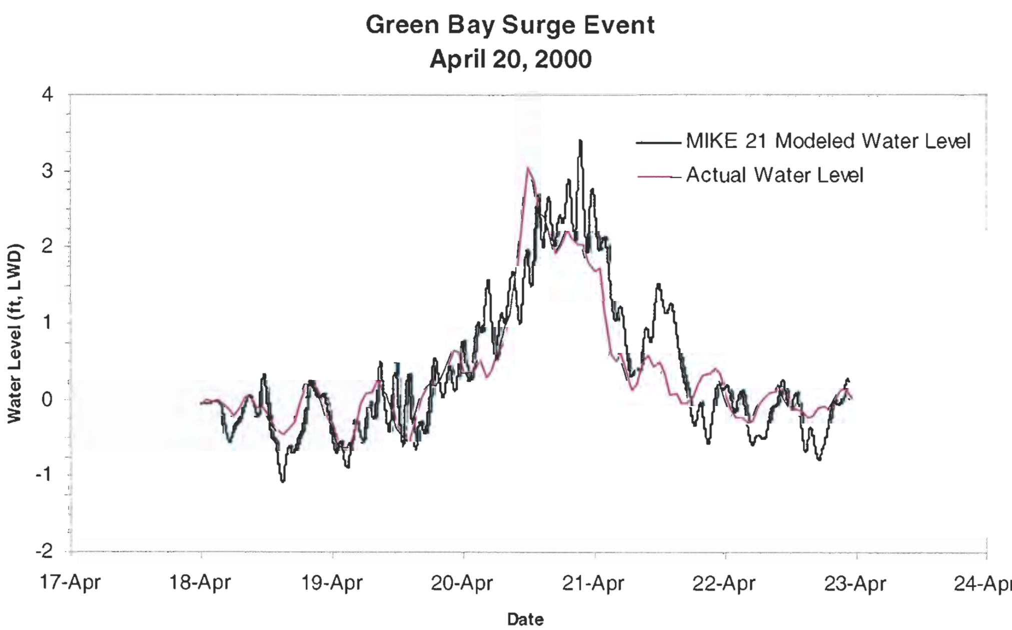


Figure 6.3 – April 20, 2000 Surge Model Results

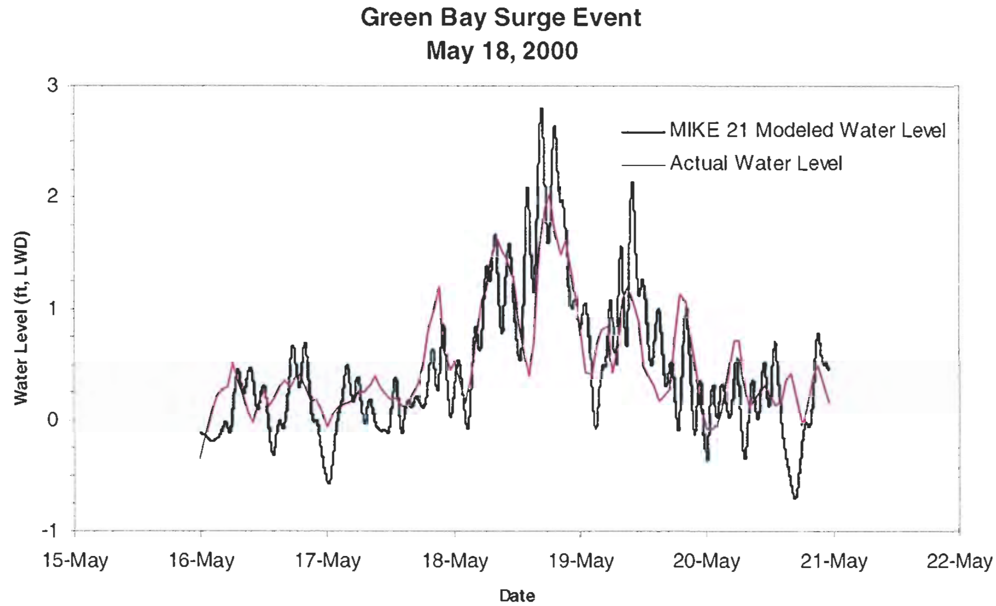


Figure 6.4 – May 18, 2000 Surge Model Results

After calibration, the four simulations were performed for each of the following conditions:

- Existing Conditions (no islands)
- Proposed Conditions (all 3 islands)
- Construction Worst Case Condition (all 3 islands, Access Road from shore to Central Island)

Bathymetric grids for the proposed islands and construction road conditions are displayed in Appendix D. The MIKE 21 Model was run for all 4 events and 3 bathymetric conditions. Figures 6.5 through 6.7 display model result velocity vector maps for the peak of the December 3, 1990 event for the three conditions. The peak velocity observed in the gaps was 0.4 m/s in the existing conditions, 0.7 m/s for the proposed conditions and 0.7 m/s for the construction road conditions. Figures 6.8 through 6.10 display velocities in the gaps for the December 3, 1990 event for the three conditions. Appendix D displays the gap velocities for the remaining event and condition combinations.

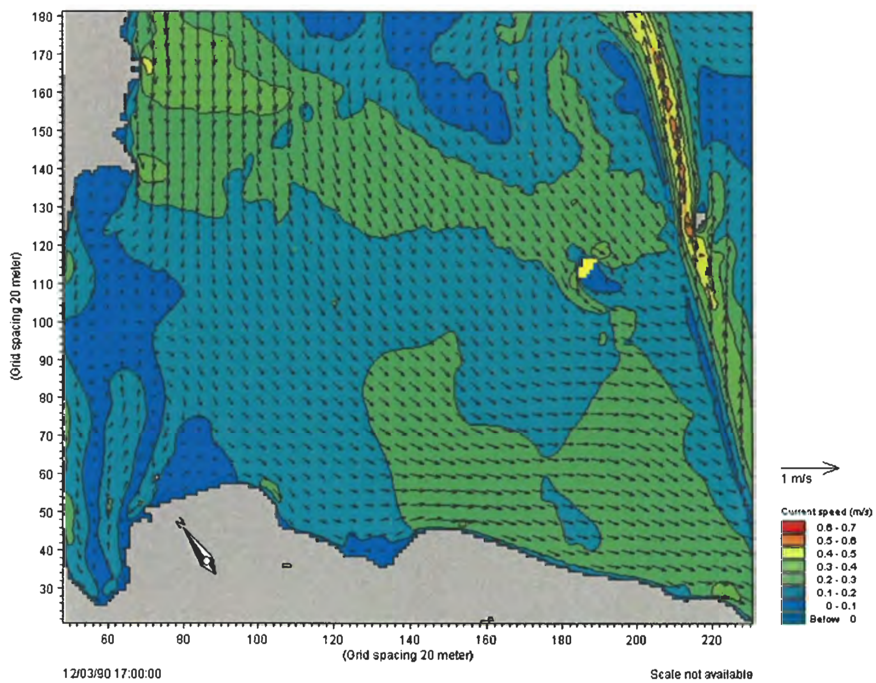


Figure 6.5 – December 3, 1990 Existing Conditions

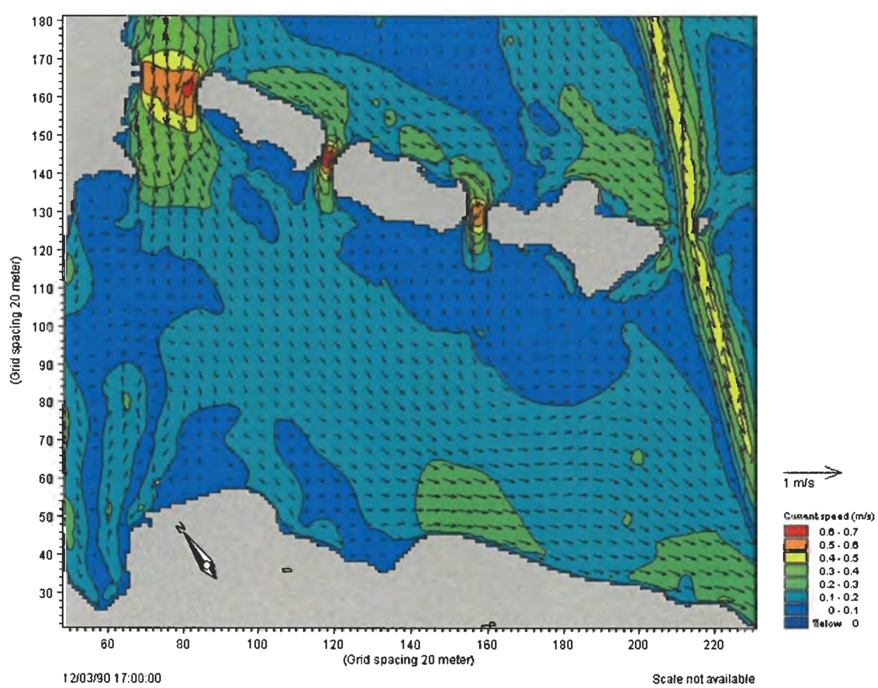


Figure 6.6 – December 3, 1990 Proposed Conditions

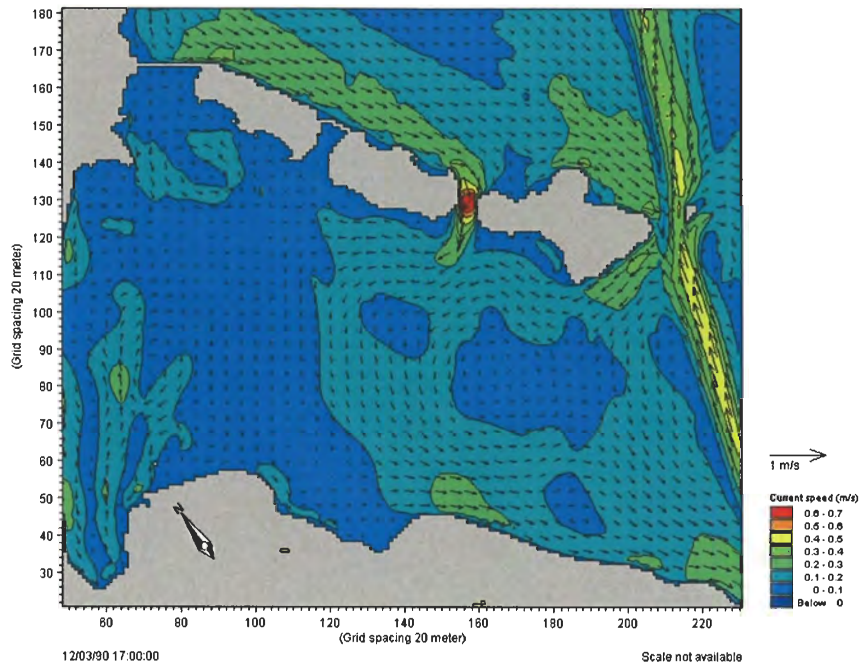


Figure 6.5 – December 3, 1990 Construction Road Conditions

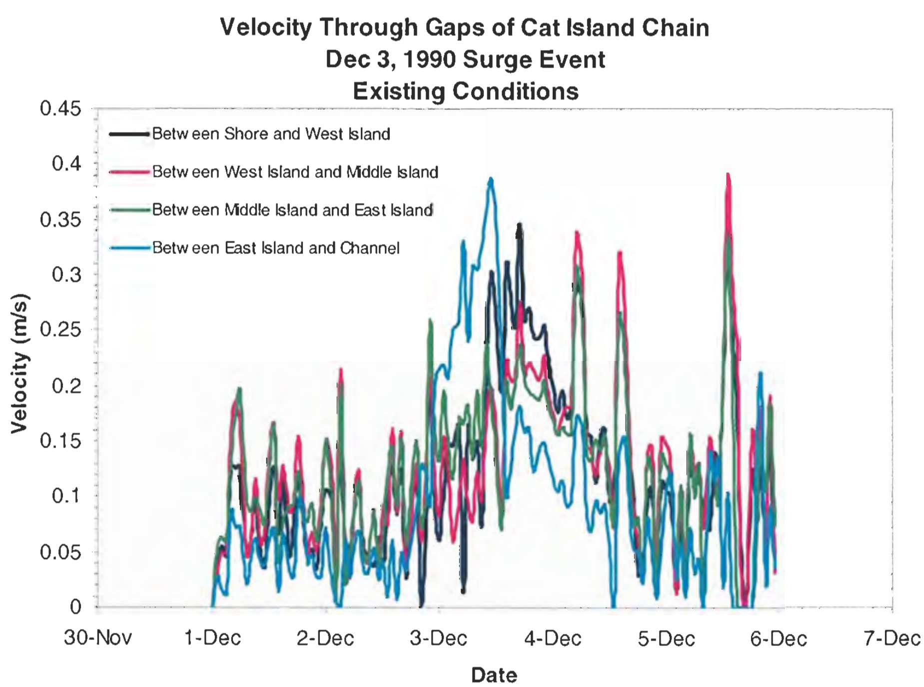


Figure 6.8 – Island Gap Velocities for Dec 3, 1990 Event – Existing Conditions

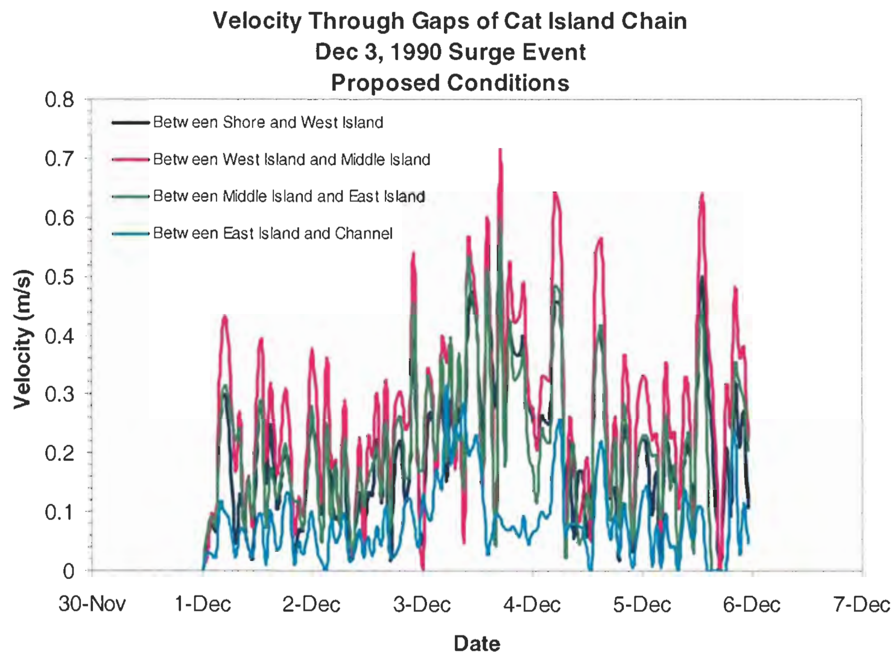


Figure 6.8 – Island Gap Velocities for Dec 3, 1990 Event – Proposed Conditions

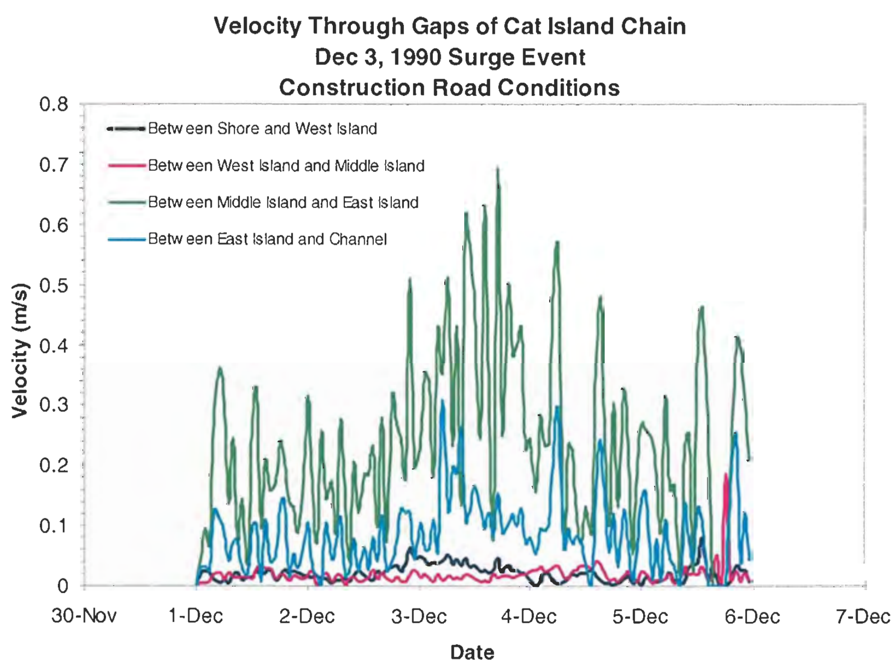


Figure 6.8 – Island Gap Velocities for Dec 3, 1990 Event – Construction Road Conditions

7.0 MODELING TOTAL SUSPENDED SOLIDS

7.1 Introduction

The primary purpose of the TSS modeling was to define the TSS and associated water clarity with and without the islands constructed. One of the primary goals of the restoration of the Cat Island Chain is to promote the re-establishment of aquatic vegetation in the areas of the mouth of Duck Creek, Peat's Lake and Peter's Marsh. Large areas of aquatic vegetation were lost after the sub-aerial part of the Cat Island Chain was washed away in 1973. It is assumed that one of the key current impairments to recovery of these areas of aquatic vegetation is less than ideal water clarity. Numerical models of waves, currents, sediment re-suspension and advection/dispersion of suspended sediment will be applied to representative conditions to evaluate the impact of the proposed islands on water clarity in the lee of the islands. In turn, these predictions will be used to evaluate the potential survivorship of aquatic vegetation with and without the islands in Section 8 of this report.

7.2 Model Approach, Setup and Inputs

7.2.1 Modeling Approach

The major causes of high TSS in Lower Green Bay are the sediment plumes from Fox River and Duck Creek and sediment re-suspension induced by waves and currents. These suspended sediments are carried by lake circulation driven by wind, surge, and waves as well as river flows. Since the wave-induced current component is generally smaller than wind driven current, and more localized, the currents generated by wave radiation stresses are neglected in this modeling assessment.

In order to account for the complicated dynamic conditions, a comprehensive numerical model system has been developed as shown in Figure 7.1. The system consists of the STWAVE model, the MIKE21 Hydrodynamic (HD) and Mud Transport (MT) models. The STWAVE model was used to simulate waves that are generated by wind with consideration of wave transformation and propagation in shallow waters (details on the STWAVE modeling are presented in Section 5). Wind and lake level data are required inputs for the STWAVE model.

MIKE21 was used to simulate hydrodynamics and sediment transport in the TSS assessment. It is a two-dimensional horizontal model employing a finite difference method. The MIKE21 model has been applied in thousands of locations around the world and is recognized as one of the most stable and reliable hydrodynamic models. There are two modules included in this modeling application:

- HD module – simulates water level fluctuation and currents in response to a variety of forcing functions in lakes, estuaries and coastal regions. The effects and facilities include bottom shear stress, wind shear stress, barometric pressure gradients, Coriolis force, momentum dispersion, sources and sinks, evaporation, flooding and drying and wave radiation stresses. It is the basic model for all other simulations.

- MT module – accounts for the erosion, transport and deposition of silt, mud and clay particles under the action of currents and waves. The module can be applied in two modes: multi-fraction mode and multi-layer mode. The multi-fraction mode enables the model to simulate the dynamics of multiple fractions of suspended sediment and is suitable for depositional environments. The multi-layer mode enables the model to simulate the evolution of, and interaction between, several bed layers and sediment re-suspension induced by waves. Generally, this mode is suitable for depositional and erosional environments.

The two modules are integrated in the MIKE21 software package that provides a convenient user interface for setup.

The inputs for the MIKE21 model include: a) river inflow and TSS from Fox River and Duck Creek, b) temporally varying wind speed and direction, and c) temporally varying mean lake level. Wave data generated by STWAVE are used as an additional input for the MT module. Coriolis force and drying process are also included in the modeling application.

Finally, the currents and sediment concentration calculated by the MIKE21 model and the orbital velocity calculated by STWAVE model are used as inputs to Baird in-house software - Spatial Data Analysis (SDA) for the aquatic vegetation analysis, which will be described in Section 8 in detail.

7.2.2 MT Model Parameters

All parameters for STWAVE are set as the same as described in Section 5, which are calibrated against the recorded waves. The MIKE21 model provides a variety of parameters for hydrodynamic and sediment transport simulation. Some of these parameters need to be adjusted through model calibration. All parameters for hydrodynamic simulation are described in Section 6 and have been calibrated with observed data. These parameters are directly used for this application. The major parameters associated with mud transport are:

- **Suspended sediment grain size** - MIKE21 doesn't provide a parameter to directly set the grain size of suspended sediment. Instead, it provides an adjustable coefficient for settling velocity, which is equal to settling velocity in clear and still water and can be completely determined by grain size. Two grain sizes of 0.02 mm (fine silt) and 0.0027 mm (clay) were used for the model simulations. Clay is the dominant fraction of sediment discharged by the Fox River and Duck Creek and will be used for sediment plume modeling. Fine silt is representative of the sediment that can be easily re-suspended by waves from the lakebed. This class is used for the simulation of sediment re-suspension induced by waves;

- **Bed sediment materials** – MIKE21 with MT multi-layer mode uses a number of layers to describe bed soil materials. The physical properties of each layer are described by parameters such as critical shear stress, dry density, and erosion coefficient. Critical shear stress and erosion coefficient are the key parameters for the simulation of sediment re-suspension. Relatively, dry density is not as important as the others because it is used only for bed change calculations, which are not important for this project. In the model application, three layers with thickness of 0.5 m, 0.5 m, and 2 m are used to describe the lakebed sediment. Based on the available borehole logs, a median grain size of 0.15 mm (fine sand) is used to determine these parameters for all three layers as described below.

- **Critical shear stress for erosion** – Critical shear stress for erosion depends mainly on grain size and consolidation. The top layer is assumed to be a fresh deposit and no consolidation is considered. In that case, the critical shear stress can be determined using Shields' Curve, giving 0.12 Pa for 0.15mm sediment. Although the grain size for the second and third layers are assumed to be the same, consolidation should be considered. Using information from other studies, the critical shear stresses in the second and third layer are set as 0.20 and 2.5 Pa, respectively;

- **Erosion coefficient factor** - This is a calibration parameter and is initially set as the default value. The value is then adjusted through calibration. There is another parameter called erosion coefficient power for which the default value (1.0) is used.

7.2.3 Incoming Sediment From Rivers

The suspended sediment load from Fox River and Duck Creek is an important source for sediment plumes in the bay. The suspended sediment concentration must be provided for the modeling test as an input. Unfortunately, continuous long-term records of TSS at the two river mouths are not available for the model setup and simulation. Therefore, the available TSS sample data are used to develop relationships between TSS and discharge for both rivers as listed below:

- Sediment sampling data collected at USGS Gage at DePere (#04085059) between 1988 to 1990;

- Sediment sampling data collected at USGS Gage at Duck Creek Near Howard (#04072150).

The developed rating curves are shown in Figures 7.2 and 7.3 for Fox River for Duck Creek, respectively. The trend of increasing TSS with flow is obvious though the correlation of TSS and discharge is not the best (particularly for Duck Creek). Nevertheless, these developed rating curves are used to generate the time series TSS from the rivers using the continuously measured discharge data at the gages.

It should be noted that the TSS calculated by using the rating curves represents only abiotic component of suspended solid from the rivers. There is no information to determine biotic component from the river. Therefore, a constant fraction is used for the biotic component (see Science and Technical Advisory Committee, 2000) for vegetation analysis. The biotic component is not included in the model simulations.

7.3 Selection of Testing Scenarios

The objective of the modeling is to reproduce TSS patterns under extreme weather conditions during the growing season for aquatic vegetation (from April to November). As the selected models were not conducive to long-term and continuous model simulation it was necessary to define representative storm conditions for modeling.

The turbidity in Lower Green Bay is generally high during rainfall events and/or windstorms. During rainfall events, large river flows carry large amounts of suspended sediment into the bay and resulting in a widespread sediment plume. Generally, the rainfall events occur more frequently in the spring and summer seasons than the other seasons. Therefore, these events may have significant impacts on vegetation growth. Depending on wind direction, windstorms can create large waves on the bay that suspend sediment from the lakebed resulting in high turbidity in the bay. Additionally, high wind speed during windstorms can generate strong lake circulation and surges that will enhance the advection of sediment. Therefore, the selection of representative storm events is based on three factors:

- Flow discharge and incoming TSS from Fox River – representing rainfall events on the Fox River Watershed;

- Wind speed and direction in the bay – representing windstorms on Green Bay;

- Lake level variation – representing storm surges in Green Bay;

Five extreme events were selected to represent distinctive scenarios as described in the following table.

Table 7.1 The Selected Five Events for Model Simulations

Runs	Date	Wind		Fox River		Duck Creek		Major Dynamics
		Speed (km/h)	Direction (deg)	Discharge (m^3/s)	TSS (mg/l)	Discharge (m^3/s)	TSS (mg/l)	
1	7/17/1993	20	E	481	140	40	30	River Flow
2	6/22/1996	28	NE	453	130	25	184	River Flow
3	3/31/1998	55	NE	453	120	40	30	River Flow + Wind
4	9/4/2000	47	NE	283	50	0.1	10	Wind
5	4/28/2002	54	NNE	354	70	20	23	Wind + Surge

The table lists the peak wind speed, dominant wind direction, maximum flow discharge, and TSS for each event. The model period for each event is generally 2 days to 15 days depending on how fast the model reaches stability. Model Runs 1 and 2 represent rainfall storm events during which the water clarity in Lower Green Bay is mainly impaired by sediment plumes discharged from the two rivers. Run 3 represents a scenario of heavy rain and high waves. Run 4 represents a wind storm (and wave) event and Run 5 represents a windstorm with large surge (large lake level rise).

7.4 Model Testing and Calibration

The model calibration was performed for Runs 1, 2 and 4 with measured TSS, when available. A number of the TSS measurements at fixed stations (see locations in Figure 7.4) have been regularly made during the summer season (from June to September) since 1986. These valuable data are used for model calibration. Unfortunately, the TSS measurements were generally conducted after storms for safety purposes (i.e. to avoid being on the bay in vessels when waves were highest) whereas the modeling focused on the peak conditions of the storms. Therefore, the model periods for these three runs have been extended to cover the measurement period. The available measured data do not cover the model periods for both Runs 3 and 5 and therefore these two runs were not directly calibrated.

The comparisons of modeled to measured TSS are shown in Figure 7.5 to 7.7 for Runs 1, 2, and 4, respectively. The modeled TSS is shown by full color shading with a TSS gradation of 20 mg/l. The measured TSS at the stations is plotted as a dot filled with appropriate color using the same gradation as the modeled TSS. Therefore, the measured TSS agrees well with the modeled TSS if the color inside a dot is the same as the surrounding color. It is evident that the modeled TSS generally agrees well with the measured TSS for the stations #22, #23, #32, and #26. Note that these four stations are most representative of the project site – the area of anticipated aquatic vegetation restoration. However, the modeled TSS at Station #25 is generally lower than the measured TSS. This may result from the fact that the lakeside open boundary condition in the model was assumed to have no incoming sediment flux from the other part of the bay, which is probably incorrect at least in some conditions.

Figure 7.7 shows the TSS levels determined by the University of Wisconsin (UW) from a satellite image as well (in smaller dots). The colors of the dots show the inferred TSS levels and are the same as the color scale used for the modeled and directly measured TSS. It is seen that the modeled TSS generally agrees with the estimated TSS from the satellite image. However, the modeled TSS is higher near the navigation channel and lower near the shores when compared to the TSS estimated by UW from the satellite image. Apart from numerical model inaccuracy, the discrepancy may result from satellite image analysis because the bands (or color channels) that are sensitive to water turbidity are also sensitive to water depth (and reflection from the lake bed). Generally, the approach using satellite image to determine the TSS may over-predict TSS in shallow water and under-predict TSS in deep water. The discrepancy between the predicted and inferred TSS levels from the satellite image may also result from inaccurate representation of the TSS load discharged from the Fox River.

In summary, the numerical model results reproduce the TSS patterns in the dynamic circumstances of rainfall events and windstorms reasonably well in the area of anticipated aquatic vegetation restoration. This calibrated model is next used to predict the TSS levels after the construction of the proposed islands, as described below.

7.5 Model Results

The calibrated model is used to predict flow and TSS patterns after the construction of the proposed east, central, and west islands. The model simulation runs include five selected events combined with the following five island configurations:

- East island;
- Central island;
- West island;
- All islands - a combination of all three islands;
- All islands together with an access road linking the west island to the shore.

Together with the existing conditions, more than 30 model runs were performed for this assessment. The model runs for each configuration used the same boundary conditions and the same model parameters as those for the existing conditions simulation. Therefore, the model results are fully comparable. Considering that all three islands may be eventually constructed within 2 to 3 years, this section will focus on the model results for the configurations of all islands and all islands with the access road. All the results are presented in Appendix E.

7.5.1 Individual Island Tests

Each individual island could possibly exist on its own during the construction period, although all three islands may be constructed within 2 to 3 years. The objective of modeling each the different cases is to provide the hydrodynamic and TSS information for possible construction conditions. Since individual islands, on their own, may not have significant impact on TSS patterns, only Run 4 (high wave-induced re-suspension of lake bed sediment) is described here. The model results for other runs are shown in Appendix E.

The TSS patterns at the peak speed wind speed are shown in Figures 7.8 to 7.11 for existing condition, east island, central island, and west island, respectively. (The model runs were dynamic and only snapshots of the results are presented here, animations of the results are provided in Appendix E on CD). It is evident that the east and central islands, on their own, do not have a significant impact on the TSS pattern in the lee of the islands. However, the construction of the west island, on its own, can reduce TSS in the sheltered area. This result suggests that it would be best to begin construction with the west island, particularly if it takes many years to construct all three islands.

7.5.2 All Islands

The TSS patterns at the maximum TSS or wind speed for all five selected events are shown in Figures 7.12 to 7.26. For each event, there are three figures to depict the TSS patterns with the existing condition, all islands, all islands with the access road for comparison purposes.

Runs 1 and 2 represent rainfall storm scenarios and the sediment plume from the rivers is main contributor for high TSS in Lower Green Bay. The TSS patterns for the current circumstance and after the construction of three islands are shown in Figures 7.12 to 7.13 for Run 1 and in Figures 7.15 to 7.16 for Run 2, respectively. The construction of all islands causes a slight increase or decrease of the TSS in the lee of islands, depending on the direction of lake circulation. The TSS is slightly reduced after the construction if the lake circulation is counterclockwise as depicted in Run 1 (see Figures 7.12 and 7.13). Otherwise, the TSS is only slightly increased after the construction when the lake circulation is clockwise as depicted in Run 2 (see Figures 7.15 and 7.16). This may result from changes to the circulation patterns caused by the construction of the islands.

The TSS patterns for Runs 3, 4 and 5 are shown in Figures 7.17 to Figure 7.26. Through the comparison of these figures, the water clarity in the lee of three islands is significantly improved after the construction of the islands. However, the TSS near the shore is still high, which probably results from the existence of the gap between the west island and the shore. This suggests that the access road linking the west island and the shore (or subsequently, a series of islands and dense aquatic vegetation after the road is removed) is necessary to restore the vegetation growth near the shore and inside this gap towards the southwest.

In summary, the construction of three islands will significantly reduce the TSS levels associated with wave and current induced sediment re-suspension but will have no significant influence (positive or negative) on the TSS levels that are derived from sediment plumes discharged from the rivers.

7.5.3 All Island with Shore Connection

As mentioned above, the existence of gap between the west island and the shore results in high TSS along the shore (see Figure 7.25). It is necessary to build the road to block the sediment transport along the shore. Clearly, after the construction of connection, the water clarity in Peat Lake and Peter's Marsh is significantly improved in most cases (see Figures 7.14, 7.20, 7.23, and 7.26). However, the connection road may trap the sediment plume if the lake circulation is clockwise as seem by comparing Figure 7.16 and Figure 7.17.

7.6 Interpretation of Findings

On the basis of model investigations for a variety of island configurations, the following conclusions can be made:

- The construction of all islands can tremendously reduce TSS level associated with wave and current induced sediment re-suspension in the lee of the islands during windstorms. It will significantly improve water clarity and promote the re-establishment of aquatic vegetation;

- The construction of the islands will not significantly change the TSS levels associated with sediment plumes from the Fox River during rainfall events. Depending on the direction of lake circulation, the TSS level in the lee of islands will be slightly higher or lower. If the lake circulation is counterclockwise, the TSS levels are reduced;

- After the construction of the three islands without an access road to shore, high TSS is found along the shore into the lower bay emanating from the gap between the west island and the shore. This suggests that flow through the gap should be blocked or significantly impeded. This could be achieved through construction of an access road during construction and possibly through a series of islands and dense aquatic vegetation after construction (i.e. when the access road is no longer required). The model test results indicate that the access road can effectively block such longshore sediment transport and the water clarity in Peats Lake and Peter's Marsh is significantly improved;

- The access road linking the west island to the shore may cause a problem by trapping the sediment plume from Fox River when the lake circulation is clockwise. The frequency of occurrence for this situation is low and this condition would have naturally occurred when the islands and a dense marsh to the west of the islands existed prior to the early 1970s;

- The construction should commence at the access road, proceeding to the west island, and then central and east islands. This construction sequence will provide the greatest reduction TSS levels in the lower bay during the construction.

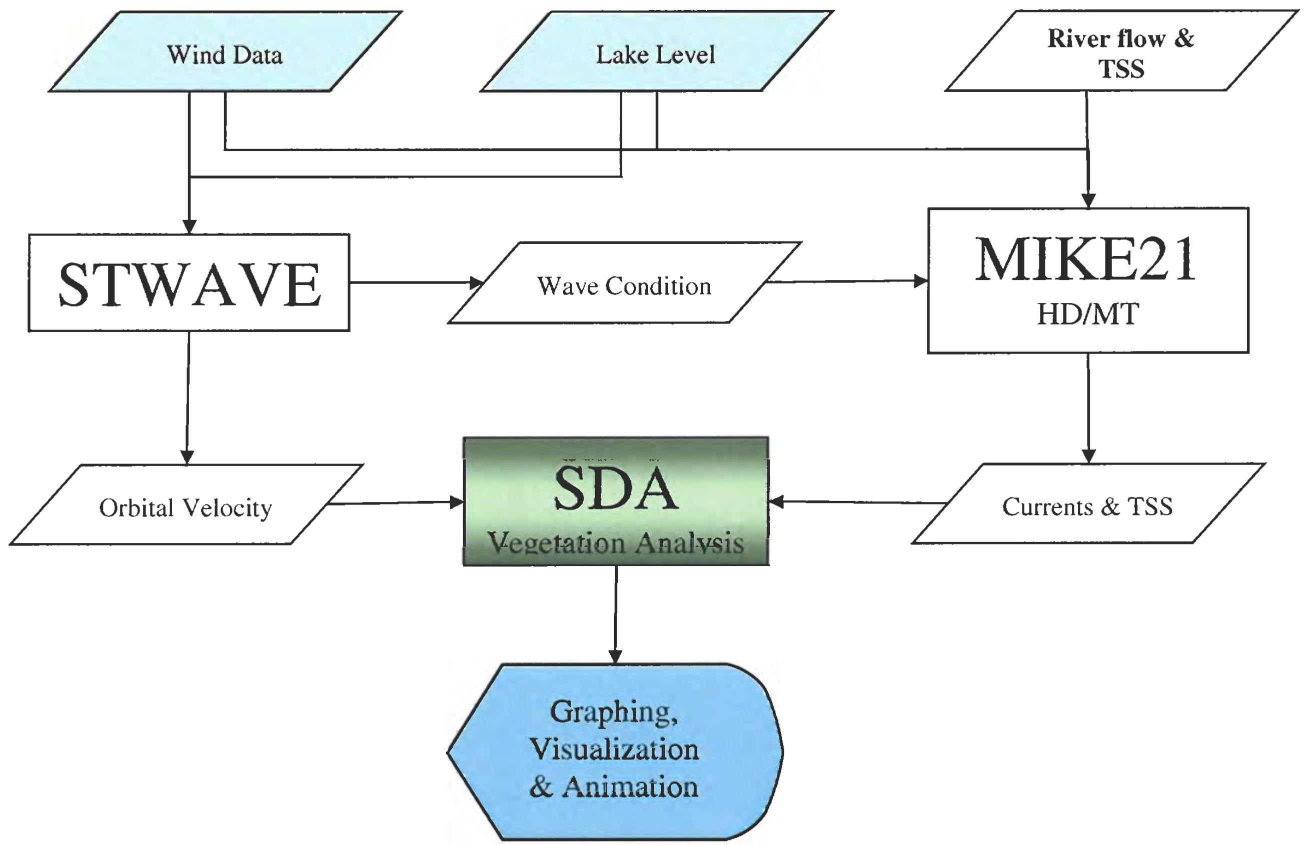


Figure 7. 1 Model System for TSS and Vegetation Analysis

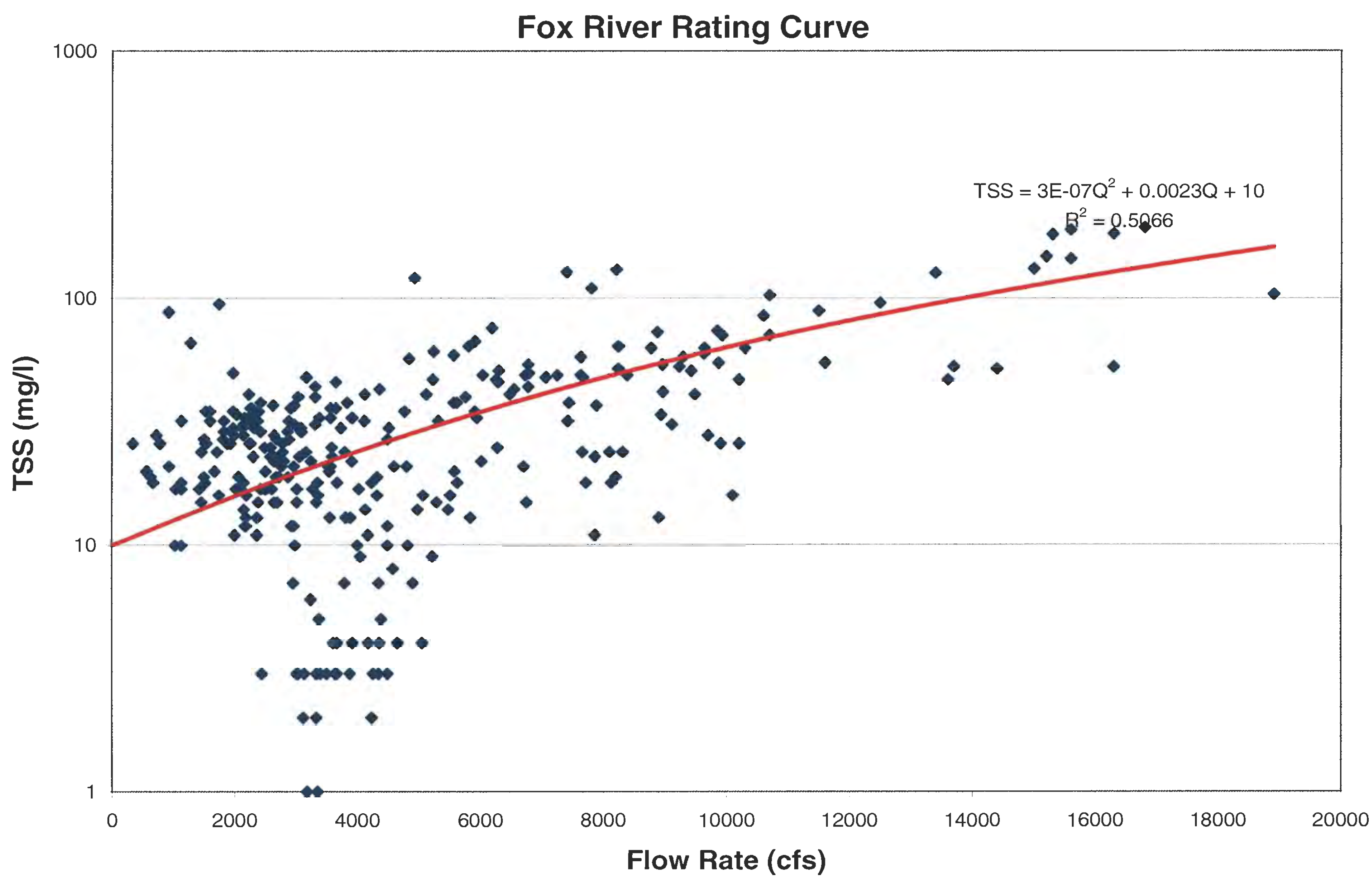


Figure 7. 2 Rating Curve of TSS for the Fox River (Using DePere Station Information)

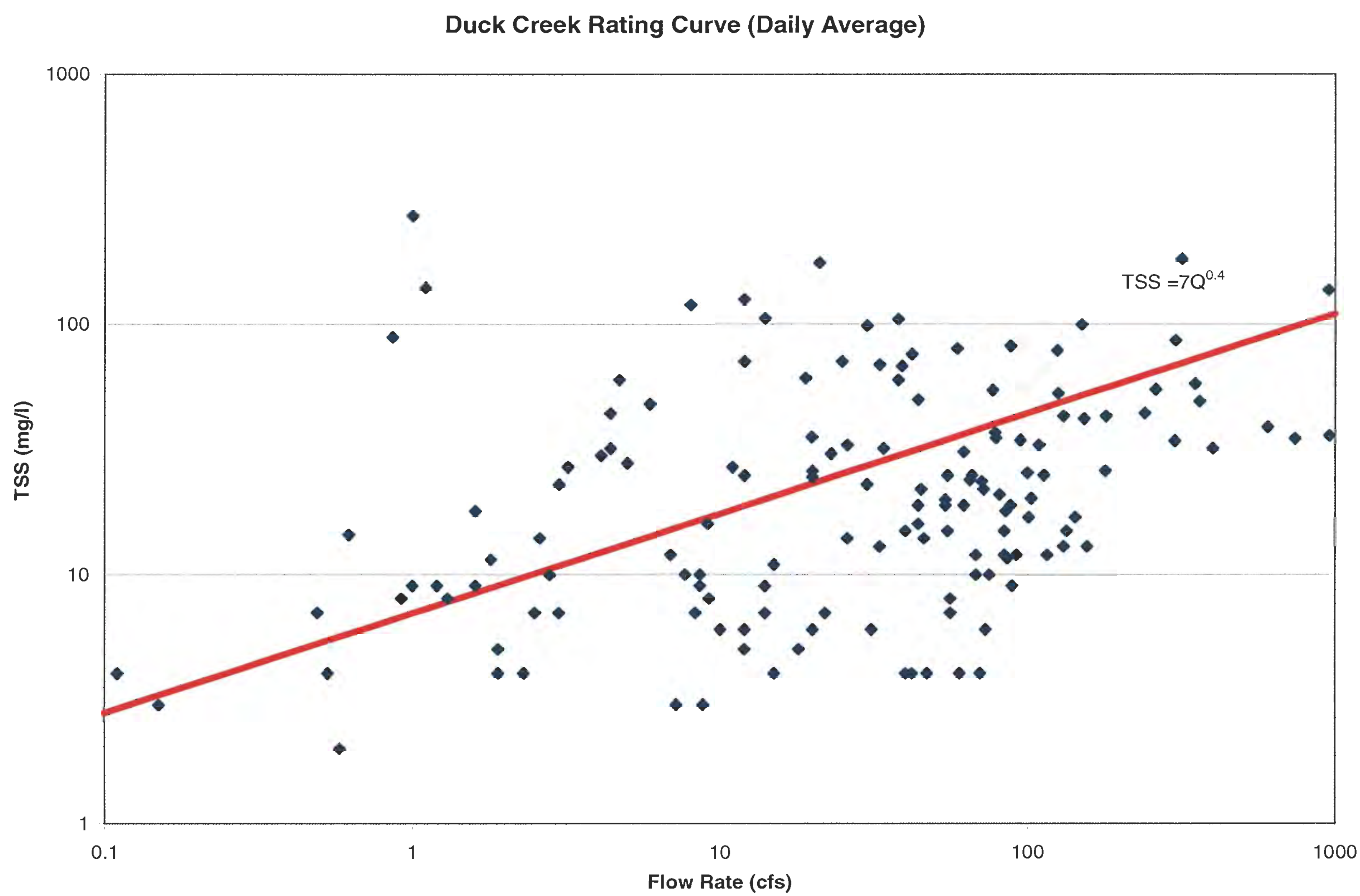


Figure 7 3 Rating Curve of TSS for Duck Creek

Figure 7.4 Locations of Water Sampling Stations

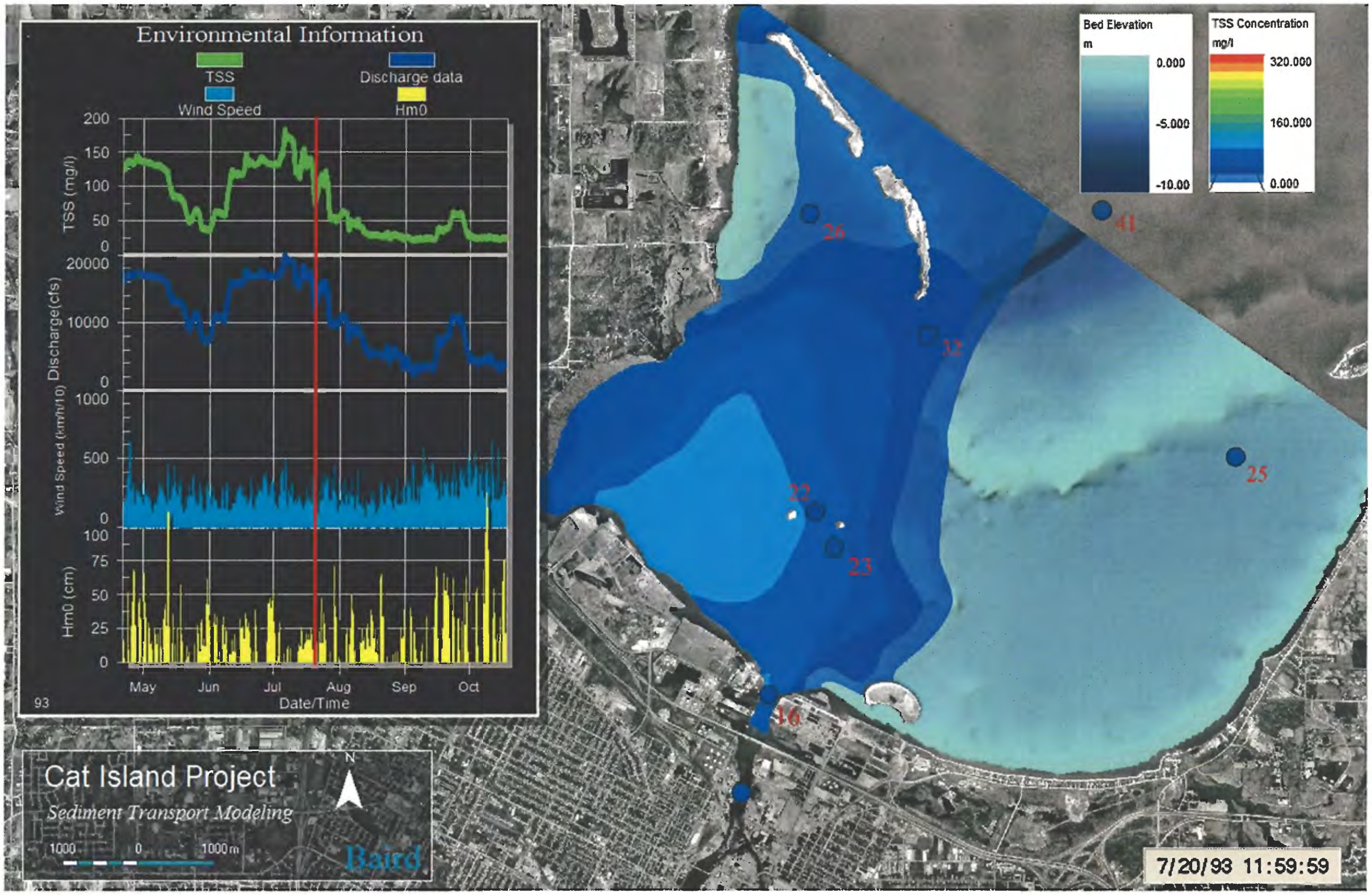


Figure 7.5 Model Calibration for Run 1

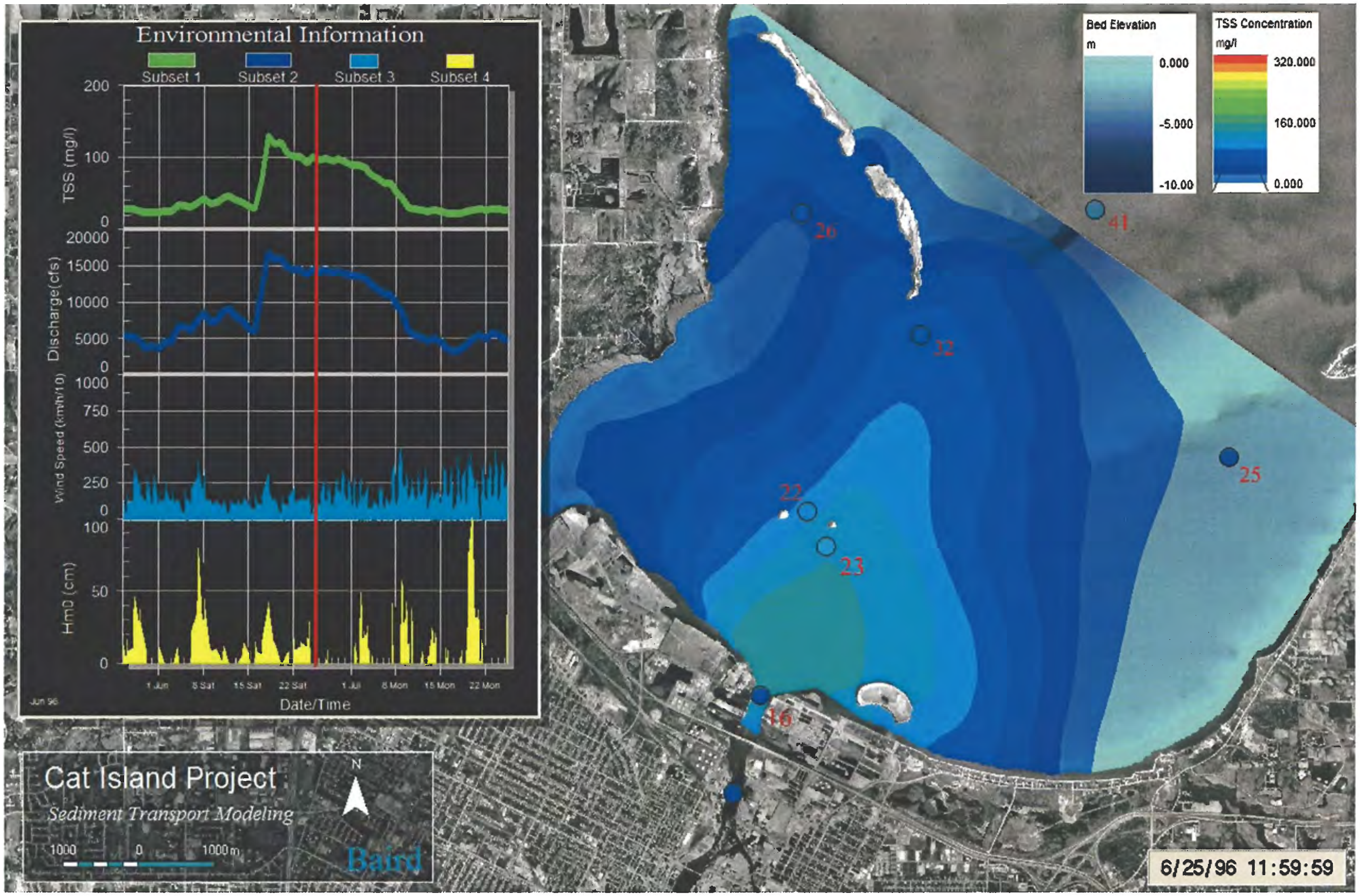


Figure 7.6 Model Calibration for Run 2

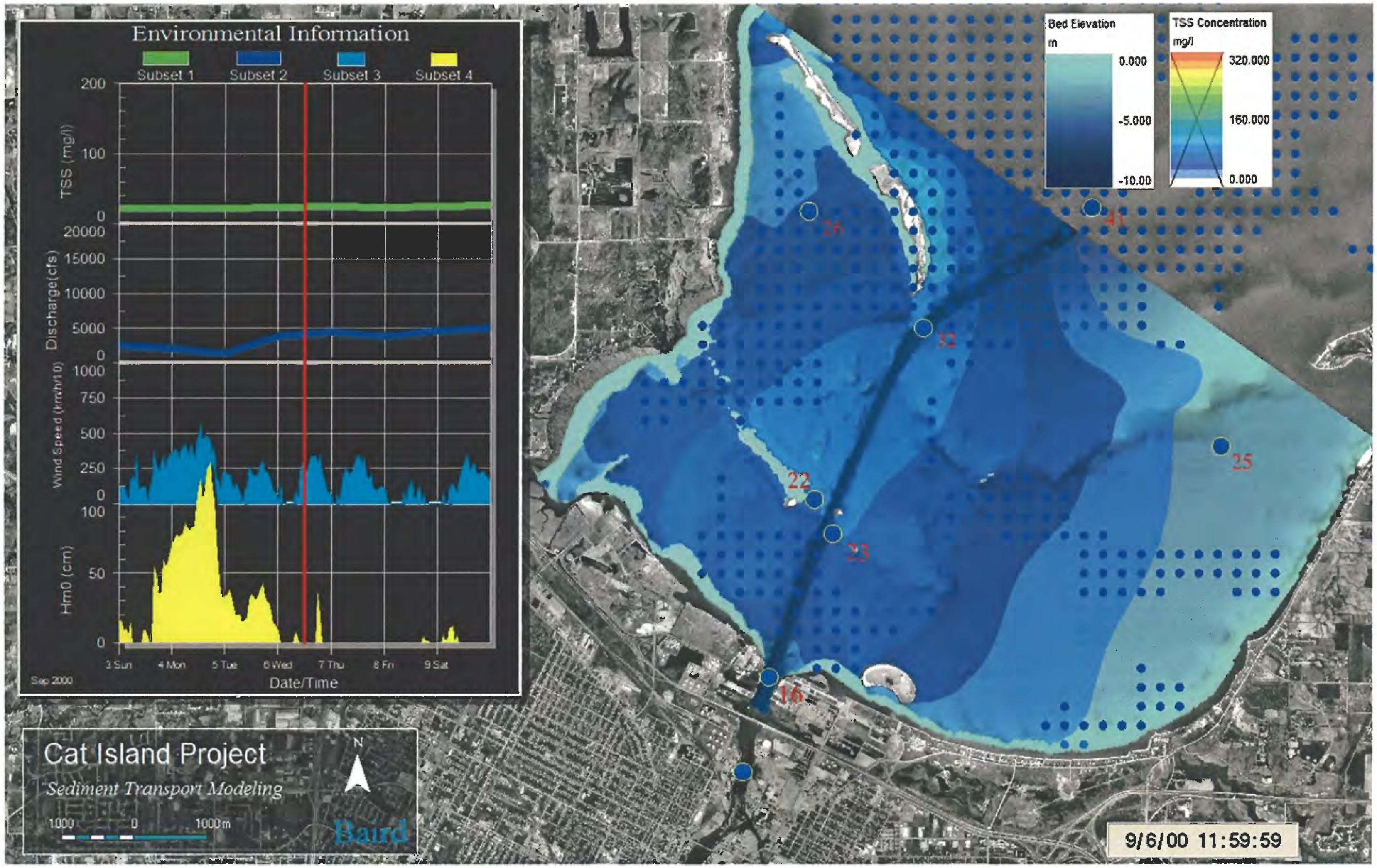


Figure 7.7 Model Calibration for Run 4

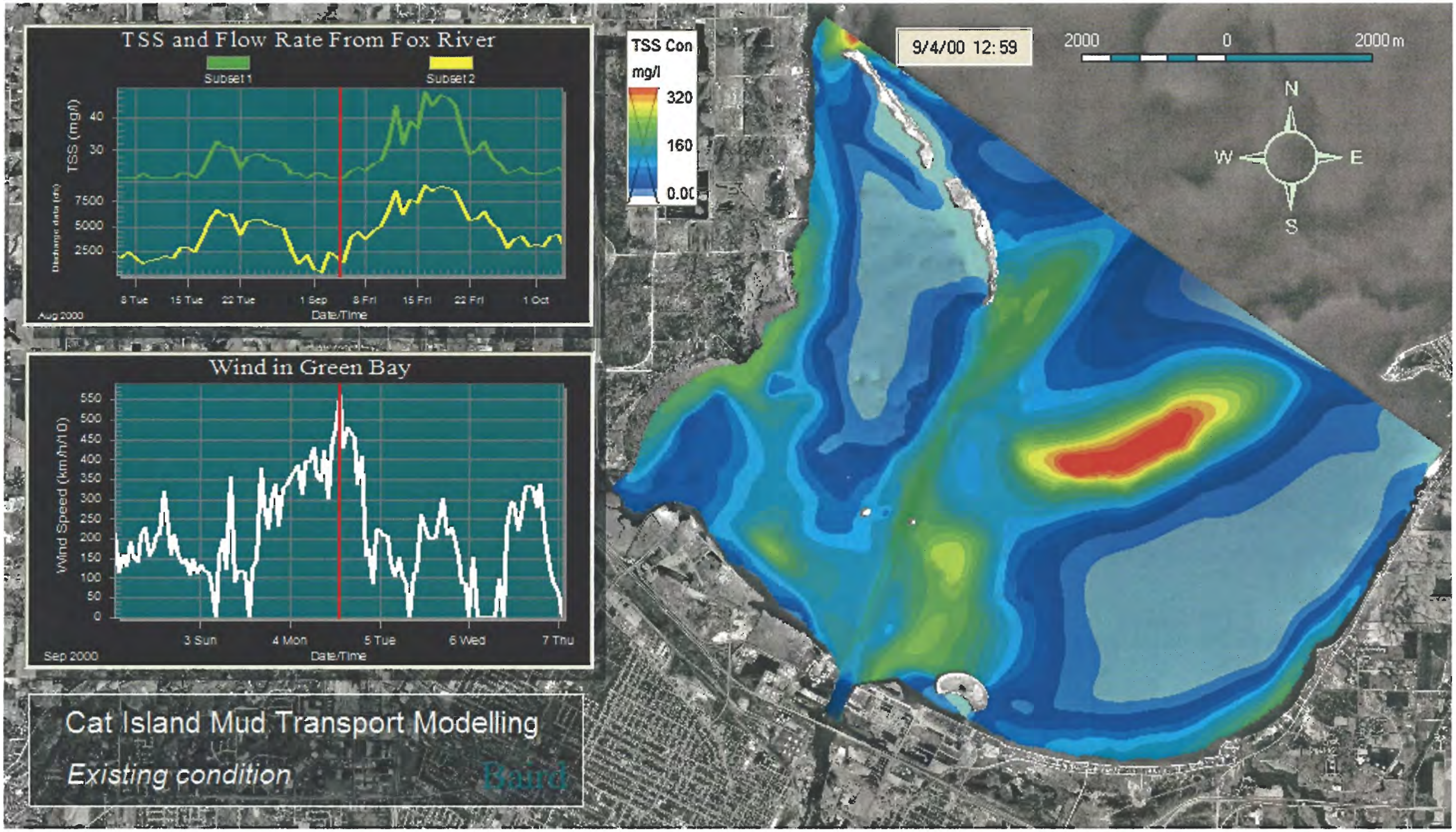


Figure 7.8 TSS Pattern for Run 4 - Existing Condition

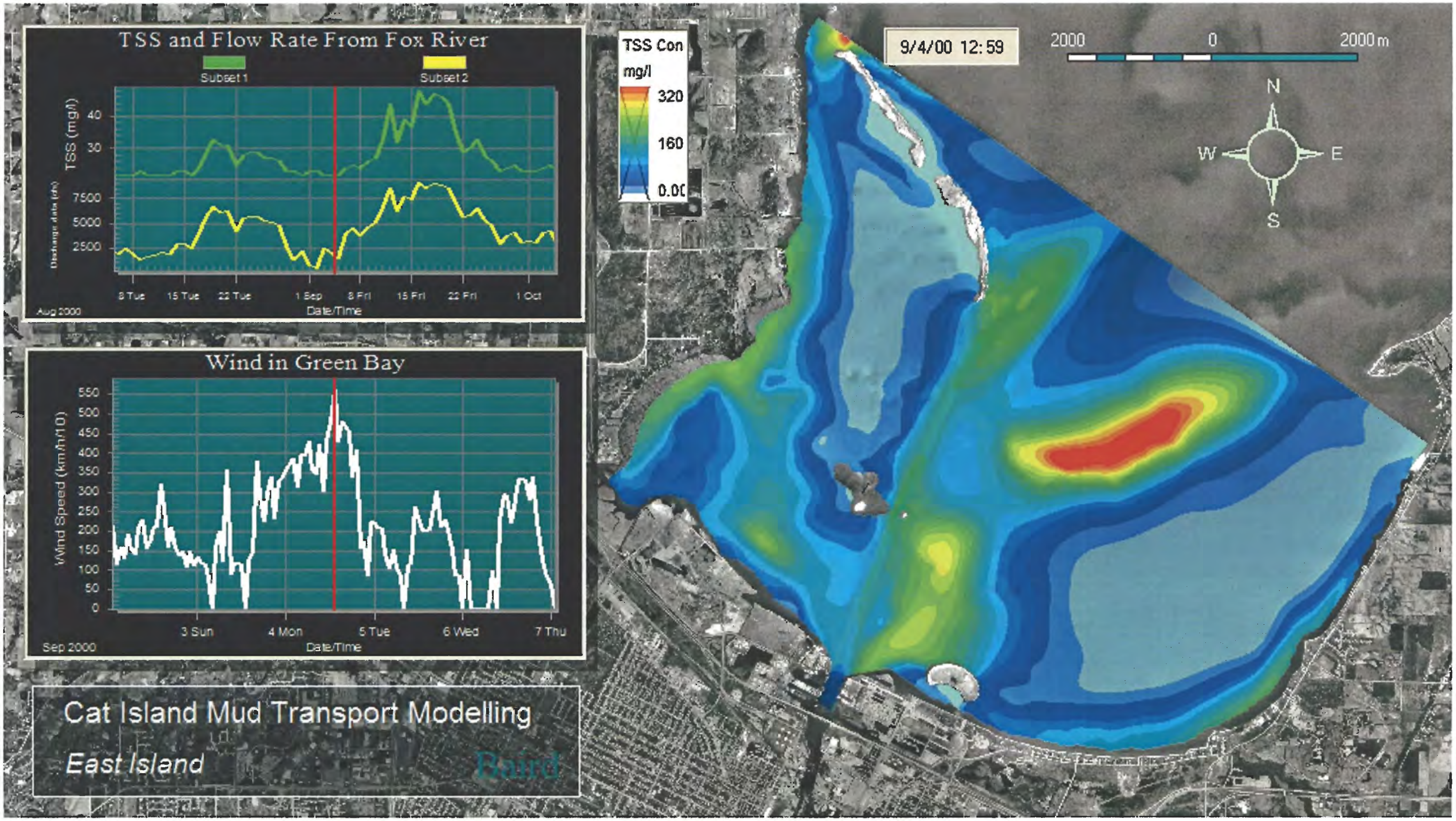


Figure 7.9 TSS Pattern for Run 4 - East Island

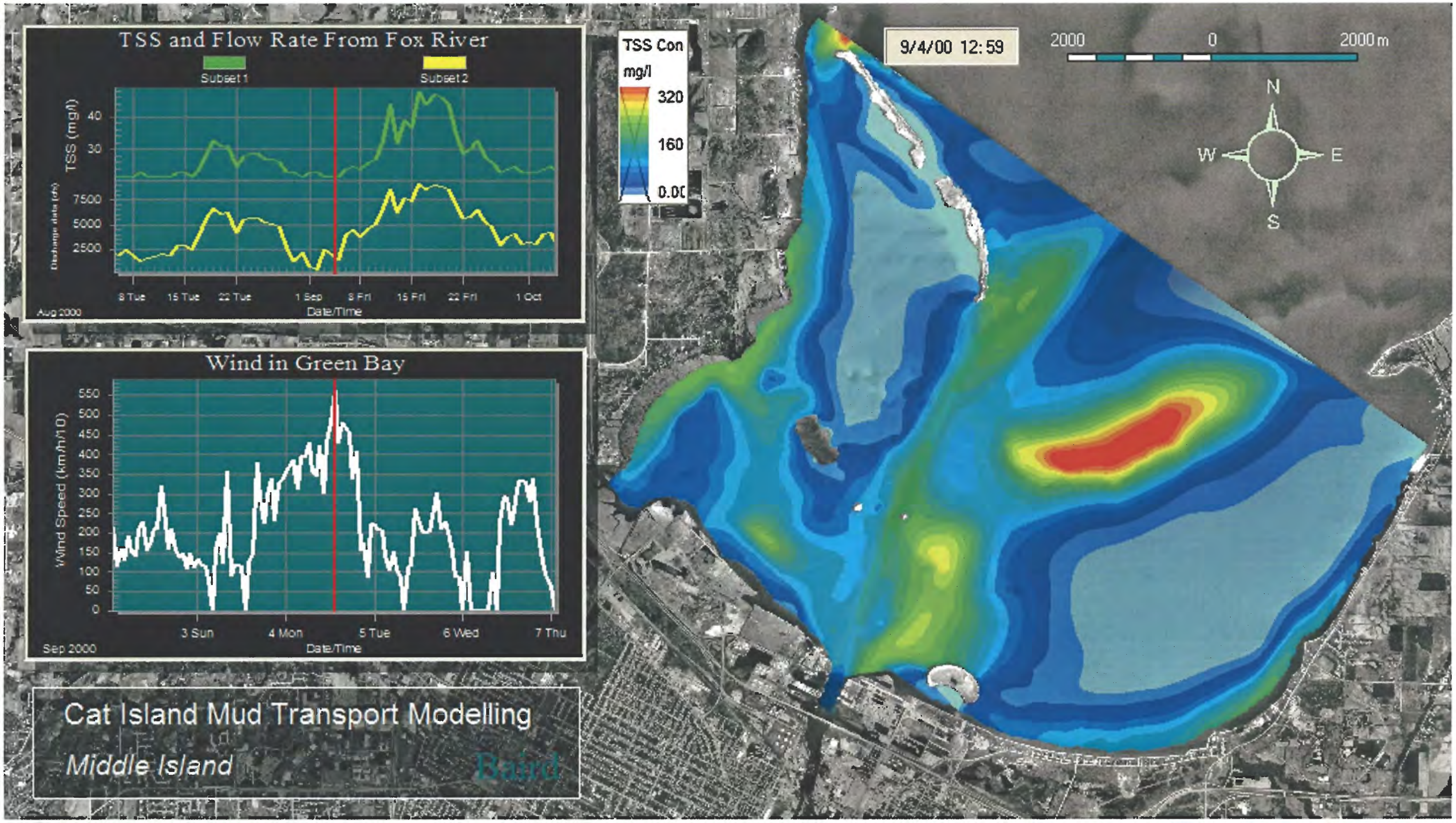


Figure 7.10 TSS Pattern for Run 4 - Central Island

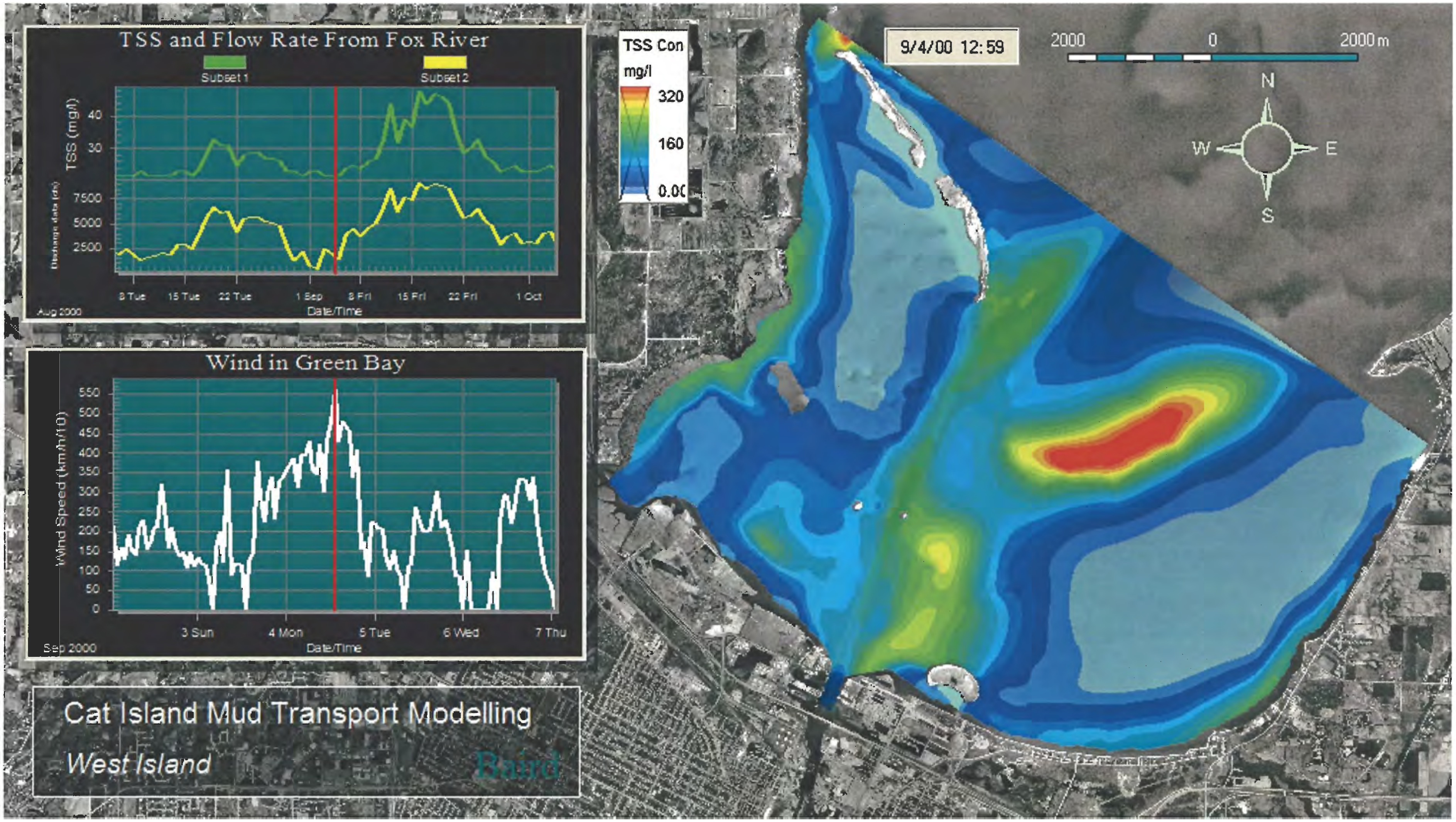


Figure 7.11 TSS Pattern for Run 4 - West Island

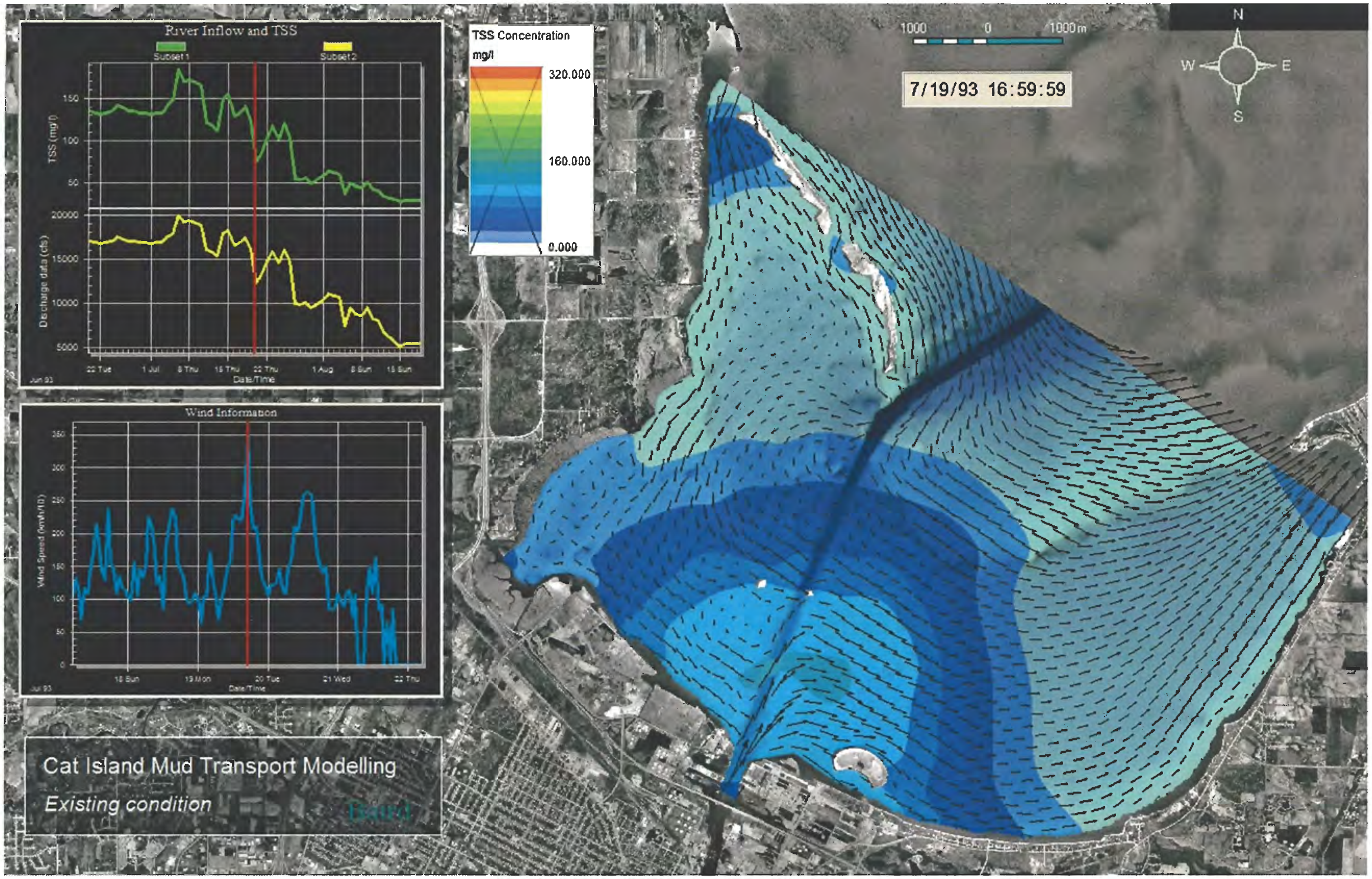


Figure 7.12 TSS and Flow Patterns for Run 1 - Existing Condition

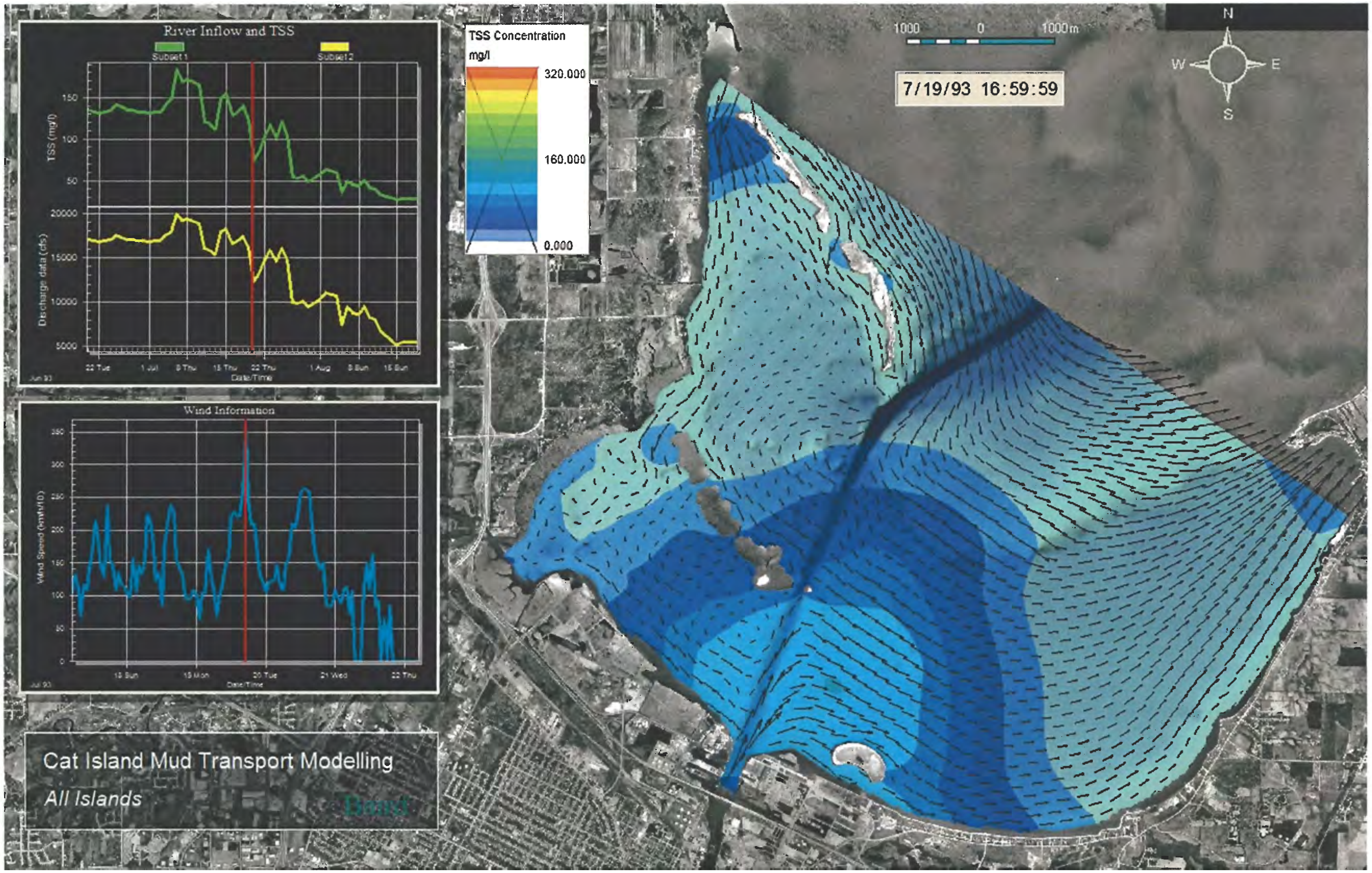


Figure 7.13 TSS and Flow Patterns for Run 1 - All Islands

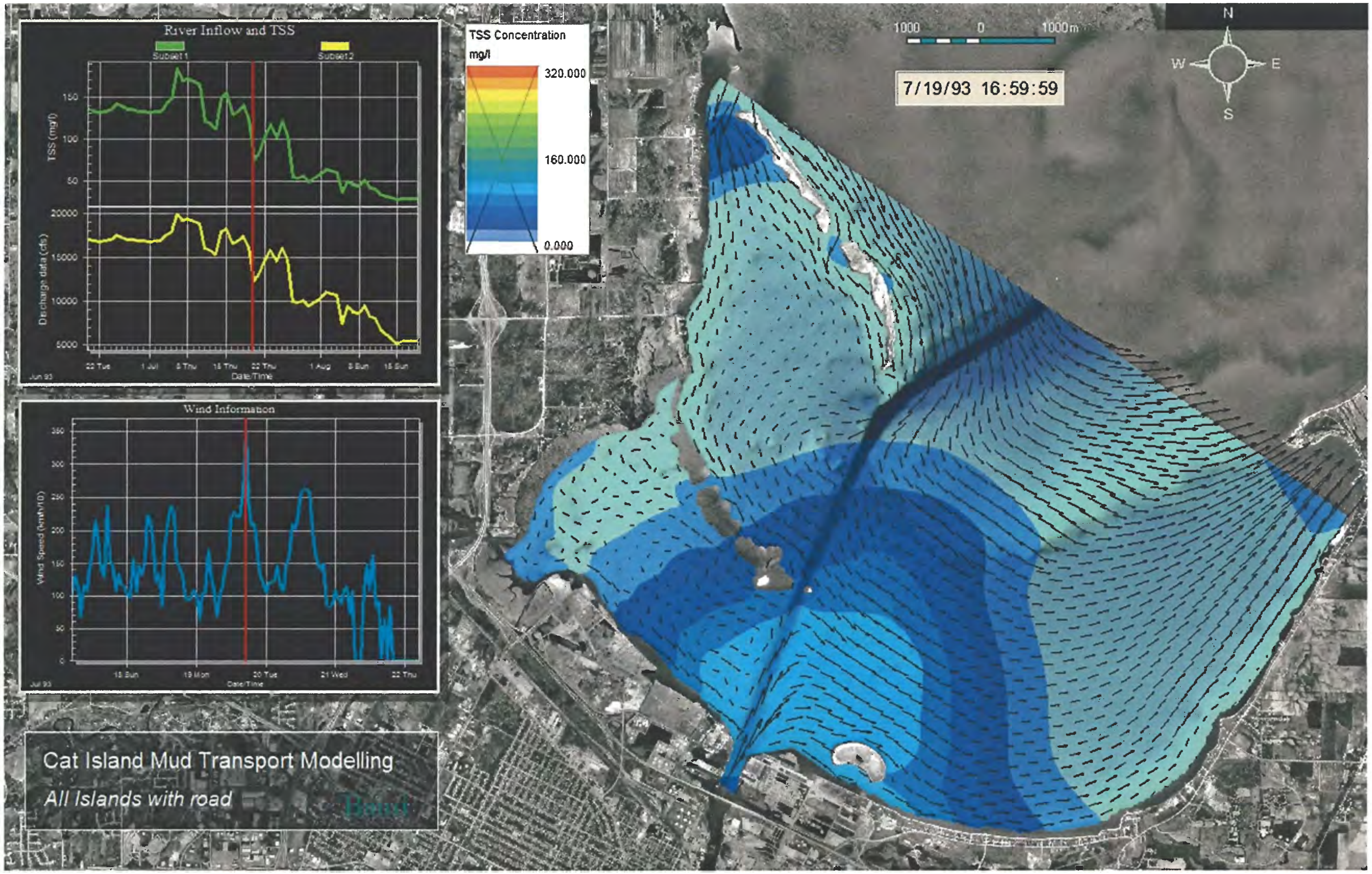


Figure 7.14 TSS and Flow Patterns for Run 1 - All Islands with Roads

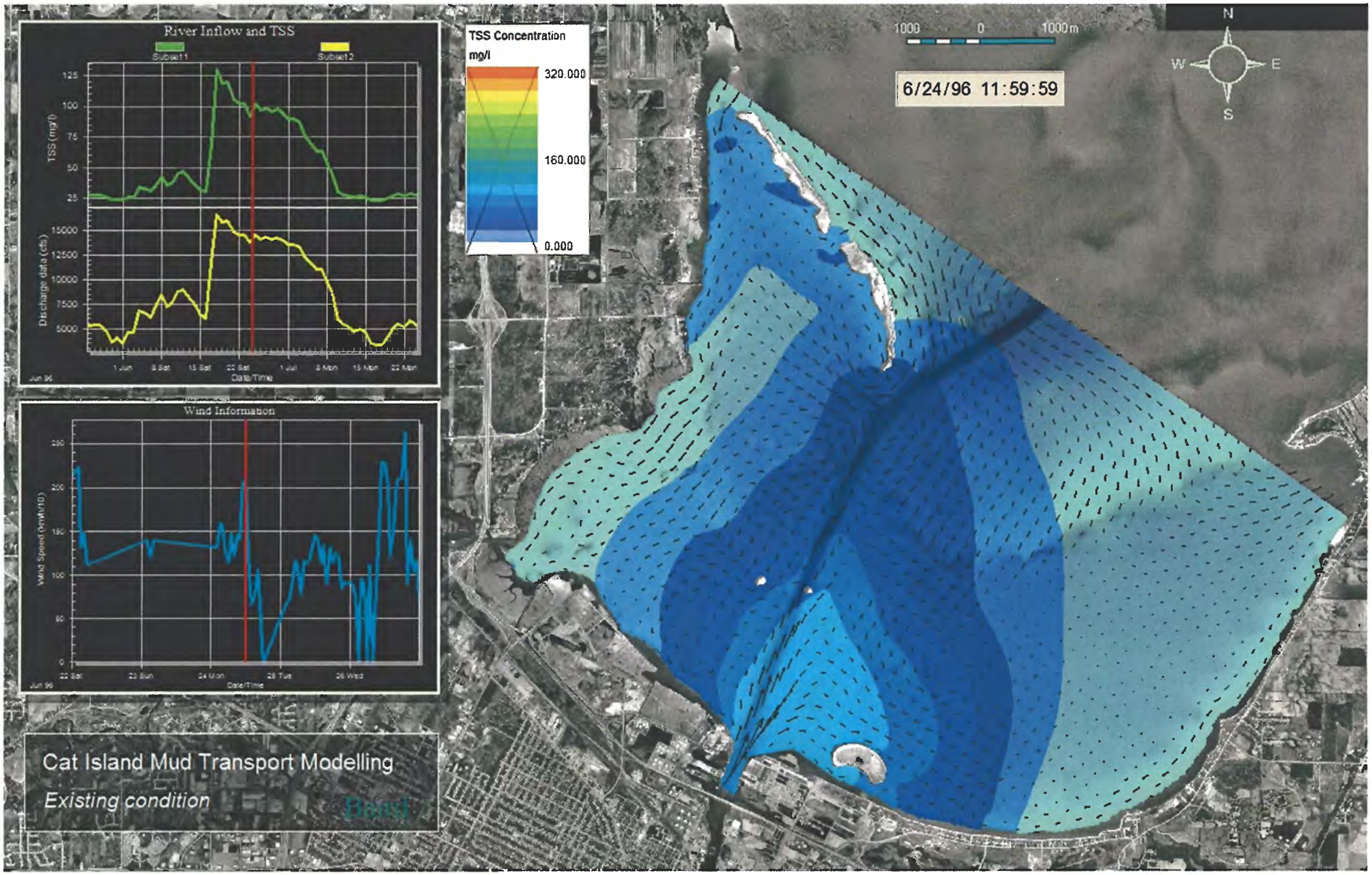


Figure 7.15 TSS and Flow Patterns for Run 2 - Existing Condition

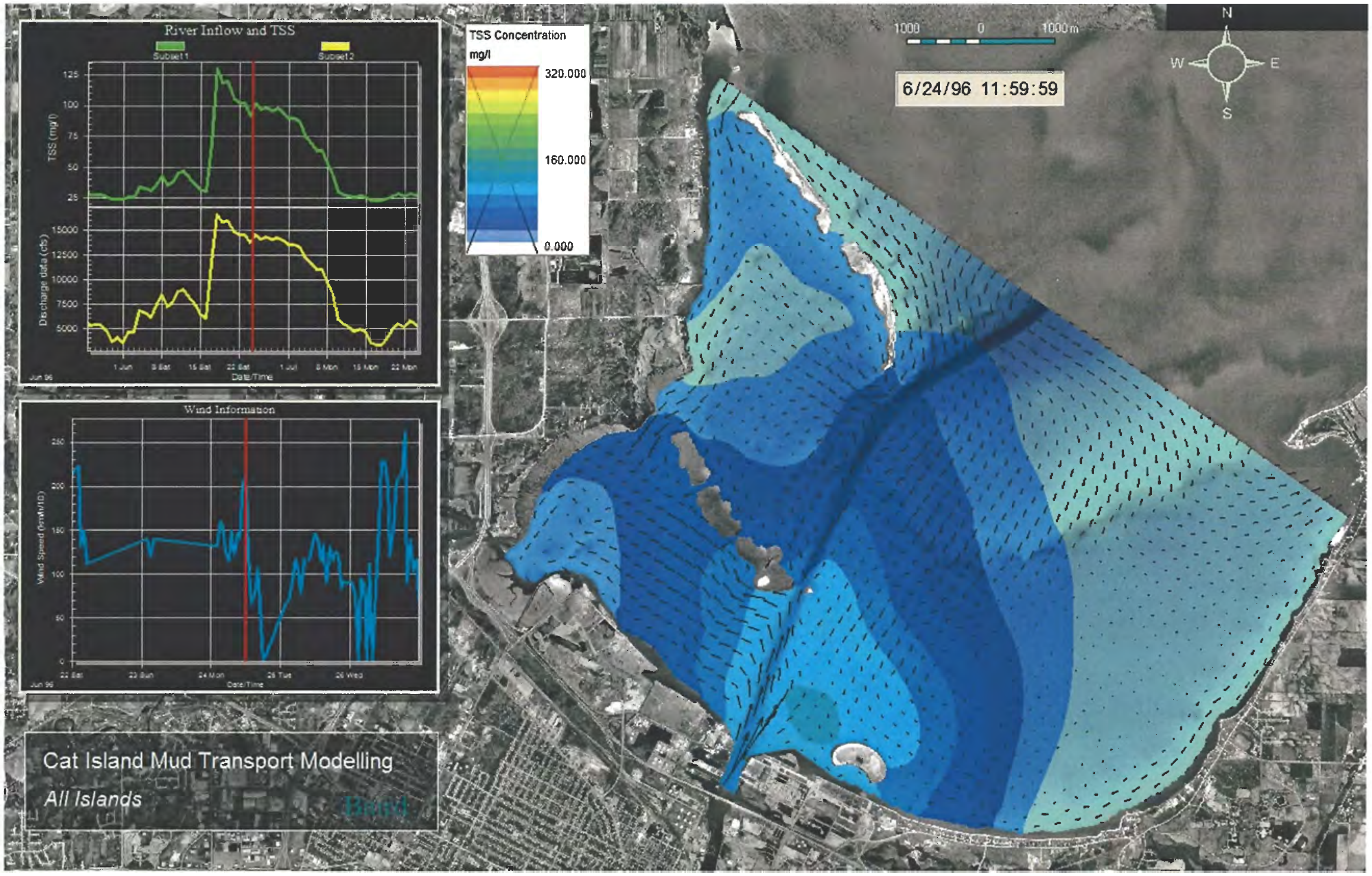


Figure 7.16 TSS and Flow Patterns for Run 2 - All Islands

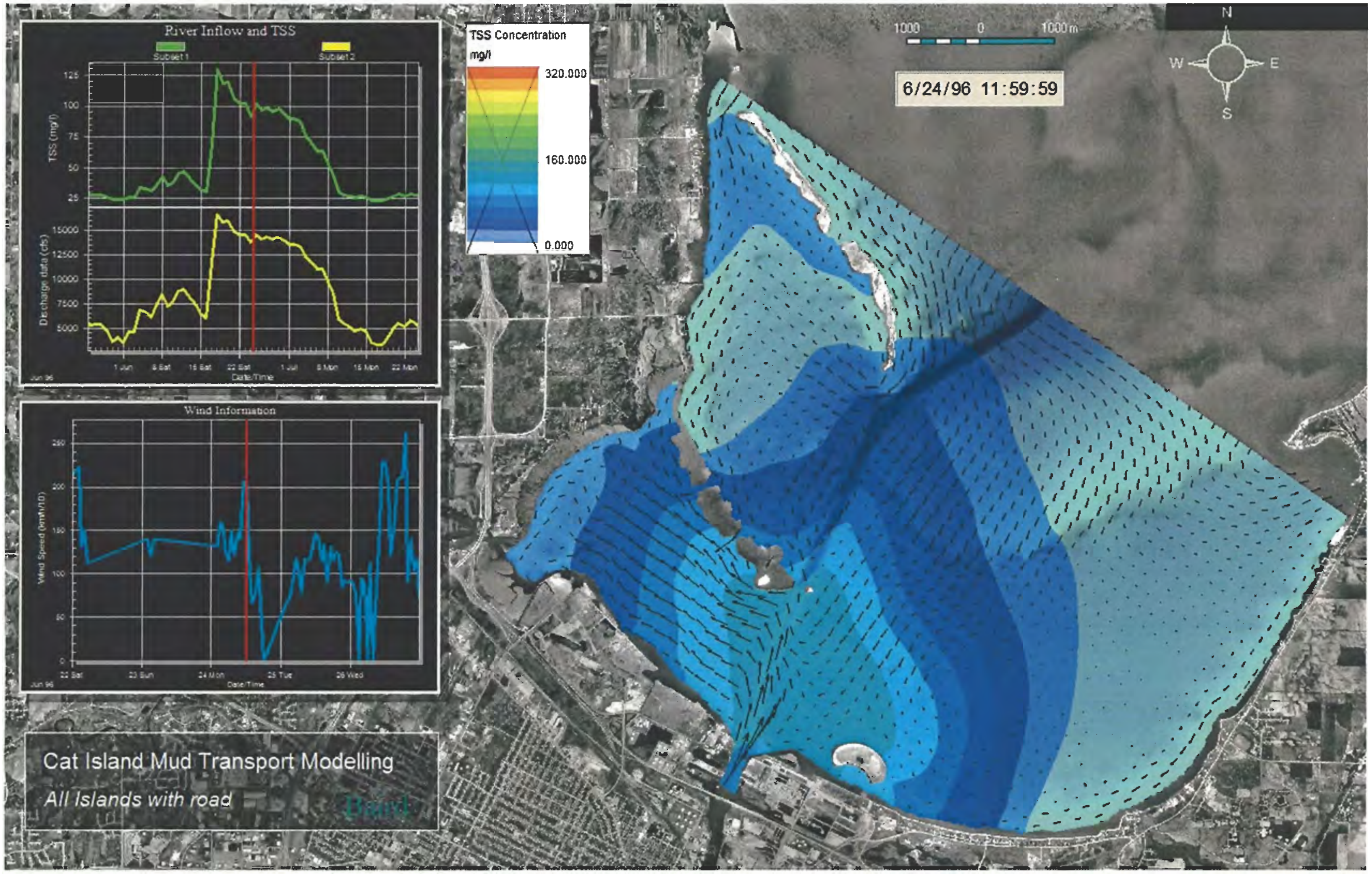


Figure 7.17 TSS and Flow Patterns for Run 2 - All Islands with the Access Road

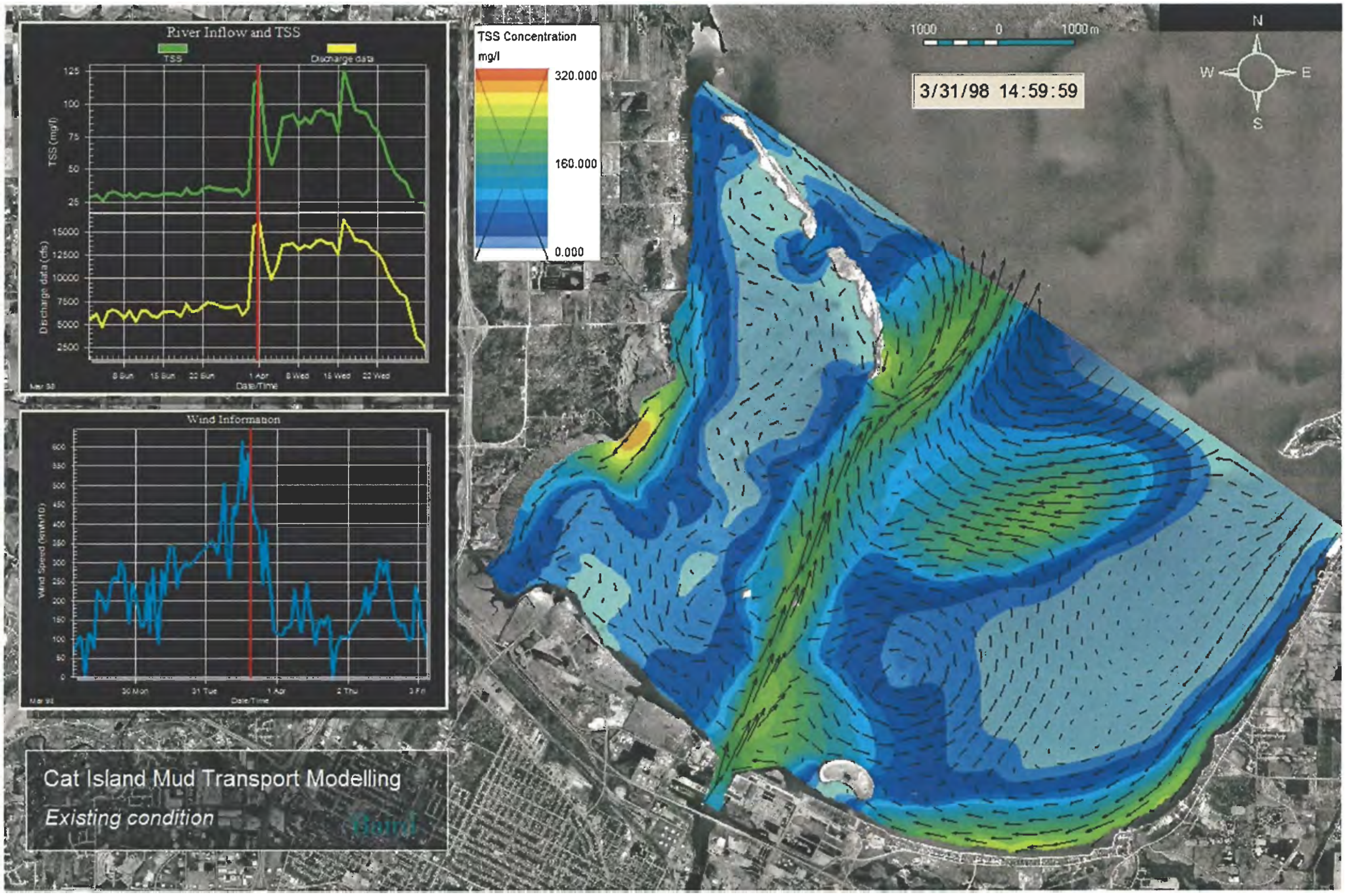


Figure 7.18 TSS and Flow Patterns for Run 3 - Existing Conditions

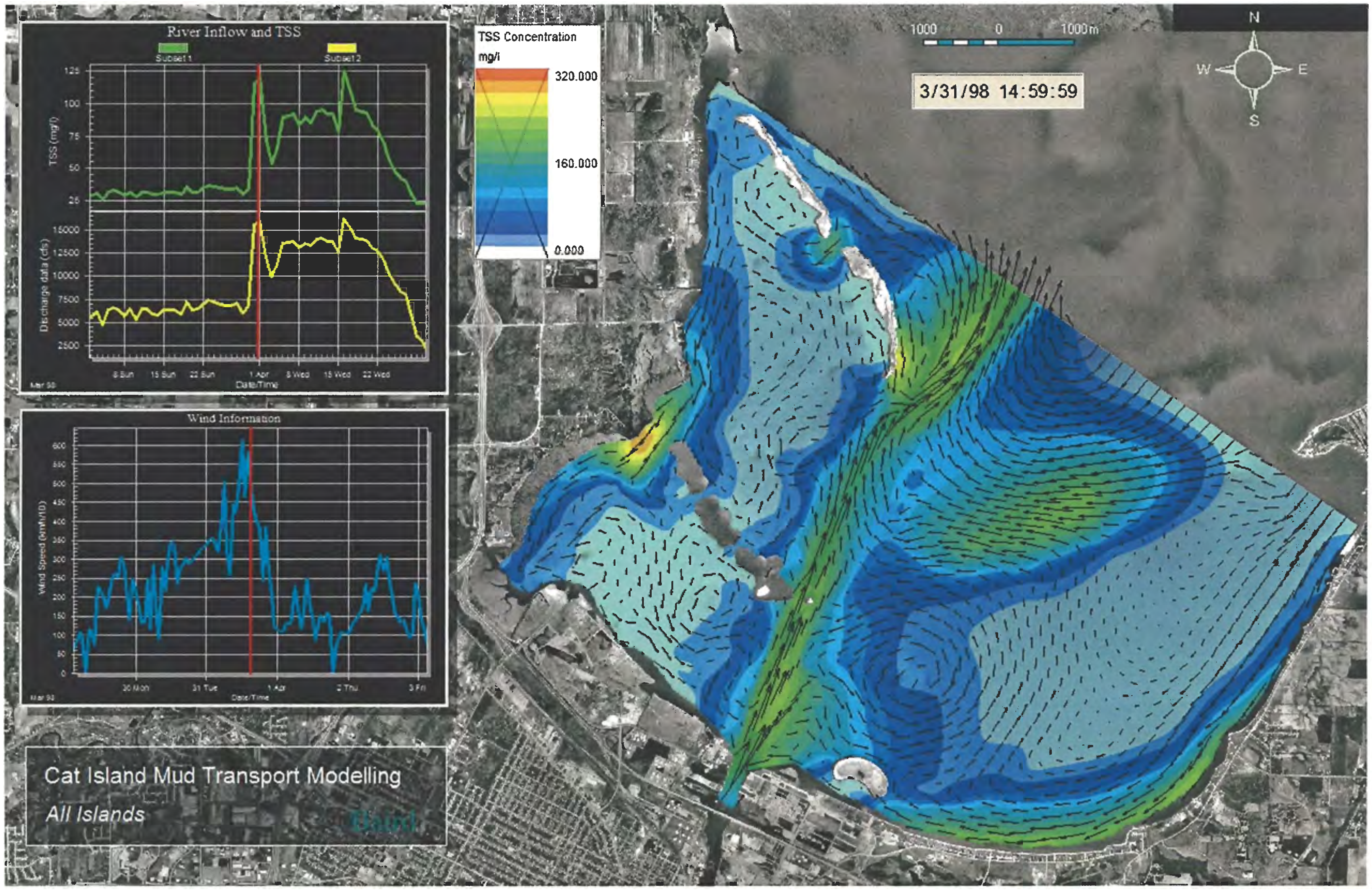


Figure 7.19 TSS and Flow Patterns for Run 3 - All Islands

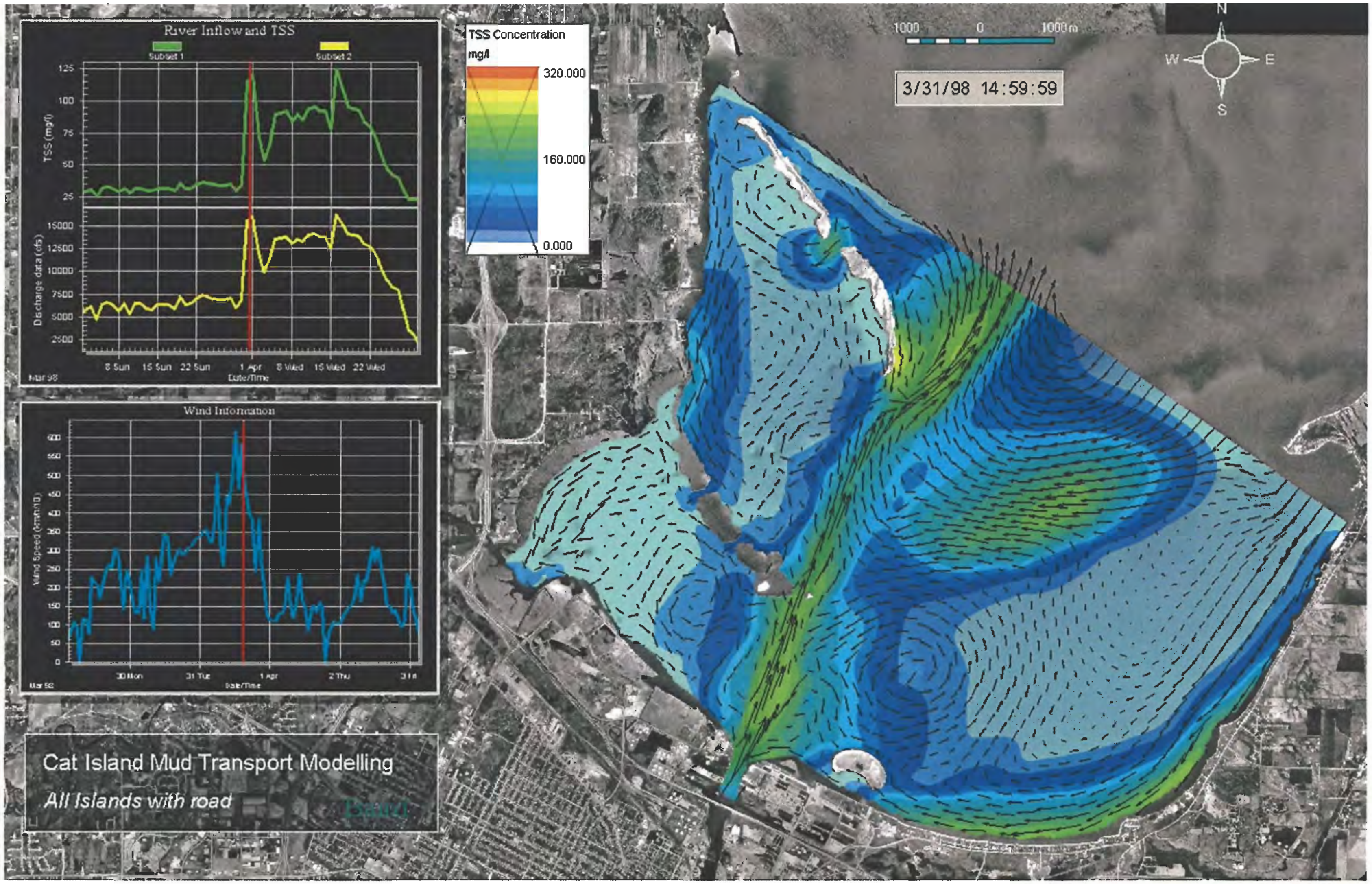


Figure 7.20 TSS and Flow Patterns for Run 3 - All Islands with the Access Road

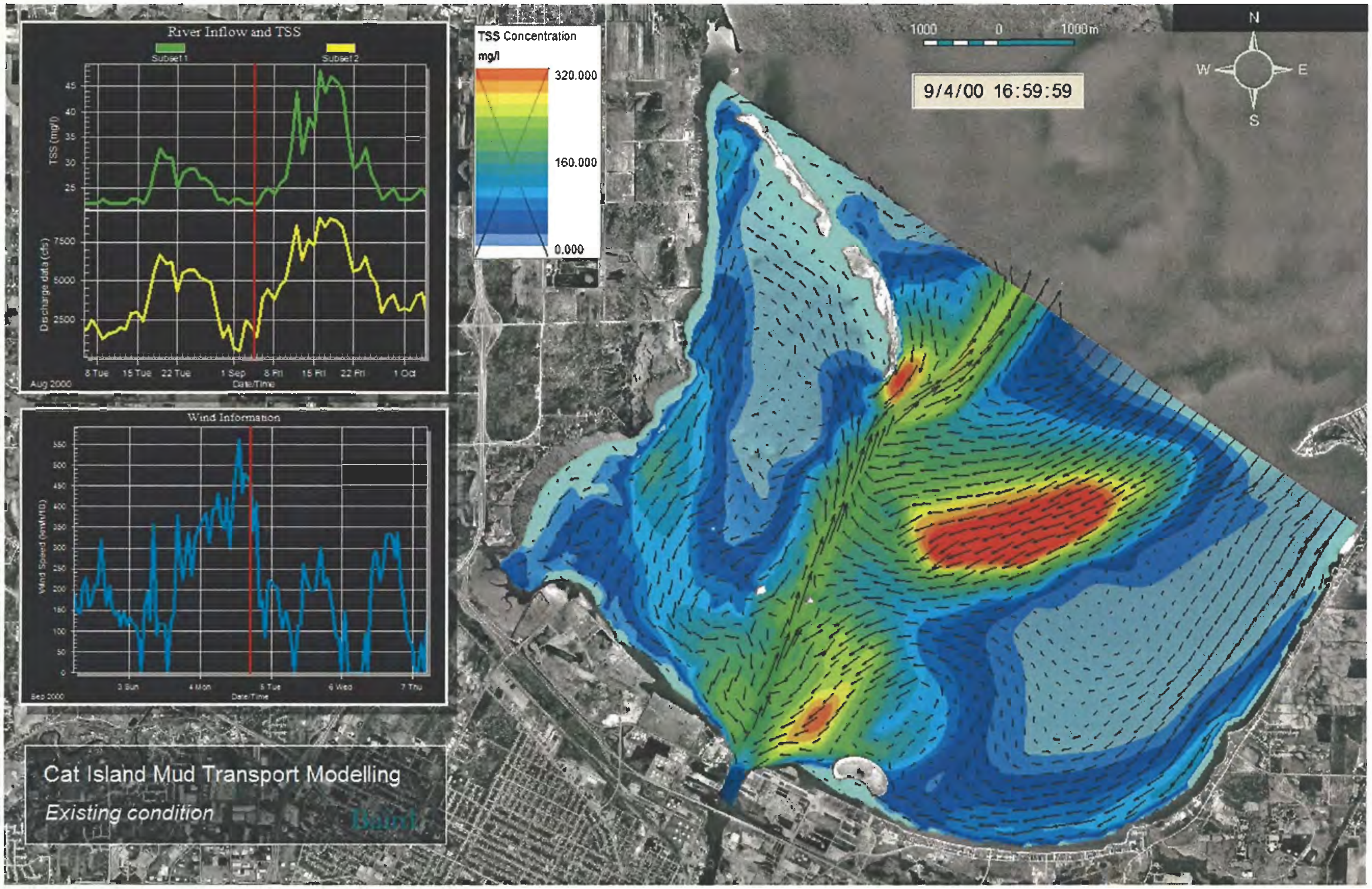


Figure 7.21 TSS and Flow Patterns for Run 4 - Existing Conditions

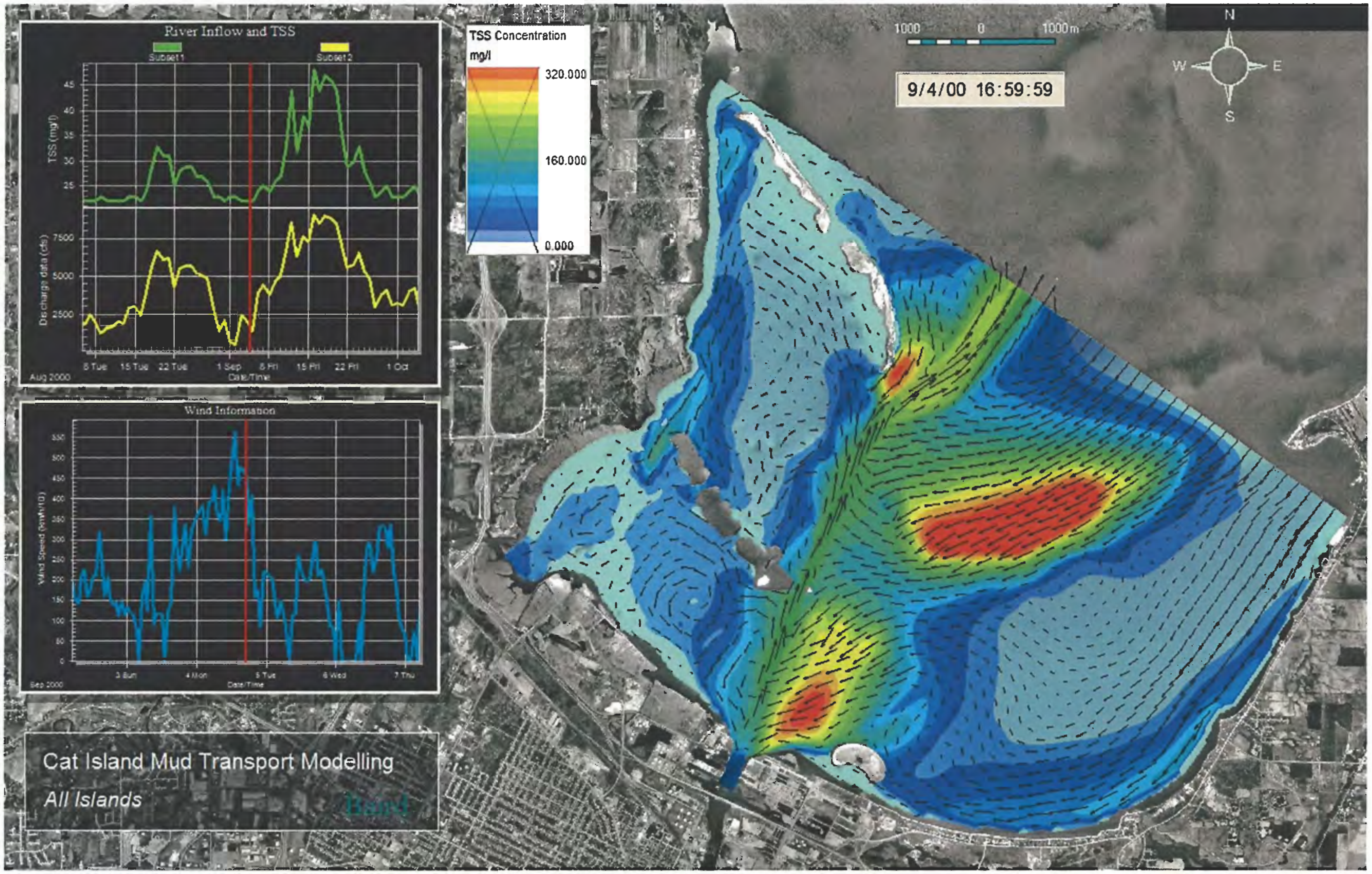


Figure 7.22 TSS and Flow Patterns for Run 4 - All Islands

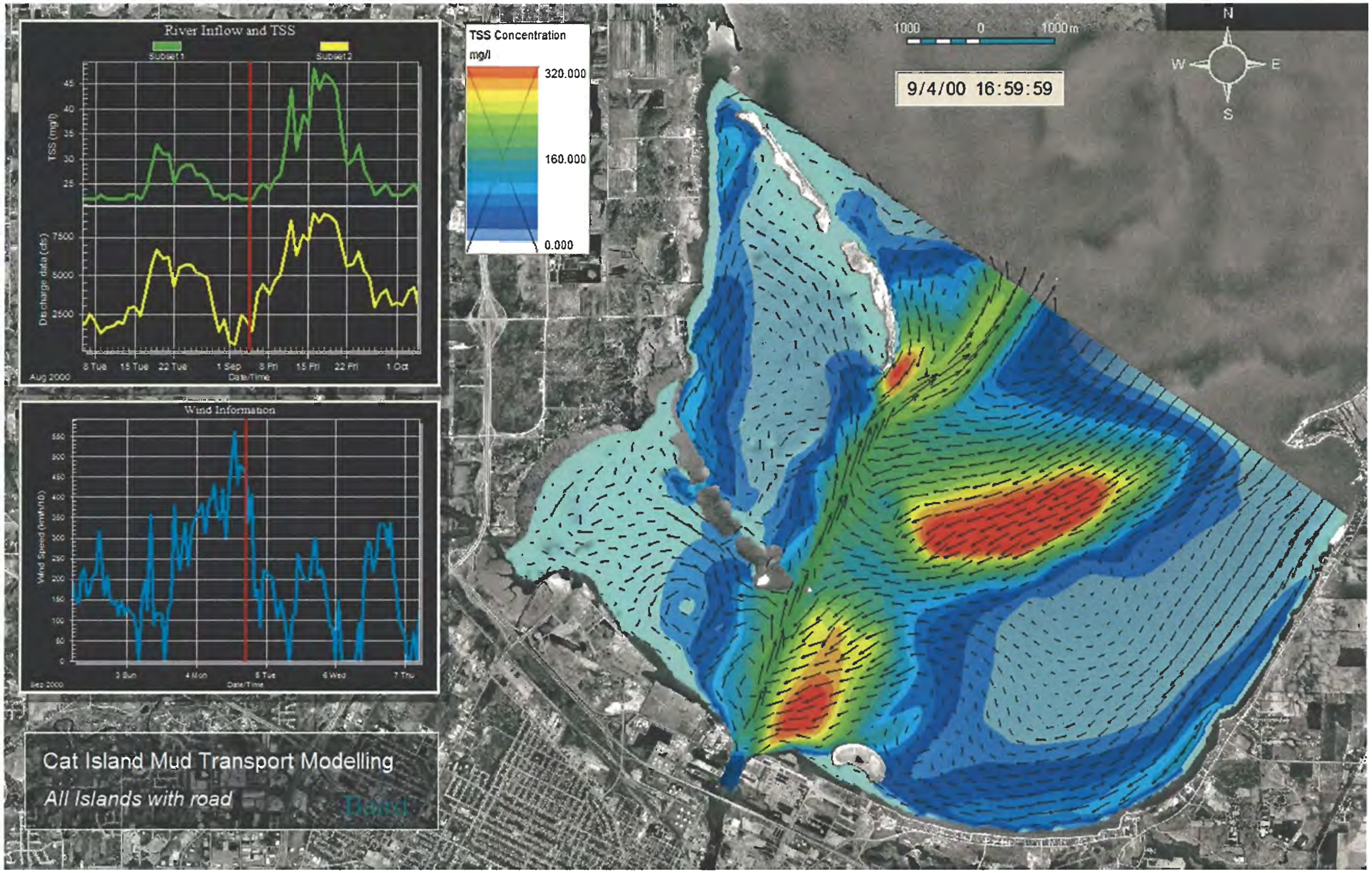


Figure 7.23 TSS and Flow Patterns for Run - All Islands with the Access Road

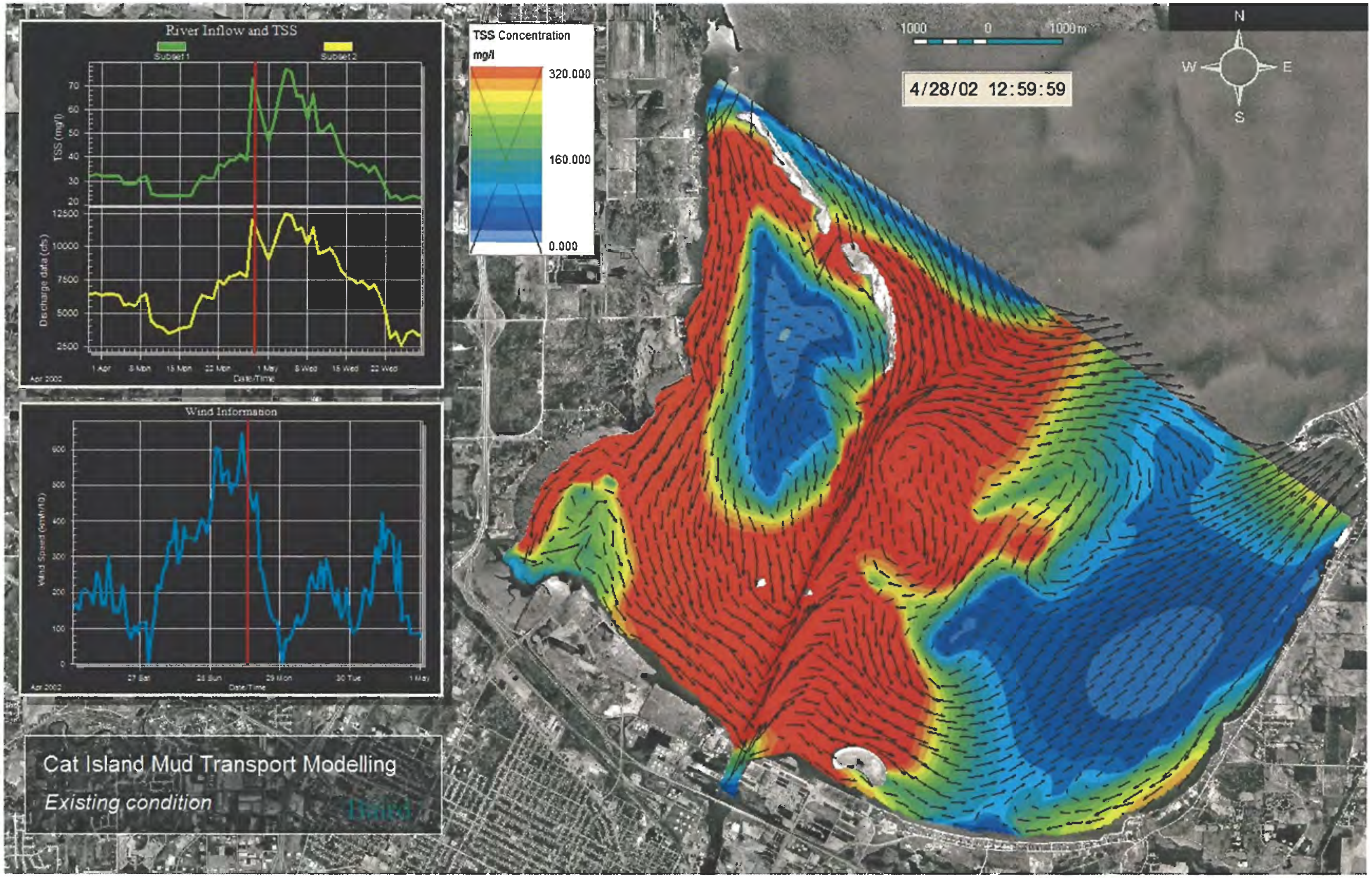


Figure 7.24 TSS and Flow Patterns for Run 5 - Existing Condition

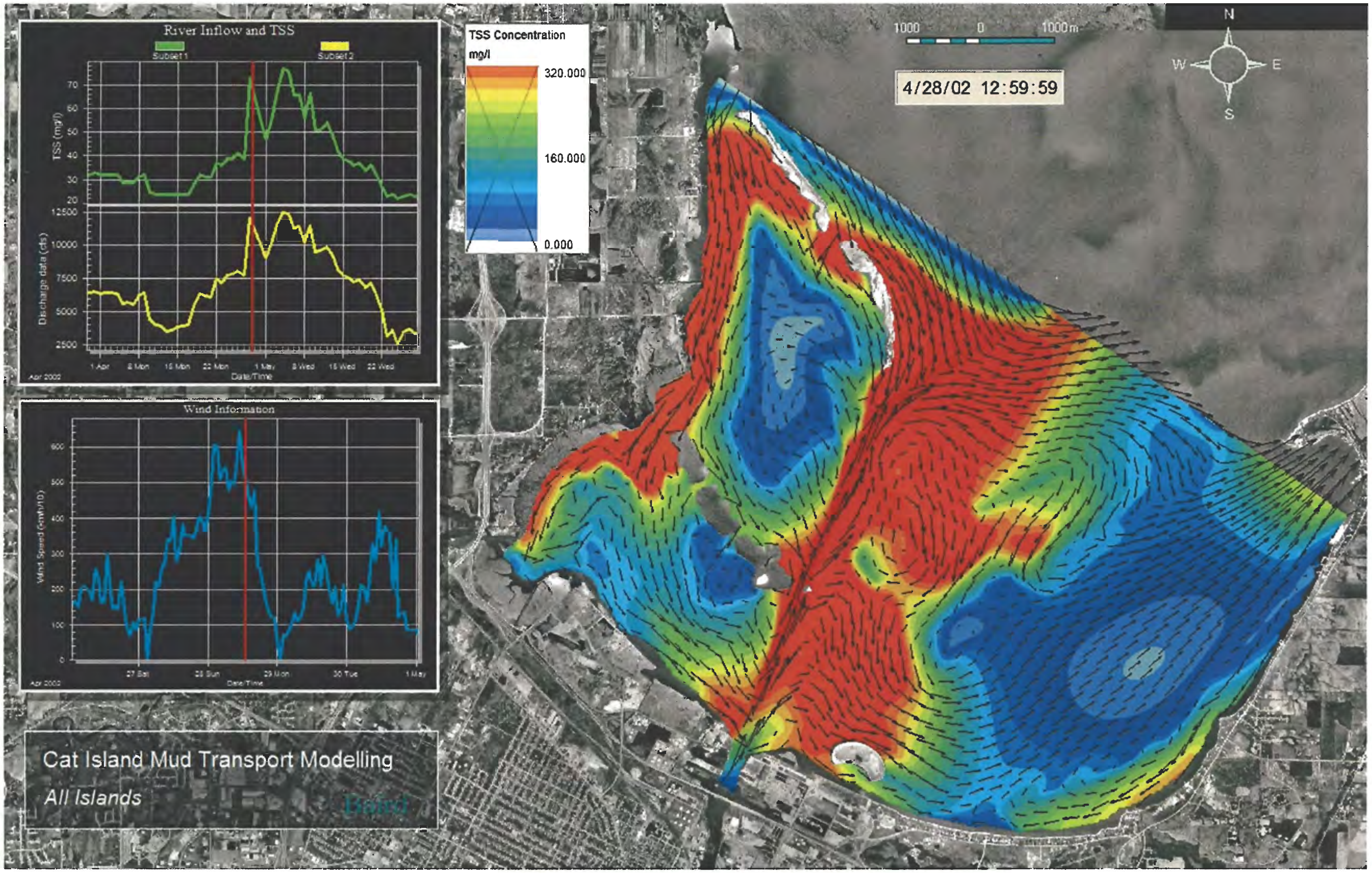


Figure 7.25 TSS and Flow Patterns for Run 5 - All Islands

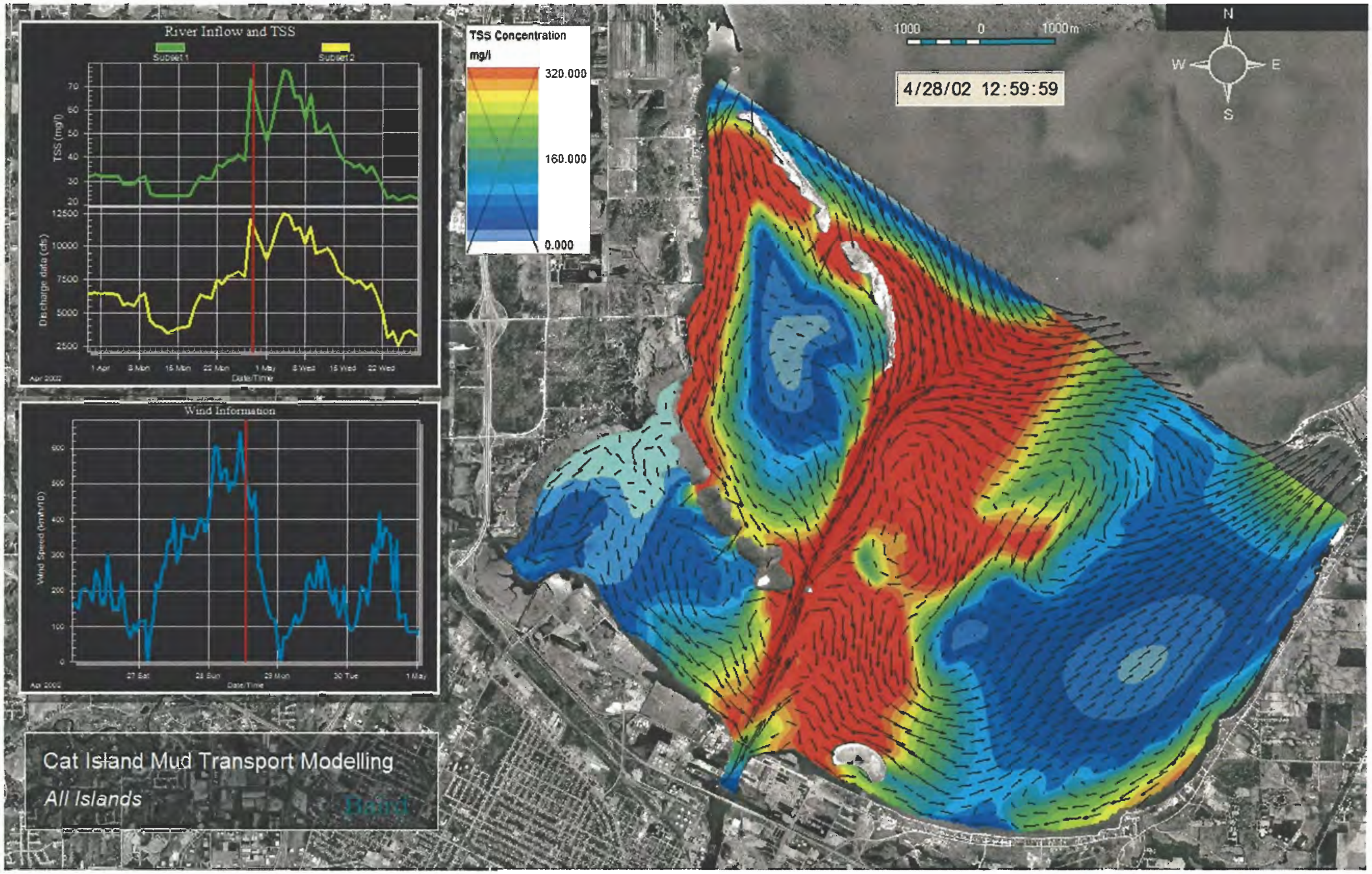


Figure 7.26 TSS and Flow Patterns for Run 5 - All Islands with the Access Road

8.0 AQUATIC VEGETATION STABILITY ANALYSIS

8.1 Introduction and Background

One of the primary purposes of restoring the Cat Island Chain is to help promote the recovery of the Duck Creek, Peter's Marsh and Peat's Lake Wetlands. This large area of aquatic vegetation was almost entirely lost subsequent to the high lake levels in 1973 that washed away the sub-aerial part of the Cat Island Chain (refer to Figure 3.5). The changes to wetlands and macrophytes in Lower Green Bay have been documented by Harris et al (1977) and Harris et al (1981). The survivorship of aquatic vegetation is contingent on protection from heavy wave attack and sufficient water clarity.

Baird & Associates have completed a series of investigations for the Department of Fisheries and Oceans in Canada to assist in the development of improved criteria to predict the survivorship of macrophytes (see Baird & Associates 1996a, b, 1997 and Minns and Nairn, 1999). The original algorithm used by Minns et al (1995) (see also Minns and Nairn, 1999) to determine whether the submerged macrophyte cover is greater than 50% (present) or less than 50% (absent) is given as:

If substrate is sand or finer and,

If depth is less than twice the Secchi Depth and,

If the effective fetch is less than 2 kilometers and,

If the maximum slope is less than 15 percent,

Then vegetation is present (i.e. cover greater than 50%),

Else, vegetation is absent (i.e. cover less than 50%).

Subsequently, Baird & Associates (1997) refined the 2 km fetch requirement based on extensive data on macrophyte coverage, water clarity, depth, wave exposure and substrate conditions at 48 sites on the Great Lakes (see Valere, 1996). The 2 km criterion did not account for the processes of wave refraction, shoaling and diffraction that are particularly important in Lower Green Bay. A more site-specific criterion for wave exposure was developed and consists of an annual peak bed orbital velocity of 0.6 m/s for the growing season (approximately May to September in Green Bay). As one of many possible combinations, such an orbital velocity is generated by a significant wave height of about 0.45 m (with a wave period of 2.5 s) in a water depth of 1.5 m.

Local investigations of the factors influencing the survivorship and recovery of macrophytes generally agree with the criteria outlined above (see Robinson, 1996, McAllister, 1991 and Sager et al, 1996).

In Lower Green Bay, the key criteria are water clarity and the wave orbital velocity (as the surrogate for wave exposure and potential root damage). The substrate criteria (fine sand or finer and slope less than 15%) are assumed to be fulfilled everywhere.

Therefore, in this section the wave orbital velocity (wave exposure) and water clarity criteria are evaluated for five representative (annual growing season extreme or greater) conditions for several scenarios representing the sequential construction of the islands (i.e. combinations of one, two and three islands with or without an access road). The explanation of the selection of these five representative conditions and a description of the events are provided in Section 7. Extreme conditions were selected to test that even under these relatively infrequent conditions the construction of the islands would create the necessary conditions to promote the restoration of aquatic vegetation.

The suspended sediment predictions from Section 7 provided estimates of the abiotic component of sediment load from local re-suspension of sediment from the lakebed and from plumes from Fox River and Duck Creek. The estimates of abiotic suspended sediment were transformed first to TSS assuming the biotic fraction as a constant 65% of the total load and with *Chlorophyll a* assumed to be constant at 50 μg/l (see STAC, 2000). Subsequently, the TSS (including abiotic, biotic and Chlorophyll a components) was converted to Secchi Depth (as required for the macrophyte survivorship algorithm) using the relationships presented in the White Paper on Nutrient and Sediment Management in the Fox-Wolf Basin (STAC, 2000).

The wave orbital velocity estimates were derived from the wave climate and transformation predictions described in Section 5 of this report. It is noted that the predicted steady flow velocity (i.e. generated by wind-driven circulation) was taken as the critical flow velocity where it exceeded the local orbital velocity. In one sense this is conservative as the threshold for survivorship of macrophytes for steady flow is probably greater than 0.6 m/s (i.e. since there is no significant acceleration and reversal component (+/- 0.6 m/s) as there is with wave orbital velocity). However, this conservative assumption was balanced by the fact one or the other was used and there was no attempt to develop a combined wave-current velocity. In any event, this condition only arises in localized areas between the gaps in the islands.

In this investigation it has been assumed that the algorithm for macrophyte survivorship also applies to emergent vegetation. It is likely that this is a conservative assumption (i.e. it is likely that emergents can withstand greater wave exposure and reduced water clarity). However, at the early stages of growth, while emergents are submerged, they would likely behave like, and be governed by the same criteria, as submerged aquatic vegetation.

The next section presents the analysis and results of this task.

8.2 Analysis and Results

8.2.1 Secchi Disk and Potential Vegetation Growth Area

As discussed above, the key factors for aquatic vegetation growth in Lower Green Bay are water clarity and wave orbital velocity. Secchi Depth is commonly used to measure the transparency of water i.e. water clarity, which mainly relies on total suspended solid, volatile material concentration, and concentration of *Chlorophyll a*. The equation for determining Secchi Depth in Green Bay is given by the White Paper (STAC, 2000) as:

$$\textit{Secchi Depth} = 0.80 - 0.174 \cdot TSS - 0.17 \cdot VS - 0.16 \cdot \textit{Chlor a}$$

where TSS - (mg/l) standardized total suspended solid;

VS – (mg/l) standardized volatile materials;

Chlor a – (µg/l) standardized *Chlorophyll a*;

With the assumption of VS as a constant 65% of TSS and using the standardized parameters as listed below,

	TSS	VSS	Chla
Mean	22.668	14.502	40.029
Stdev	12.163	5.987	27.452

The above equation can be expressed as

$$\textit{Secchi Depth} = 1.77 - 0.03248 \cdot TSS - 0.005828 \cdot \textit{Chlor a}$$

in which TSS is total suspended sediment directly from the model prediction. Using the above equation, the Secchi Depth for the five selected storm events with a variety of configurations are calculated using Baird in-house software – Spatial Data Analyzer (SDA), which is a GIS-based application to visualize and animate modeling results over a GIS map (see Figure 7.1 for a description of the system). It also provides powerful functionality for data analysis using the model results with mathematical equations such as the one above.

Water depth less than twice the Secchi Depth is a sufficient condition for the growth of aquatic vegetation provided that all other criteria are met. Areas with a Secchi Depth greater than 0.8 meters will promote the growth of aquatic vegetation in Lower Green Bay where the water depth less than 1.6 meters (providing the wave exposure criterion is met). Figure 8.1 shows the potential vegetation growth areas in Lower Green Bay where the water depth is less than 1.6 m for three lake levels: low water (water surface elevation is -0.2m above Lower Water Datum), mean water (+0.6m) and high water (+1.4m). The potential growth area for the mean lake level (area in light green and orange) corresponds well to the original coverage of wetlands on historic air photos (see Figure 3.5), suggesting that a Secchi Depth of 0.8 m provides a rough approximation of pre-1970 water clarity conditions.

8.2.2 Vegetation Growth Prediction

Vegetation growth analyses were carried out by SDA using the model predictions for five extreme scenarios as described in Section 7. TSS and orbital velocity are the two main factors influencing vegetation growth in Lower Green Bay and these will be modified after construction of the islands. Though *Chlorophyll a* is another important factor for Secchi Depth determination, it relies on the nutrient supply from the watershed that is assumed to remain the same after the construction of the islands. The current level of *Chlorophyll a* (50 µg/l) was assumed to be constant for this vegetation analysis.

Using SDA, Secchi Depth is first calculated with TSS predicted by the MIKE21 HD/MT model and then the ratio of Secchi Depth to water depth, which is recognized as one of the most important criteria for vegetation growth, is calculated. The ratio as well as the orbital velocity predicted by STWAVE is graphically interpreted in SDA to distinguish the area where there are sufficient conditions for vegetation growth, that is, the area where the ratio of Secchi Depth to water depth is larger than 0.5 and the orbital velocity is less than 0.6 m/s. Figures 8.2 to 8.16 show the vegetation restoration area for the five selected events with the existing condition, three islands, and three islands with a connection road to shore. In these figures, areas with a ratio of less than or equal to 0.5 (areas where the water depth is more than twice the Secchi depth) would have water clarity issues that will impede the growth of aquatic vegetation and therefore a low potential for vegetation growth. The areas that are unlikely to support aquatic vegetation growth are shown in red and orange. The regions shown in purple correspond to ratios between 0.5 and 1.0 (areas that have water depths equal to or less than twice the Secchi depth). The potential for vegetation growth is moderately high in this region, however some water clarity issues may still affect growth (mostly associated with plumes discharged from the rivers as noted in Section 7). Areas with a ratio greater than 1.0 have a high potential for vegetation growth and are shown in green on the figures. Zones with orbital velocities greater than 0.6 m/s (areas where there is the potential for root damage) are also indicated on the figures and are shown in beige or brown.

Runs 1 and 2 represent scenarios of sediment plume only from Fox River and Duck Creek (i.e. no re-suspension by waves). The potential vegetation growth areas are shown in

Figures 8.2 to 8.7. Similar to the TSS pattern described in Section 7, the construction of three islands may not significantly improve conditions for vegetation growth under these circumstances (TSS discharged from the rivers only). Depending on the direction of lake circulation, the change is small (better or worse) for vegetation growth after construction of the islands. If the lake circulation is counterclockwise, the plume from the Fox River will turn to east so that vegetation growth potential is slightly improved after construction of the islands and slightly more improved with the construction of the access road (see Figures 8.2 to 8.4). However, if lake circulation is clockwise, the plume will turn to west. The construction of the islands induces larger currents towards the area between Cat Island and Duck Creek and causes more sediment advection towards the west. Therefore under these conditions, the water clarity is slightly reduced in that area (see Figures 8.5 to 8.7).

However, the water clarity is significantly improved after the construction of the islands when high TSS is associated with wave and current induced sediment re-suspension. Runs 3 and 4 are the scenarios representing such conditions. Since the three islands can effectively block wave propagation from the outer bay, the TSS induced by waves and currents is reduced tremendously. The vegetation growth potential is significantly improved in the lee of the three islands (see Figures 8.9 and 8.12). However, the high TSS is still an issue for vegetation growth along the shore since the sediment can be transported along the shore through the gap between the west island and the shore. The construction access road (or a subsequent series of islands and dense aquatic vegetation after the construction road is removed) between the west island and the shore can prohibit such sediment transport and can significantly improve the water clarity in Peats Lake and Peter's Marsh (see Figures 8.10 and 8.13).

Run 5 represents a scenario of windstorm with surge. Strong lake circulation is present in Lower Green Bay induced by both wind and surge (see Figure 7.24). The sediment re-suspension induced by both waves and currents is important. Though the water clarity is significantly improved after the construction of three islands (see Figure 7.25), the TSS level in the lee of the islands is still high enough to inhibit vegetation growth (see Figure 8.15). This may result from the longshore sediment transport through the open gap between the west island and the shore. However, the water clarity in Peats Lake and Peter's marsh is significantly improved if the construction access road (or a series of islands after the construction road is removed) is built together the three main islands (see Figure 8.16).

8.3 Summary

The following is a summary of the key findings of this investigation:

- The most limiting factor for macrophyte growth in Lower Green Bay is the water clarity impairment associated with local re-suspension of sediments since the TSS induced by waves generally much higher than the TSS associated with sediment plumes from Fox River and Duck Creek. The influence of plumes is less prominent, less widespread and likely less frequent. The influence of direct wave exposure on aquatic vegetation survivorship (i.e. the 0.6 m/s criterion) is very localized.

- There is a tremendous improvement to the water clarity associated with re-suspension of lakebed sediment once all three islands are constructed. Commencing construction with the west island would be much more beneficial in promoting the conditions for aquatic vegetation restoration compared to starting construction at the east island (the east island on its own provides only limited protection).

- The construction of three islands may not have a significant influence on the water clarity associated with the plumes discharged by Fox River and Duck Creek. It is possible that the constructed islands will trap the plumes somewhat when the lake circulation is clockwise.

- Even with all three islands constructed, there is a critical need to close the gap (or significantly close the gap) between the west island and the shore to ensure recovery potential in the old Peter's Marsh area. A review of historic air photos shows that prior to 1973, this area was largely closed off by small islands and dense emergent vegetation.

- Optimum conditions for promoting restoration of submerged aquatic vegetation in the lee of the restored islands requires that the sediment load from Duck Creek and the Fox River are managed to levels that once allowed these areas to thrive prior to 1973. Specification of these levels or investigation of their change through time (and the changing impact of the plumes from these rivers) was beyond the scope of this investigation.

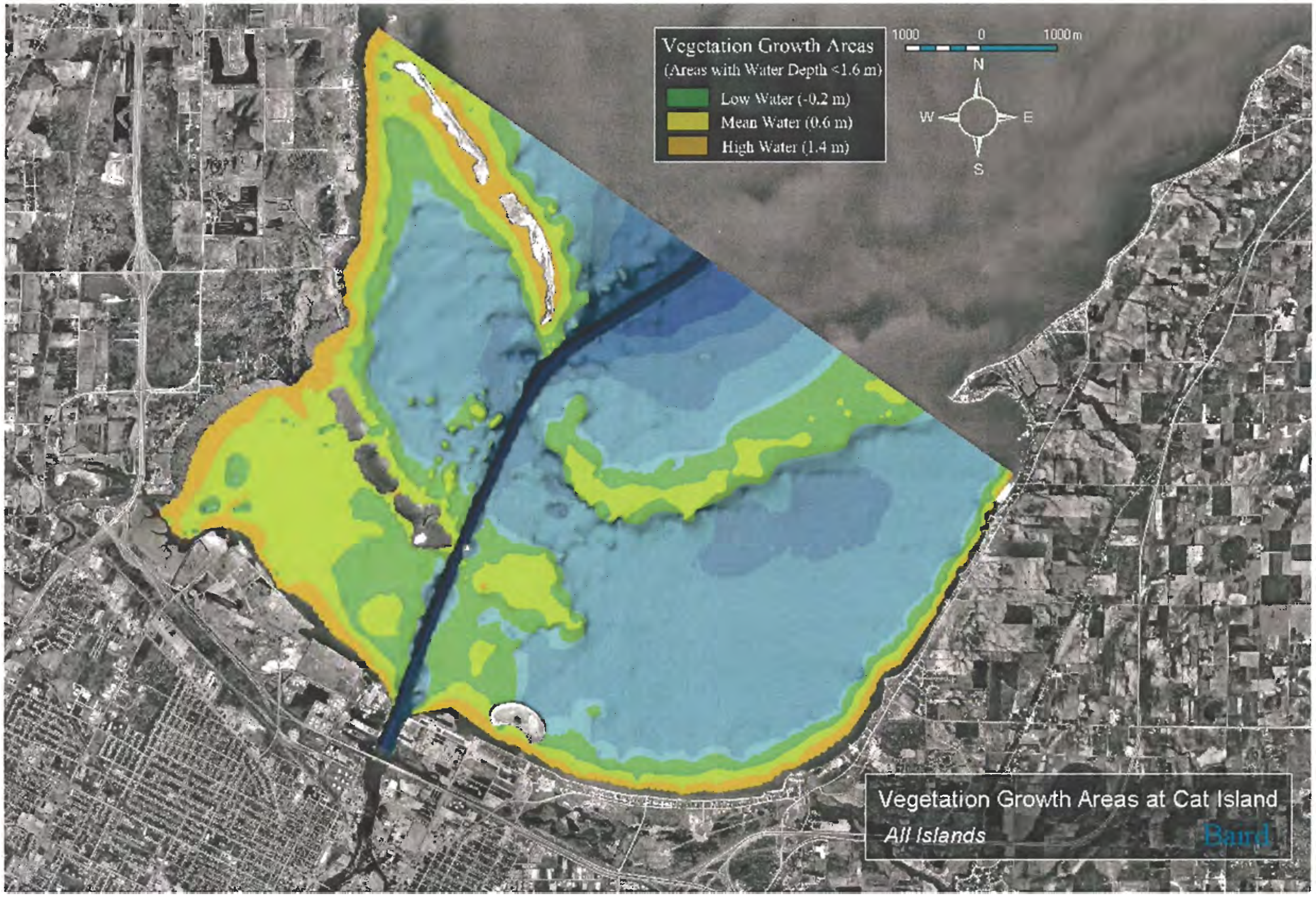


Figure 8.1 Potential Vegetation Growth Areas for Secchi Depth Greater Than 0.8m for Different Water Levels

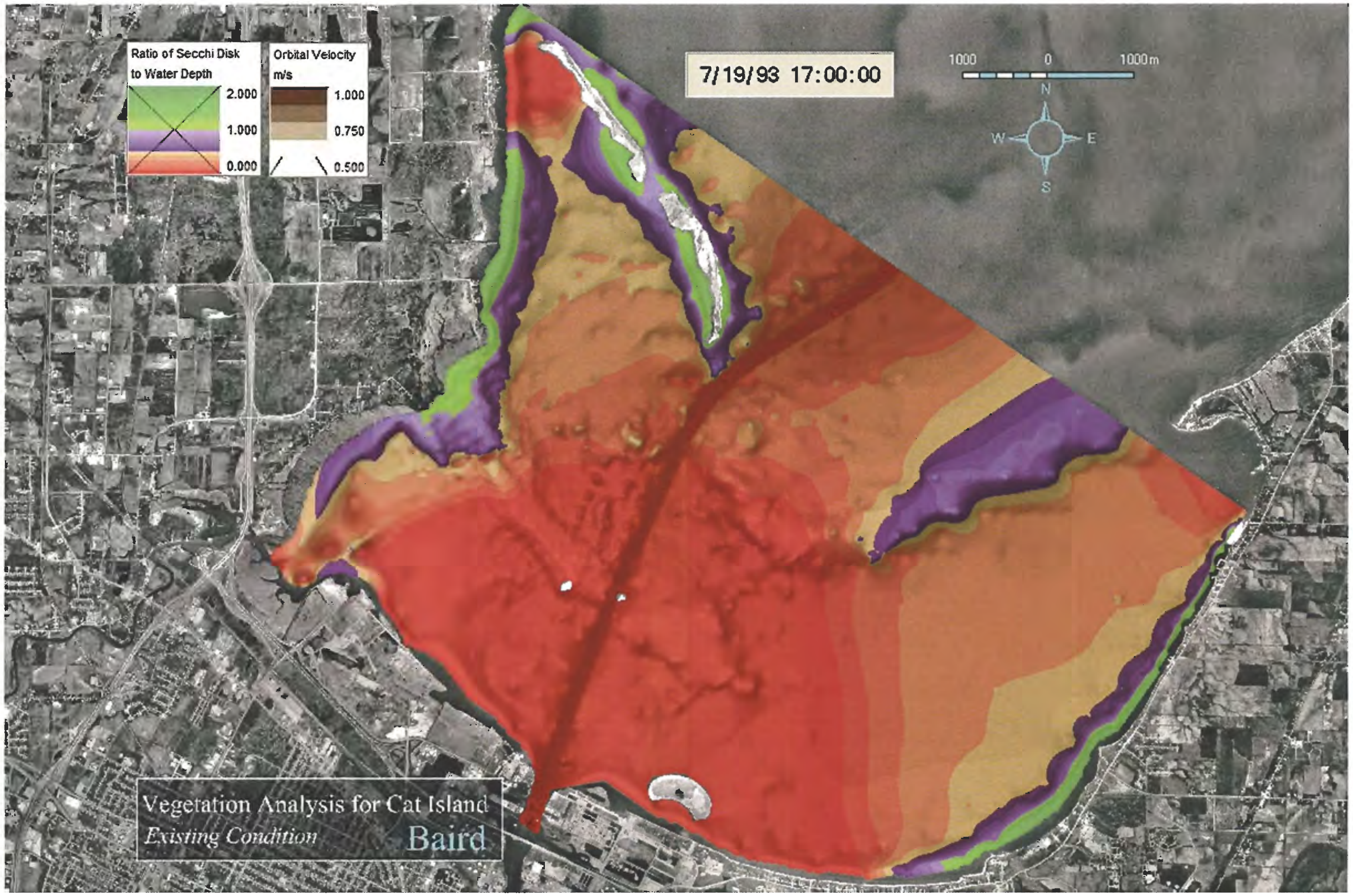


Figure 8.2 Vegetation Analysis for Run 1 – Existing Conditions

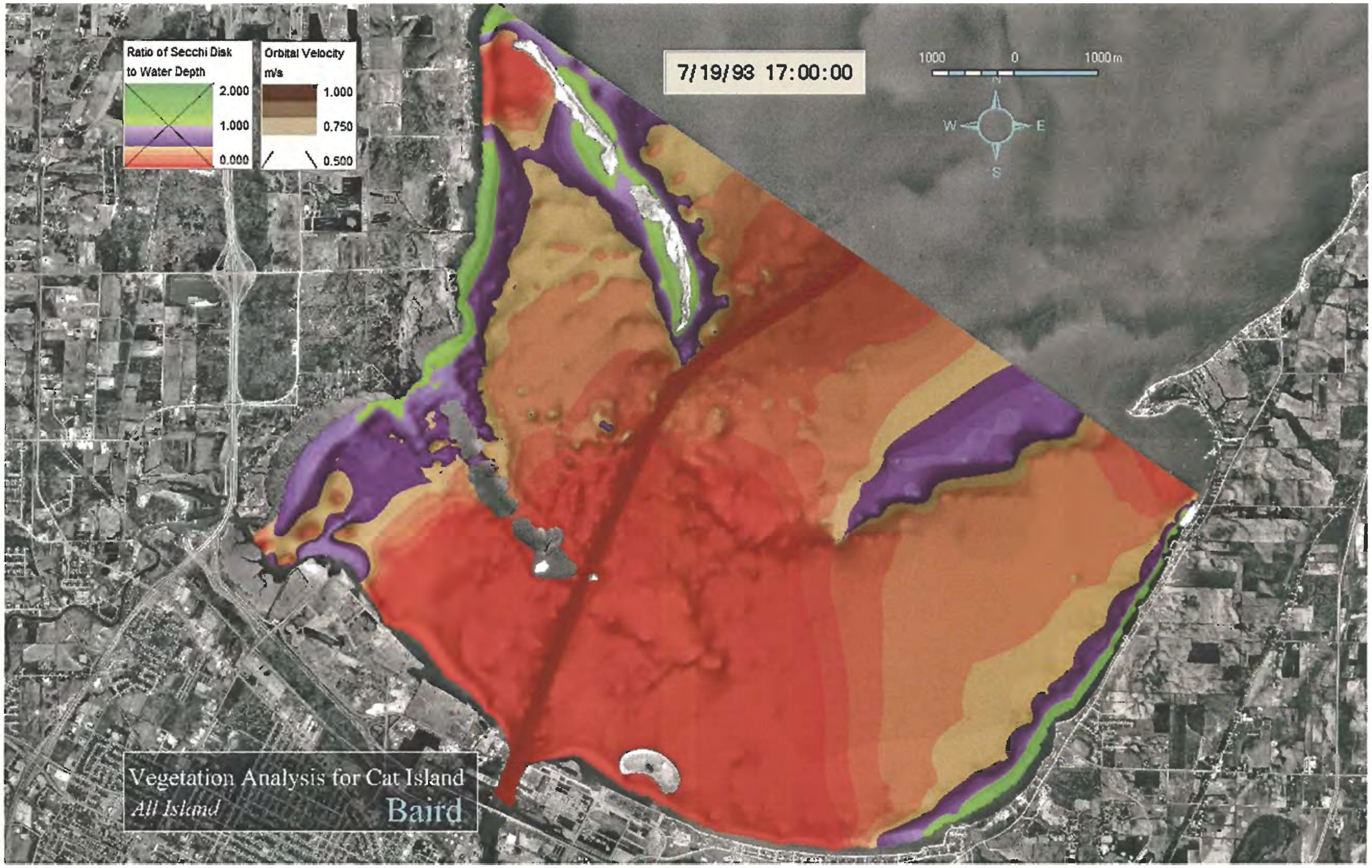


Figure 8.3 Vegetation Analysis for Run 1 – All Islands

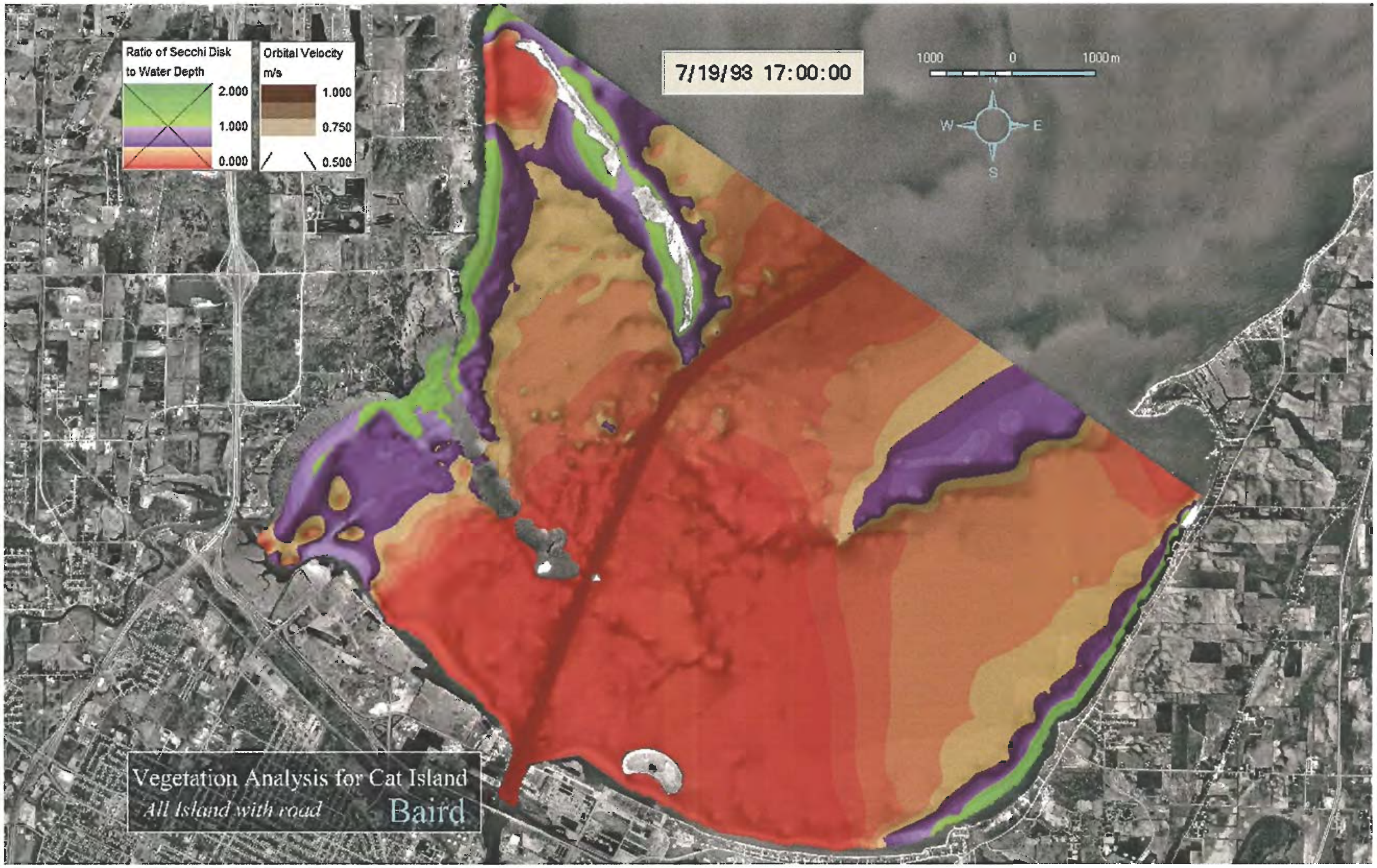


Figure 8.4 Vegetation Analysis for Run 1 – All Islands with Roads

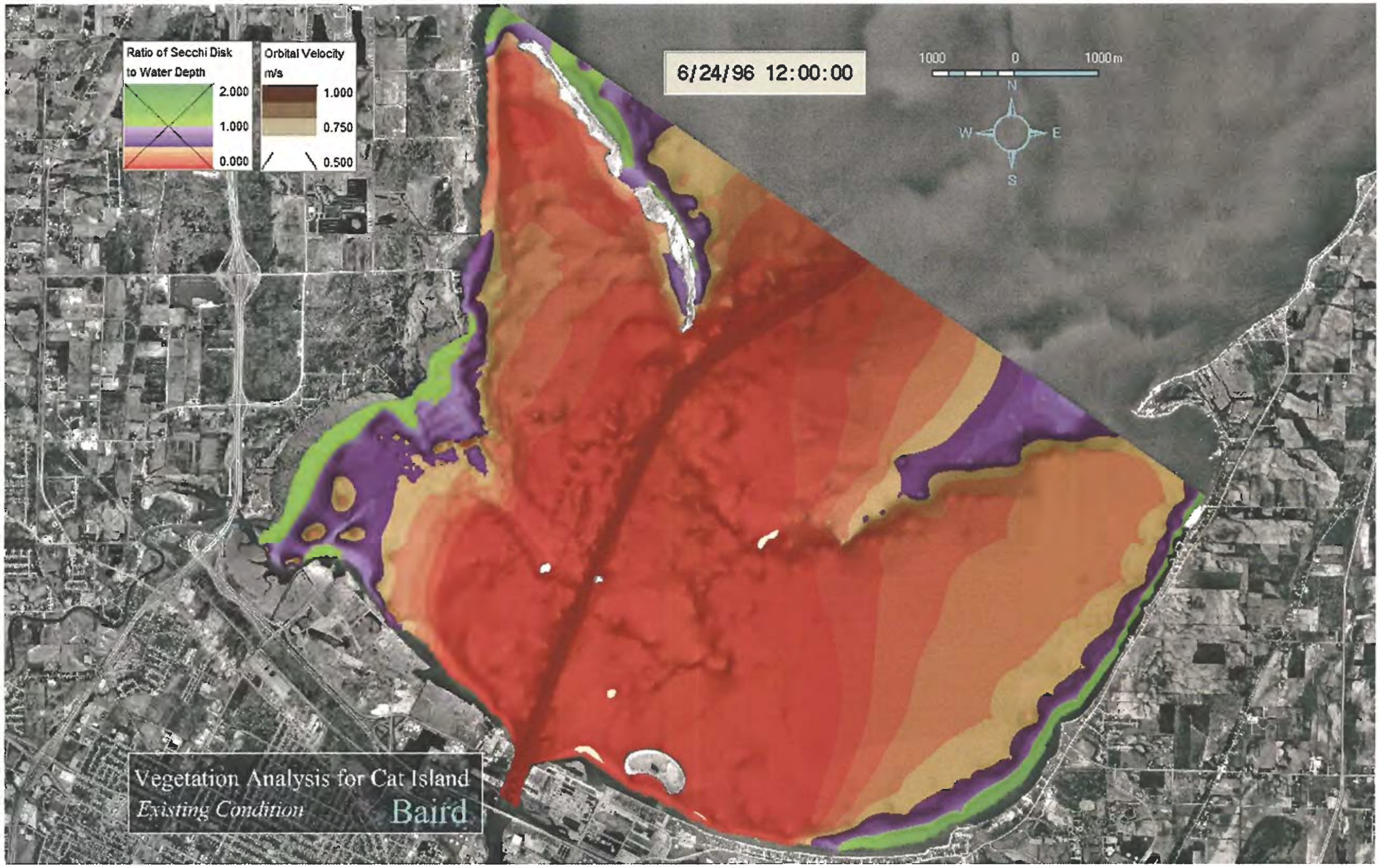


Figure 8.5 Vegetation Analysis for Run 2 – Existing Condition

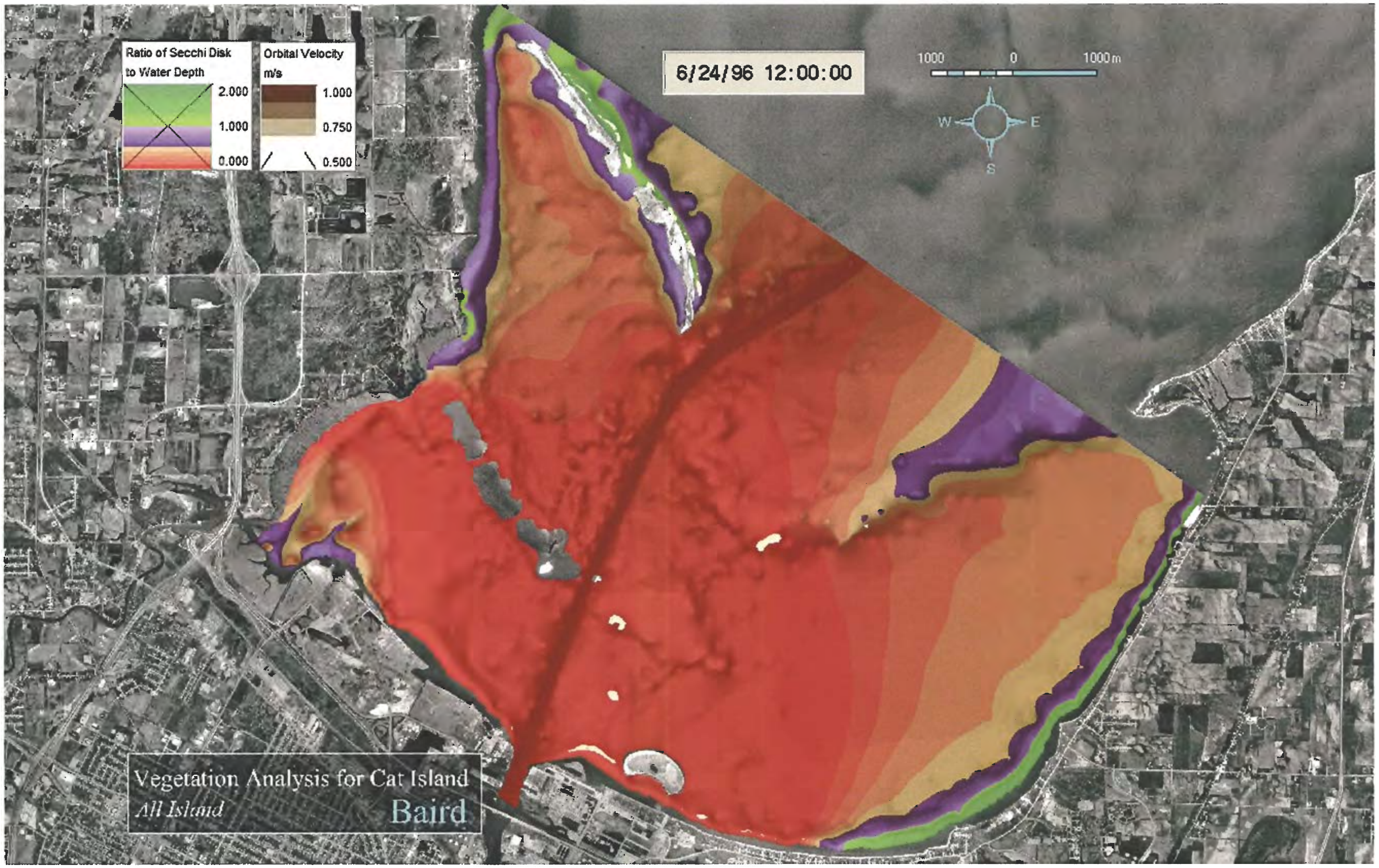


Figure 8.6 Vegetation Analysis for Run 2 – All Islands

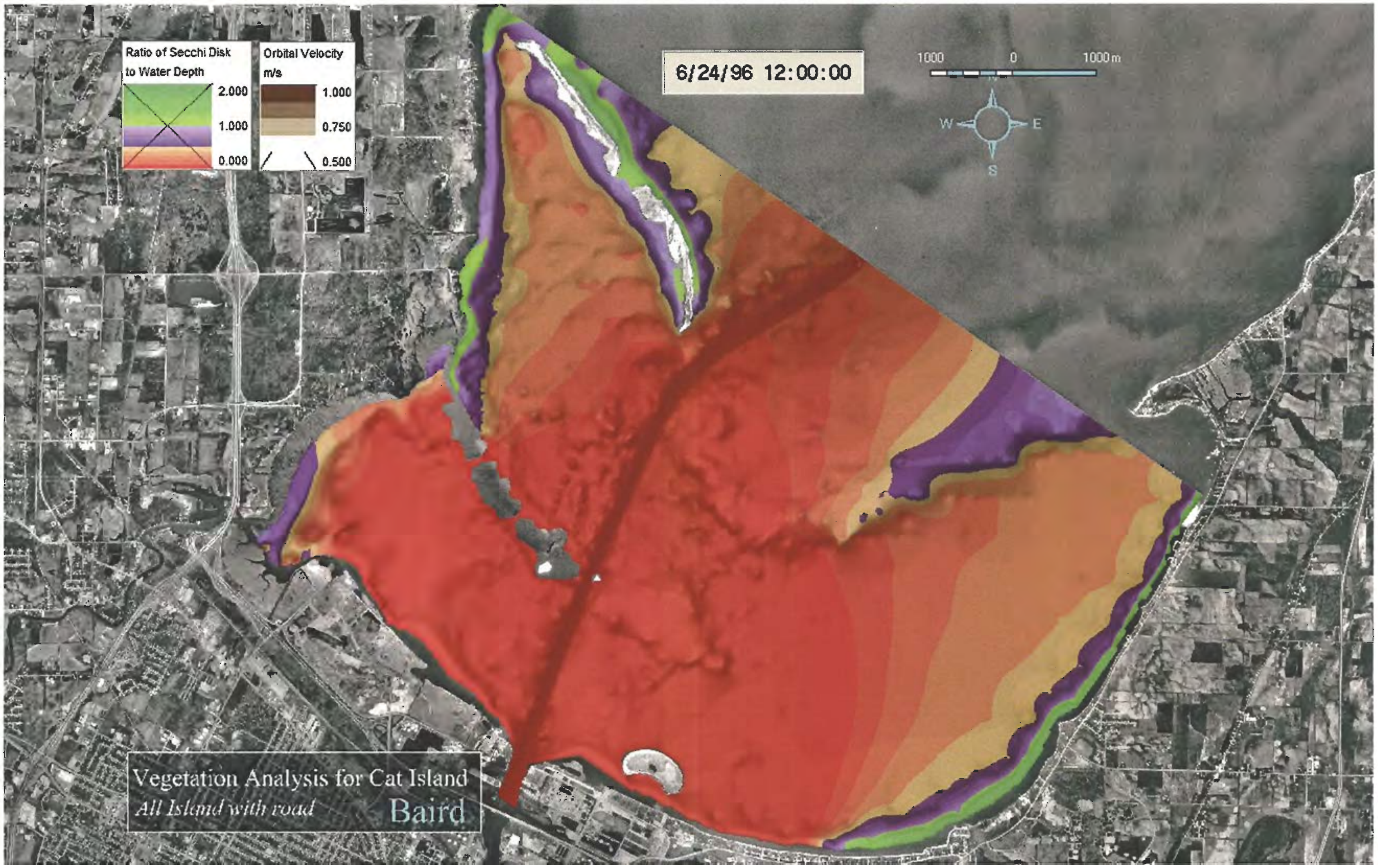


Figure 8.7 Vegetation Analysis for Run 2 – All Islands with Road

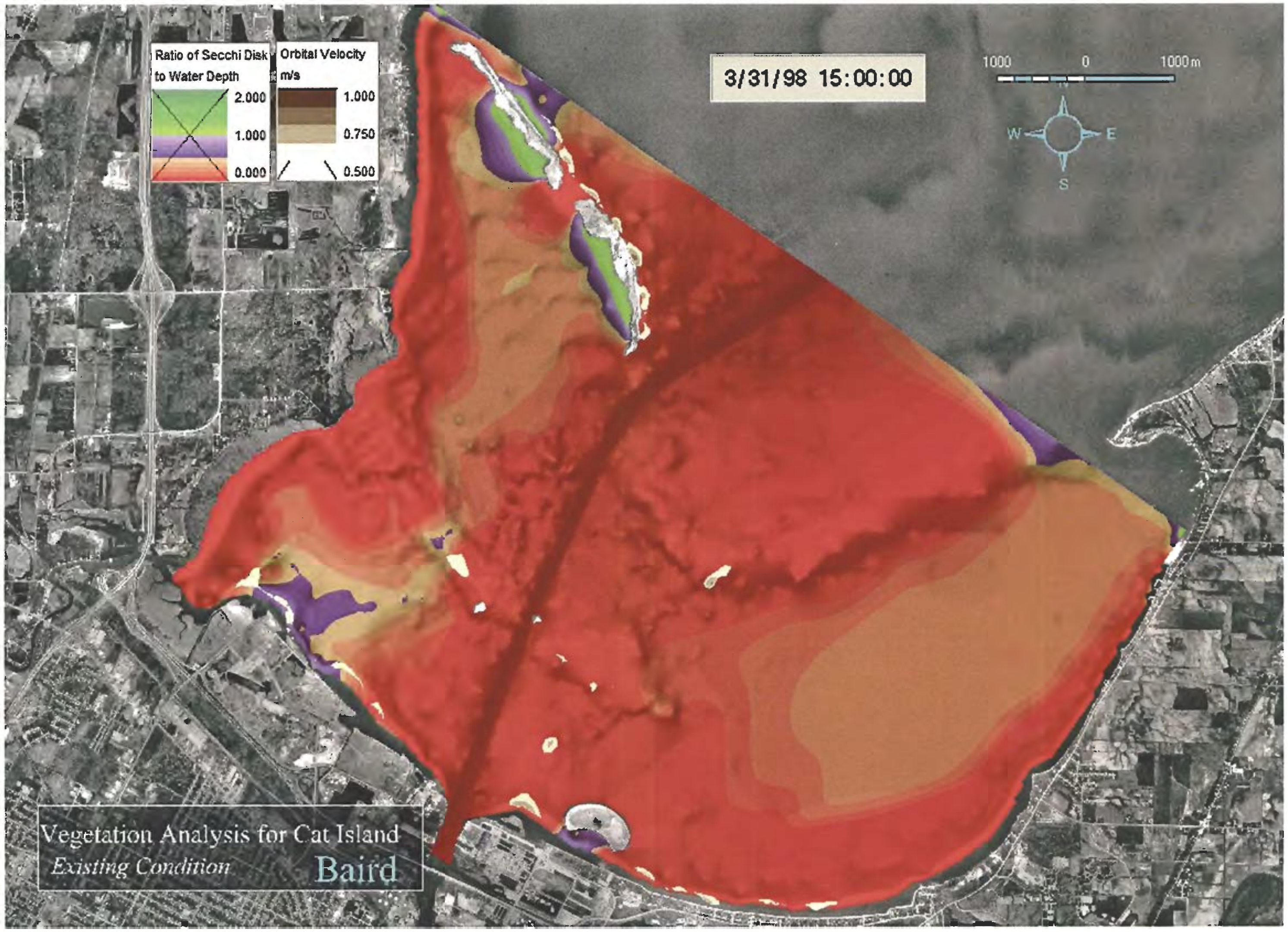


Figure 8.8 Vegetation Analysis for Run 3 – Existing Condition

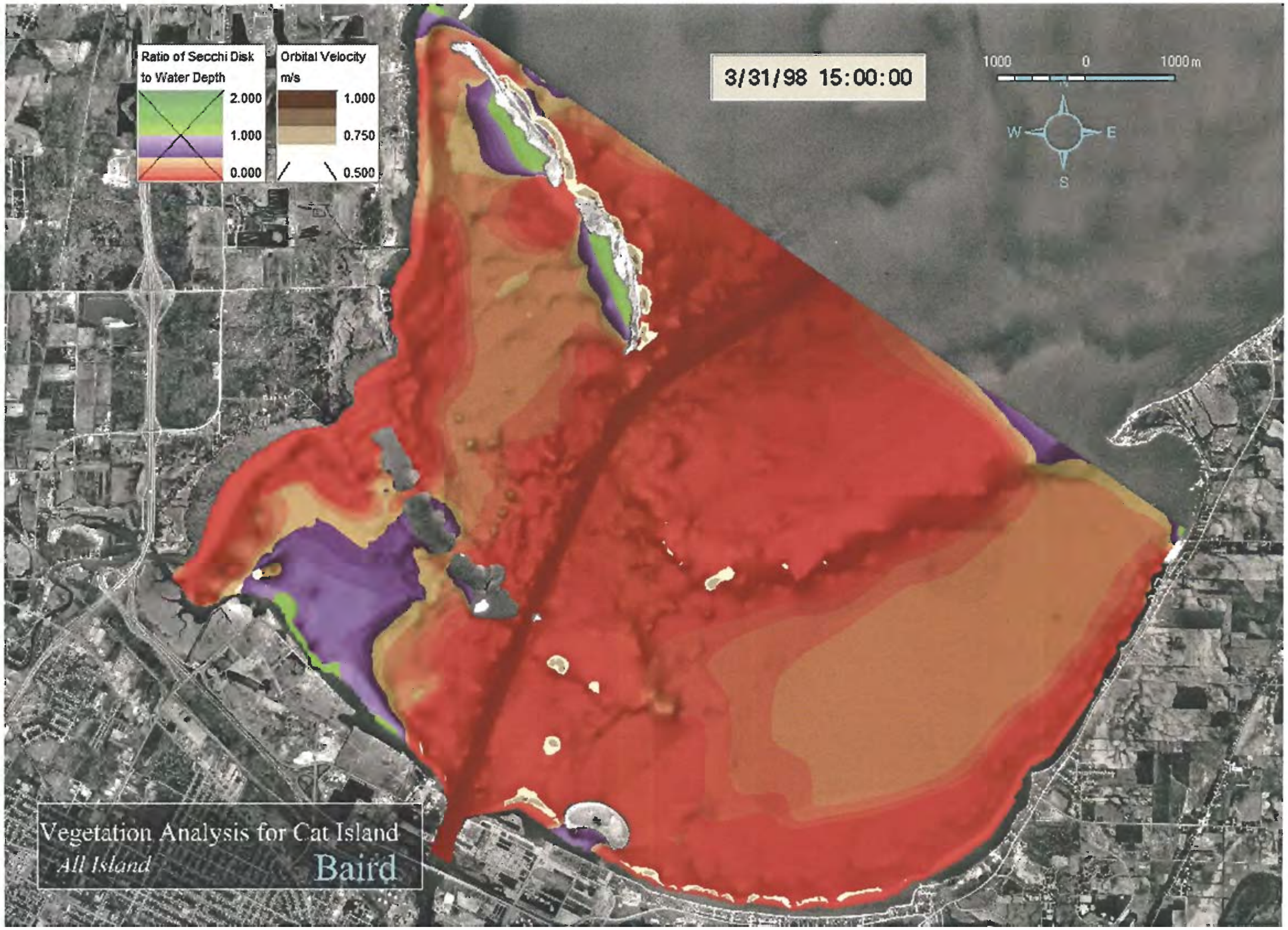


Figure 8.9 Vegetation Analysis for Run 3 – All Islands

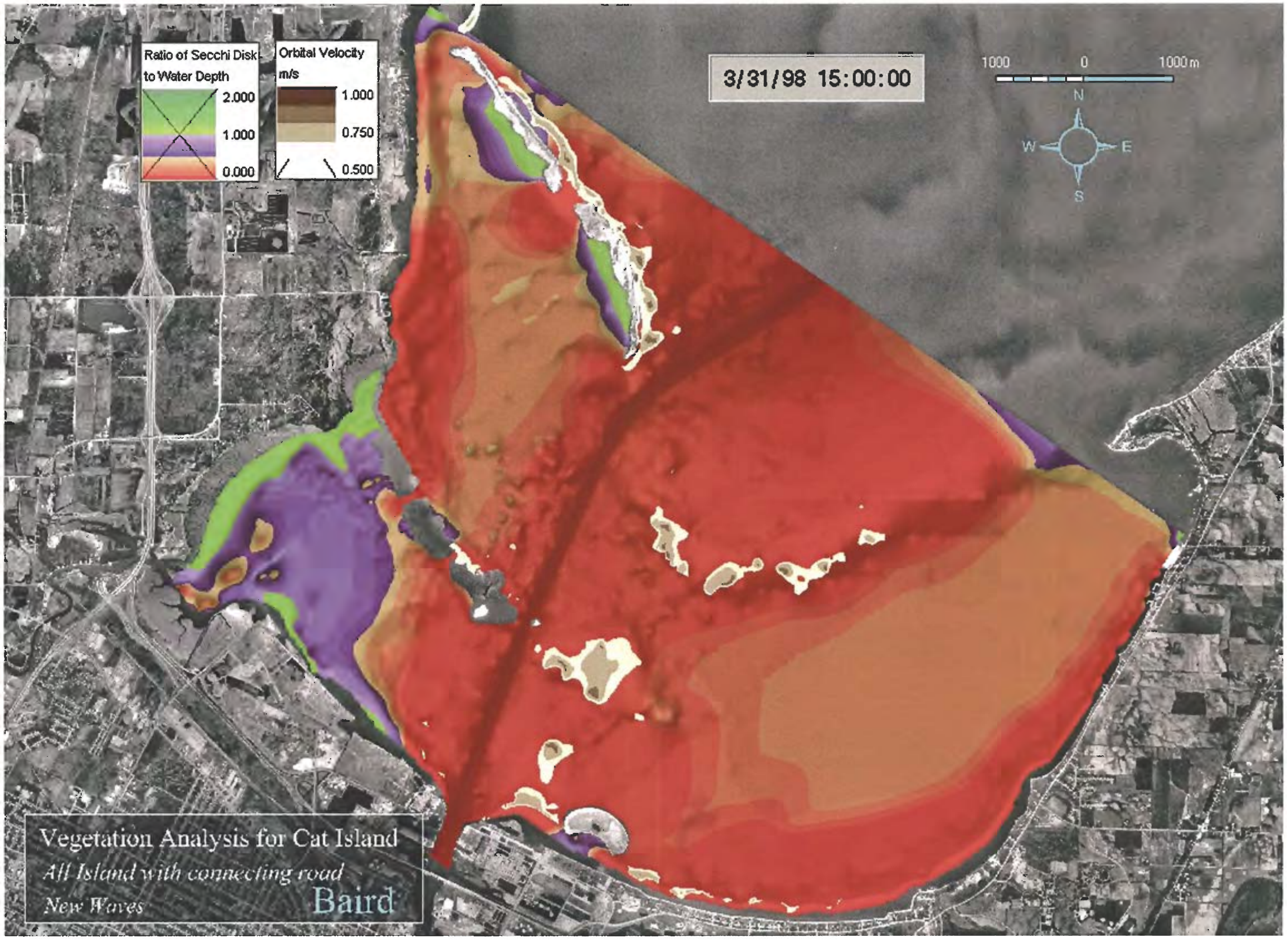


Figure 8.10 Vegetation analysis for Run 3 – All Islands with Roads

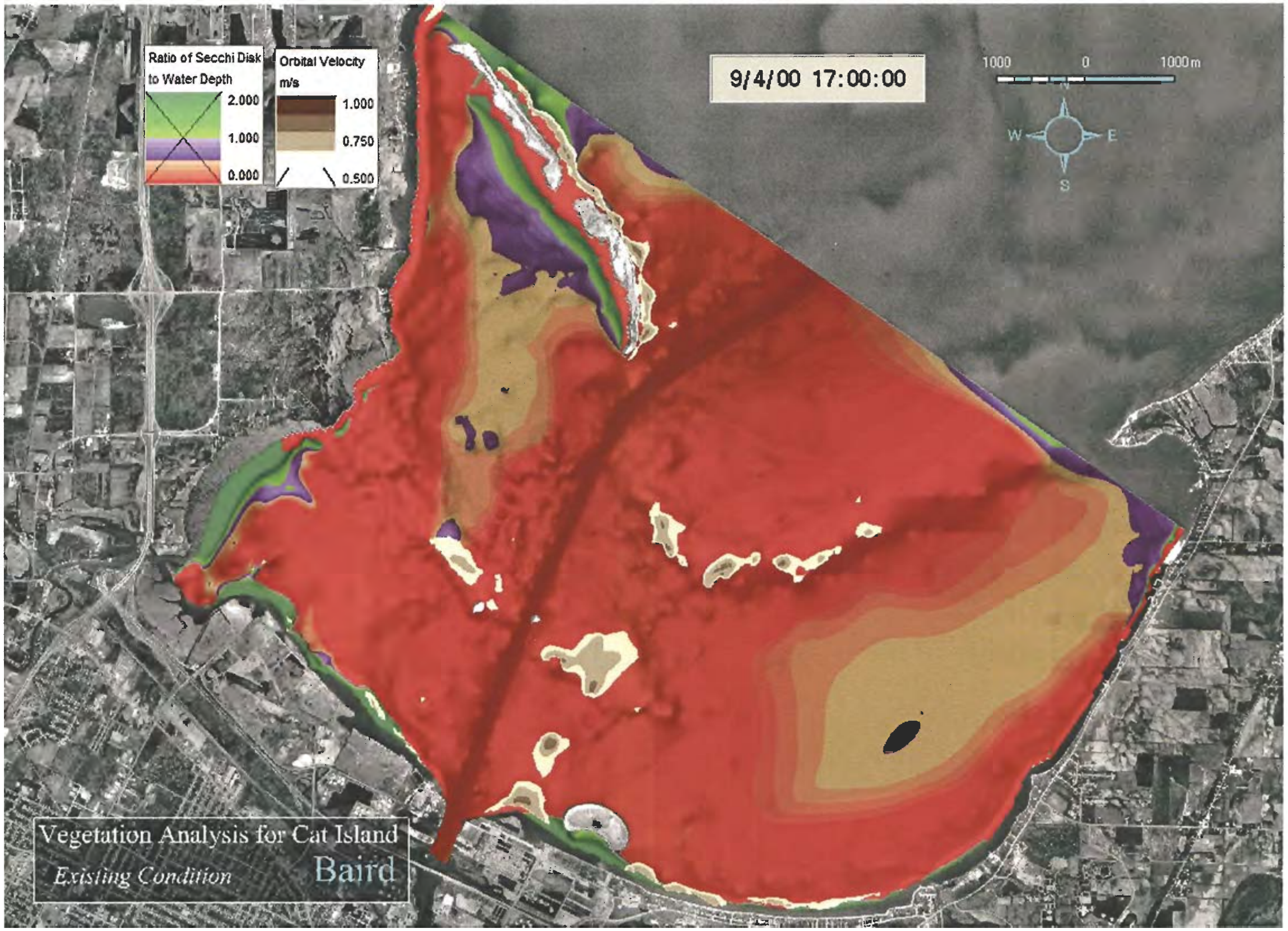
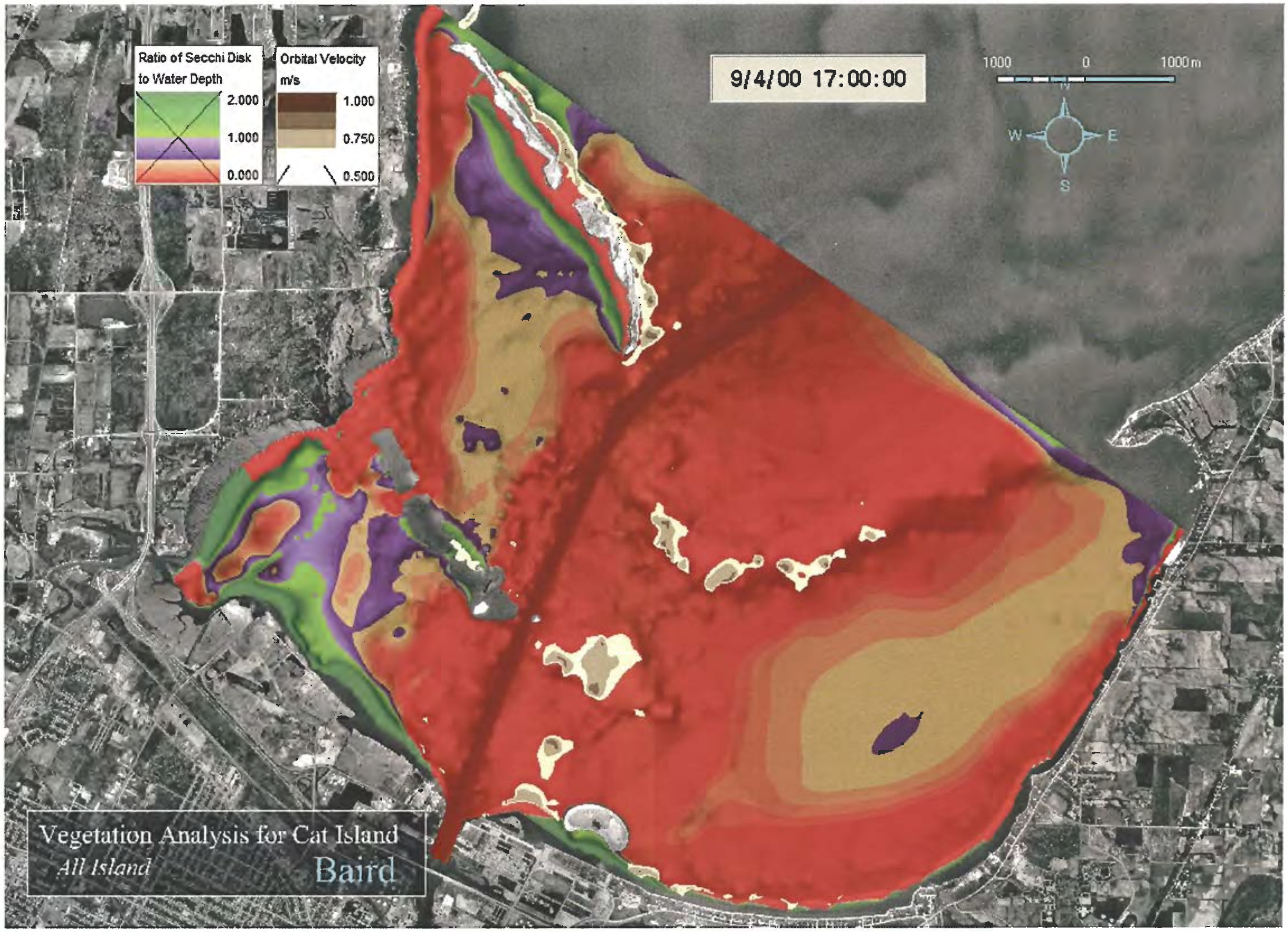


Figure 8.11 Vegetation Analysis for Run 4 – Existing Condition



8.12 Vegetation Analysis for Run 4 – All Islands

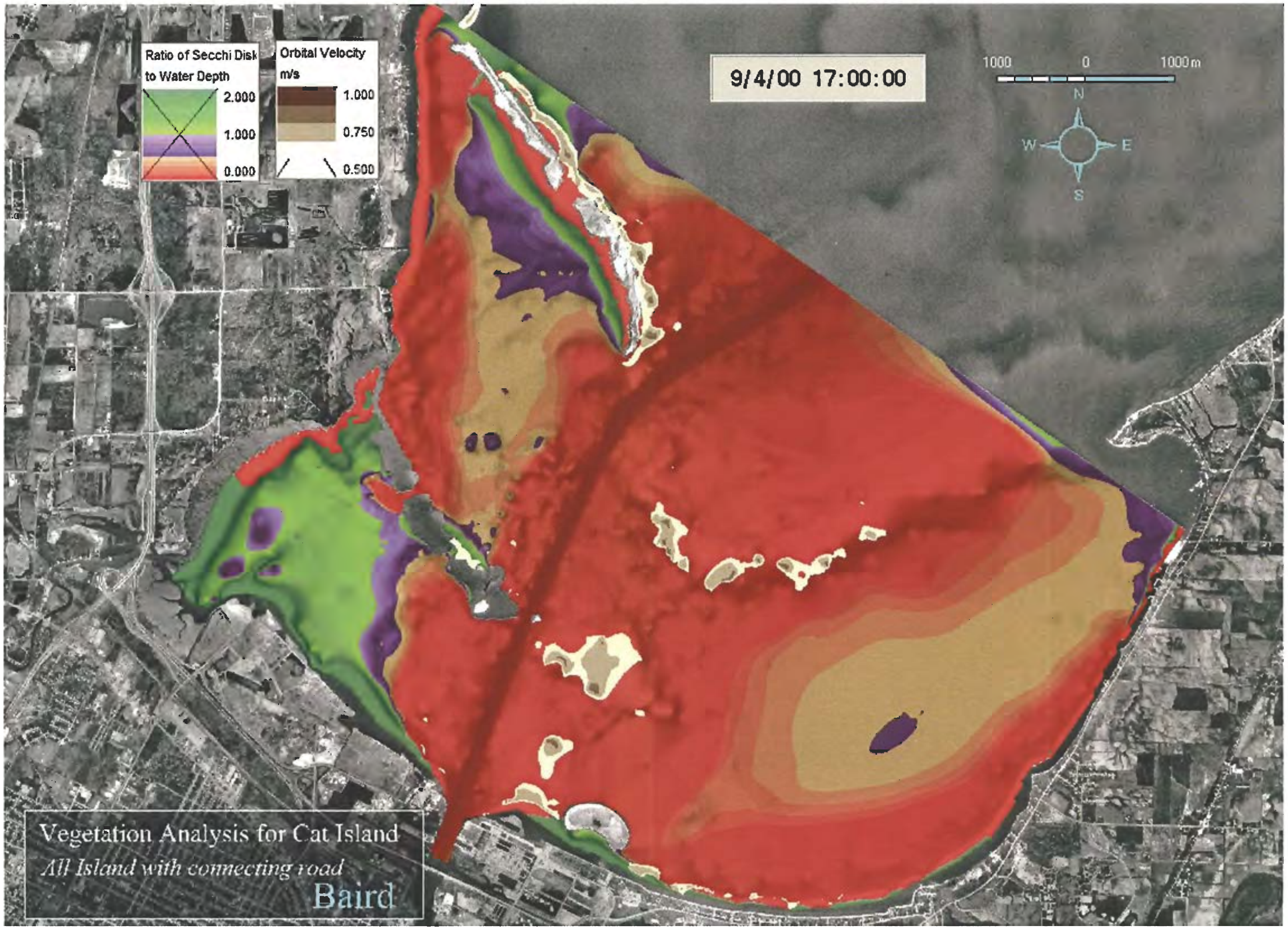


Figure 8.13 Vegetation Analysis for Run 4 – All Islands with Roads

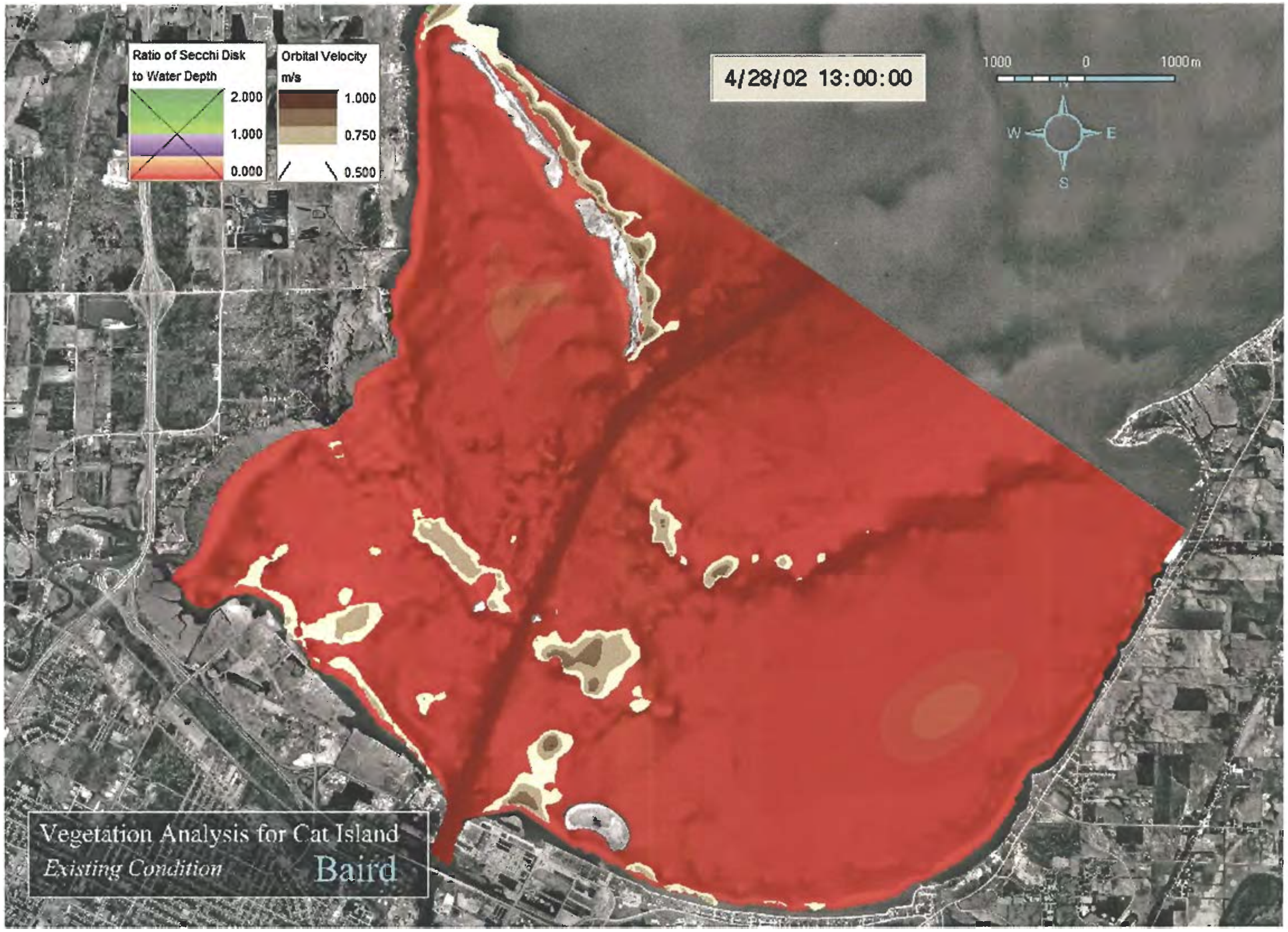


Figure 8.14 Vegetation Analysis for Run 5 – Existing Condition

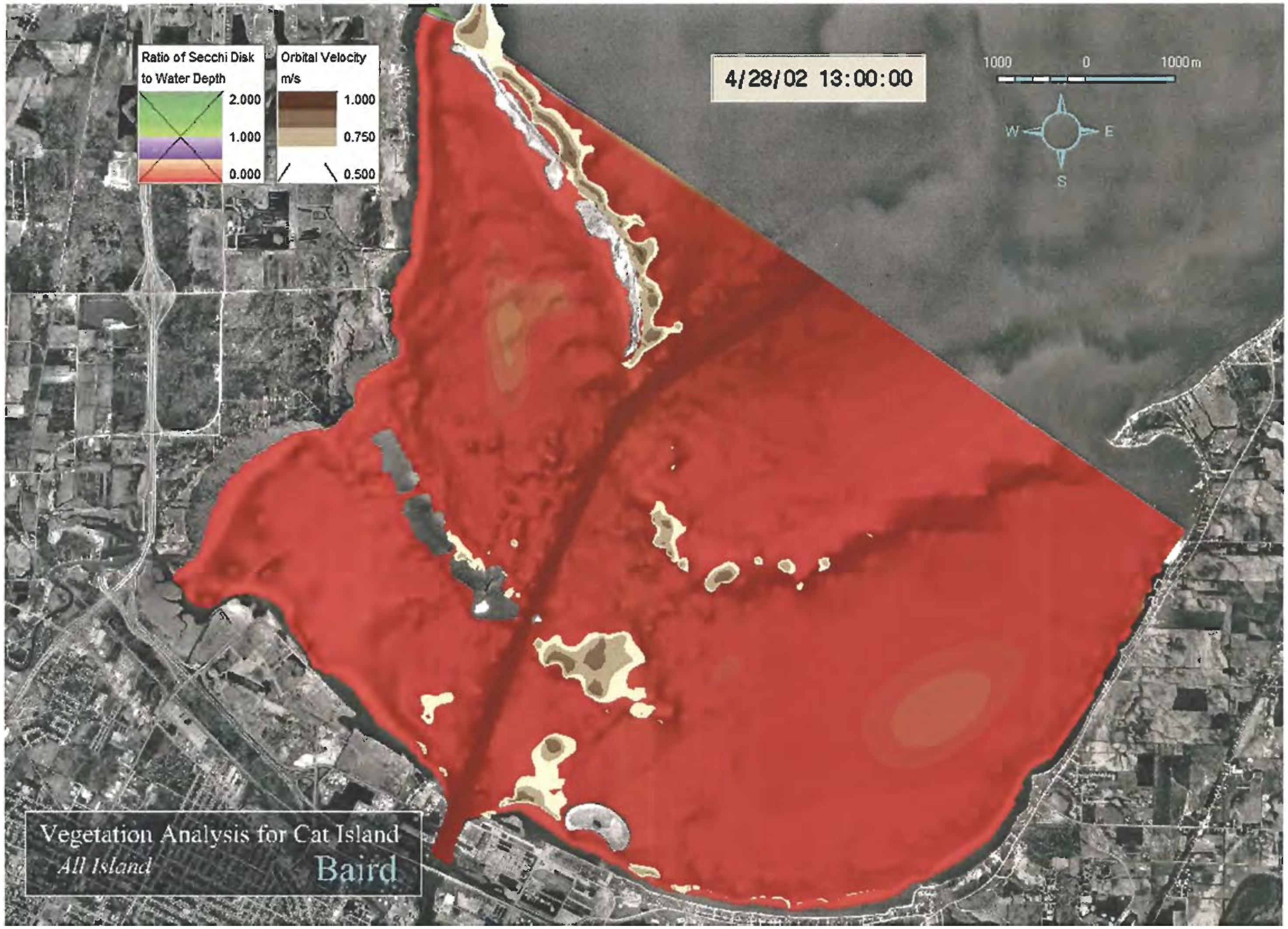


Figure 8.15 Vegetation for Run 5 – All Islands

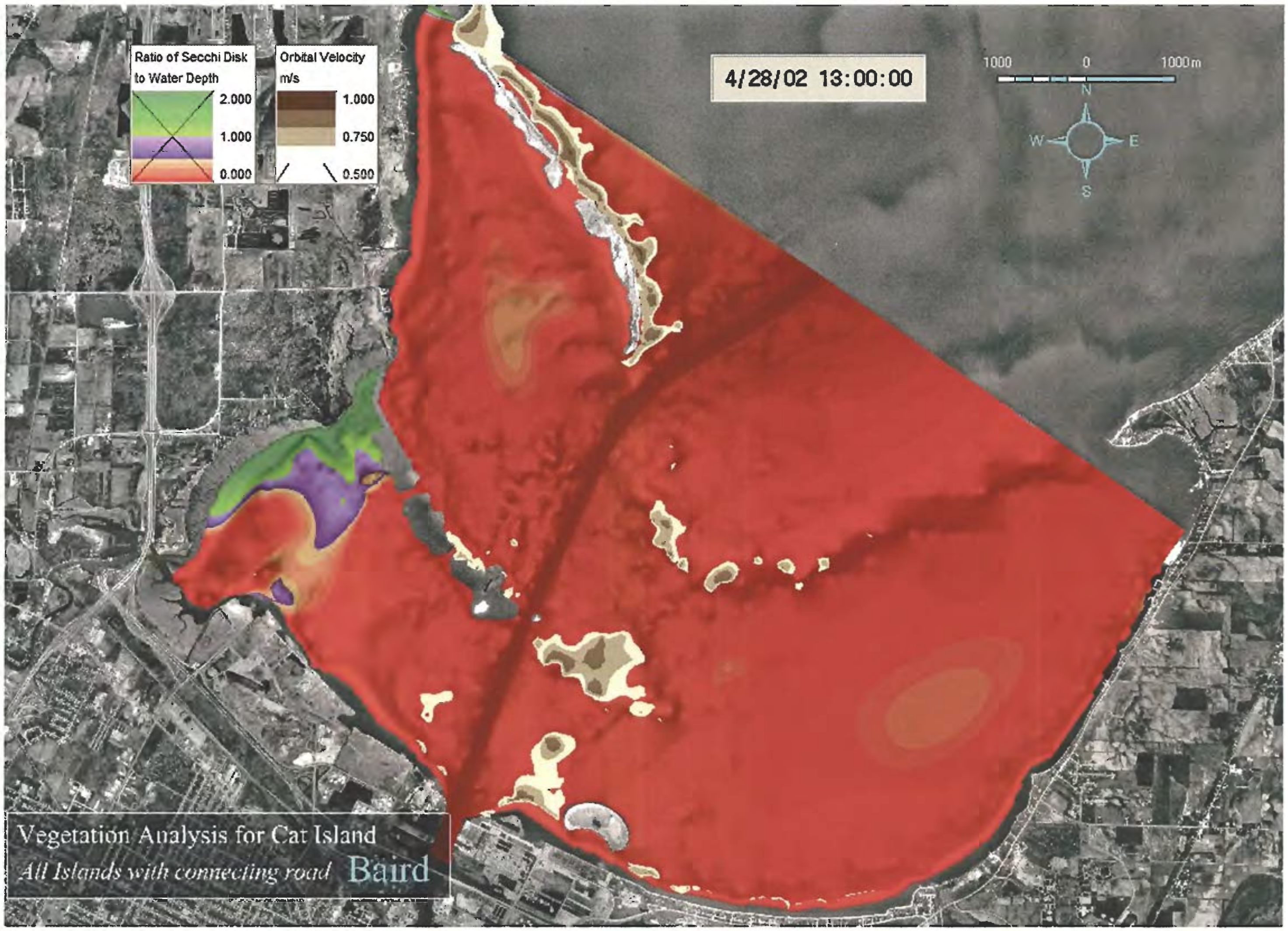


Figure 8.16 Vegetation Analysis for Run 5 – All Islands with Roads

9.0 DESIGN DEVELOPMENT

9.1 Island Design Layouts

There are three key objectives of restoring the Cat Island Chain:

- Creating the conditions for re-establishment of emergent and submerged aquatic vegetation southwest of the Cat Island Chain;
- Providing capacity for placement of clean dredge spoils of Green Bay Federal Shipping Channel dredging activities;
- Restoring habitat associated with the islands.

The initial goal of the project was to restore the Cat Island Chain to their historic original position. The historic Cat Island chain perimeter boundaries have been established by US Fish & Wildlife and Brown County. This boundary is presently being utilized in an application to obtain a Lake Bed Grant. A Lake Bed Grant is required prior to placing any fill materials on the existing lakebed.

In 2002, Baird prepared an "Initial Design Development and Concept Evaluation" report, which included a conceptual island chain restoration design. Figure 9.1 displays this 2002 design. Drawings from this report are included in Appendix G.

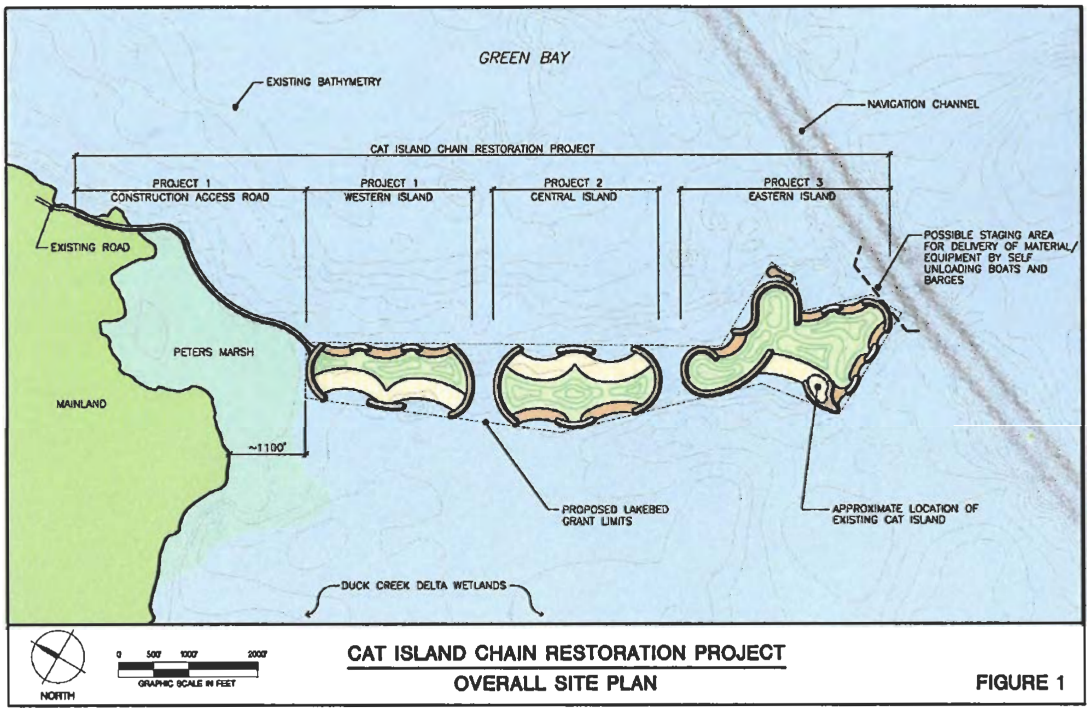


Figure 9.1 – Conceptual Plan - Baird, 2002

During this Design Development Phase of the project, the 2002 plan has been revised based upon the expanded technical analysis previously described in this report. The primary revisions include:

- The use of stone headlands, rather than near shore parallel breakwaters, to contain proposed beach material and increase storage capacity;
- Beach cells on the exposed northeast side of the islands consist of coarse gravel material and beach cells on the southwest side will mostly consist of the clean dredged sand placed in the islands and to a lesser extent fine/coarse gravel material;
- Beach orientation, design and layout are based upon additional wave analysis completed as part of this Design Development phase of the project;
- The shore access road between the west island and the shore will be preserved after the construction phase in the form of a series of islands to close this gap, preventing significant circulation along the shore from the north.

Figure 9.2 displays the Preliminary Plan that was prepared following the completion of the technical analysis. The perimeters of the islands are composed of stone headlands and three different beach types. Beaches consist of imported material (coarse/fine gravel and coarse sand). The entire island chain is within the originally proposed Lake Bed Grant limits. All drawings for this Preliminary Plan are included in Appendix H.

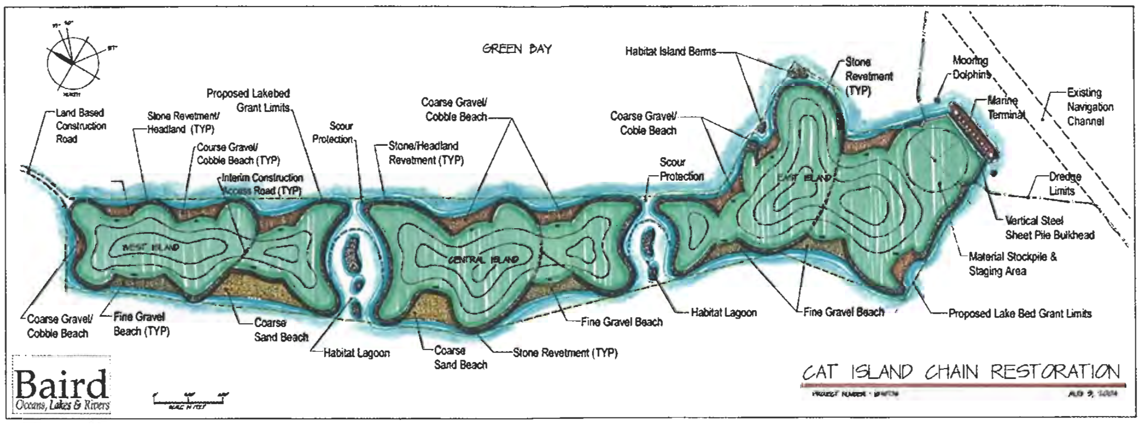


Figure 9.2 – Preliminary Plan

A workshop was conducted on August 3rd, 2004 with the US Army Corps of Engineers, US Fish & Wildlife, Brown County, Department of Natural Resources and Baird & Associates to review the technical analysis and the Preliminary Plan. It was decided, for the purposes of habitat creation and ease of construction, to design the perimeter of the islands to be exposed to the southwest sides and create shallow sloped beaches comprised of dredge sand material. This design would decrease construction costs by reducing the length of construction access roads and eliminate the need for imported beach material along the southwestern perimeters. Flat-sloped natural beaches would also provided ideal habitat for a variety of desirable shore birds.

Since the anticipated dredge material is likely to consist of very fine grained material, the slope of the proposed beaches will be much flatter than the slopes indicated in the Preliminary Plan which utilized a coarser imported beach material to create steeper slopes and additional storage capacity.

In order to include the flatter sloping dredged sand beaches and maintain storage capacity in the islands similar to that provided in the Preliminary Plan, a Revised Plan was developed. This plan incorporates extended beach confining structures to contain the sand dredge material at much milder slopes on the southwest side of the islands. The original Lake Bed Grant application will need to be revised by increasing the width to accommodate the new footprint of proposed islands. Although the footprint of the revised plan extends beyond the original lakebed grant limits, the water line around the islands will be similar to the original lakebed grant limits.

During the final design phase an option may be considered for the east island. The Revised Plan suggests that the southwestern perimeter consists of a dredge sand beach. As an option, the perimeter could remain as gravel beaches contained by stone headlands as shown in the Preliminary Plan. This may be an attractive option due to deeper water depths in that vicinity, the jetty length required to contain dredge sand and the potential for dredge sand to migrate back into the navigation channel. The Lake Bed Grant Limits would not have to be expanded as much if gravel beaches were constructed in lieu of dredge sand beaches. A final decision on the form of the island perimeter for the East Island should be made following the monitoring of the west and central island beach development.

Alternatively, additional storage capacity could be added to the project by constructing extended jetties and efficiently utilizing the area within the proposed Lake Bed Grant limits southwest of the east island.

This Revised Plan is displayed in Figure 9.3. Detailed plans, cross sections, optional beaches and revised Lake Bed Grant limits are indicated in Figures 10.1 through 10.10.

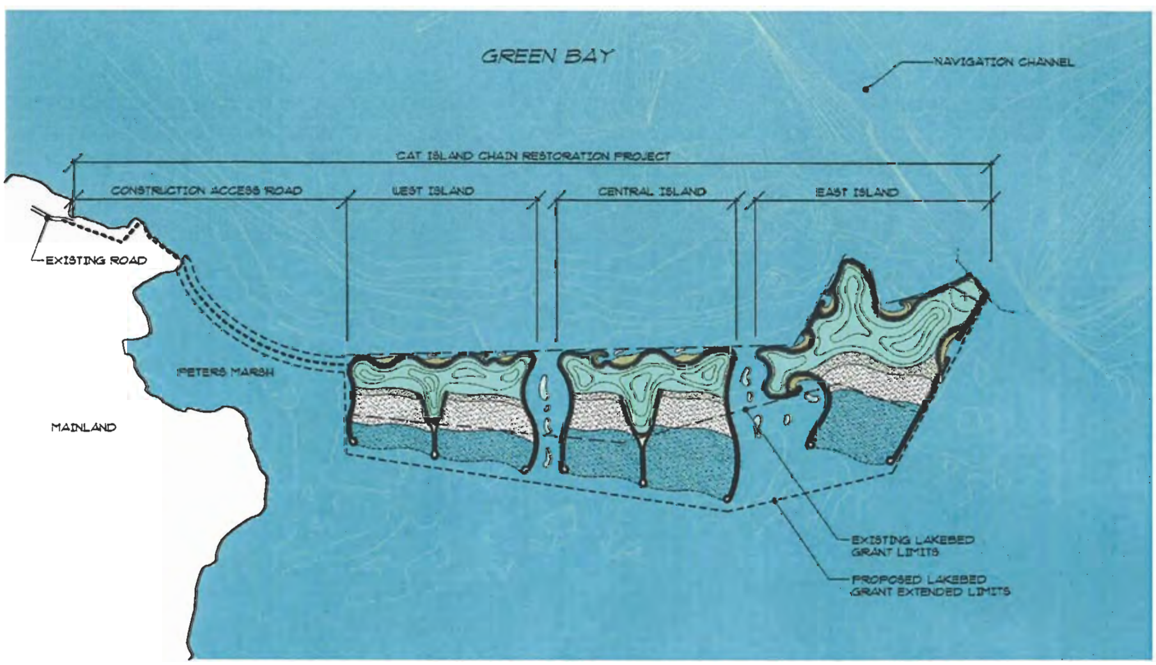


Figure 9.3 - Revised Plan

Both the Preliminary Plan and the Revised Plan include coarse gravel beaches and revetments along the northeastern perimeter of the islands. Between the islands a 300-foot wide gap, or circulation channel, has been incorporated to deter predator and pedestrian access between islands and to promote water circulation. Gravel/cobble material is included within these gaps to create island berms to provide additional habitat for birds that are suited to smaller islands. Due to flow velocities through these gaps, during storm set-up and surge events, additional stone will be placed on the lake bottom to provide scour protection. The gap between the islands will have a depth below low water in the range of 1 to 2 ft allowing small fishing boats to pass between the islands during low water and larger craft during higher water levels. The ideal and ultimate depth between the islands could be controlled by allowing flows to scour out the existing sediment until sufficient depths are achieved, followed by placement of the stone bed protection and the island berms.

During the construction phase, access between islands will be required. Temporary construction access roads, with circulation culverts, will be constructed though these gap areas. Once access is no longer required these temporary connections will be removed and the excess material utilized to create habitat islands and provide scour protection. See Figure 10.7 for drawings that indicate construction sequencing.

The beaches proposed for the entire island chain have a great deal of potential to provide varied and specialized habitat. Beach slopes will vary from flat slopes consisting of fine-grained material to steeper slopes with coarser grained material. From preliminary information provided by the US Fish & Wildlife Service, these variations in slope and particle size are attractive to numerous bird species.

During the final design phase, as well as during and following construction, individual beach cells can be designed on a detailed level to accommodate desired bird species. Refinements could include: adjusting beach slopes, integrating sand and stone materials, widening beaches, creating wetland lagoons, creating island berms, introducing vegetation or importing logs and deadfall. Alternatively, this detail in topography and substrate could be created through time through experimentation and monitoring to develop the most desirable and successful habitat.

Headlands between the beach cells will offer diversity to the adjacent topography and have the potential to support native tree and shrub species. Figure 9.4 depicts a conceptual beach detail that incorporates several of these refinements.

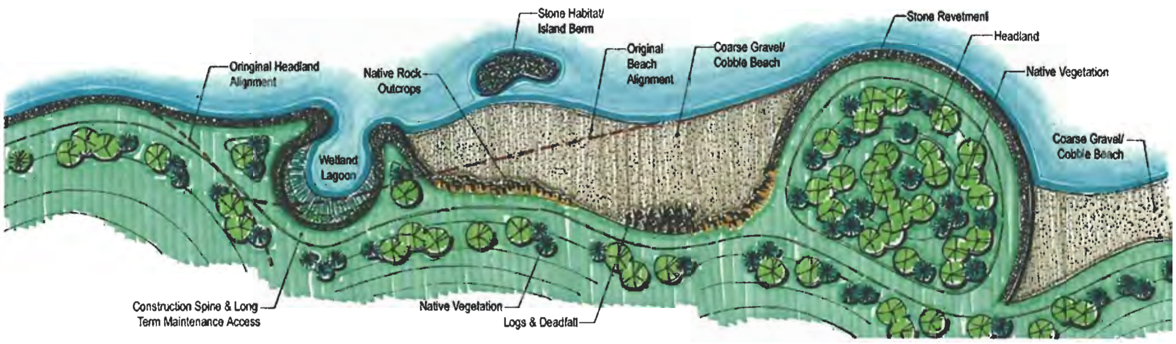


Figure 9.4 – Island Beach Detail

The final island elevation is expected to vary from +10 to +15 ft, LWD to be compatible with the regional landscape, provide natural diversity and provide additional storage capacity. A detailed grading plan will be developed during the final design phase.

9.2 Storage Capacity

The following table summarizes the storage capacities for both the Preliminary and Revised Plan. The extent of the jetties in the Revised Plan was established to create an Island Chain with relatively the same storage capacity as the Preliminary Plan. The dredge sand beach on the east island shown in the Revised Plan could be optional as mentioned above. The gravel beaches shown in the Preliminary Plan could be implemented as an alternative on the east island.

Since the Lake Bed Grant limits must be revised to accommodate the flat beaches proposed on the Revised Plan, the proposed marine terminal is located closer to the existing Navigation Channel to minimize required dredging during the construction of the facility.

Table 9.1 displays the storage capacity anticipated for the three islands as shown for both the preliminary and revised plans.

Table 9.1 – Island Storage Capacity Summary

Island	Storage Capacity (cubic yards)
West Island	630,000
Central Island	720,000
East Island	1,000,000

9.3 Physical Model Results & Island Design Requirements

Review and analyses of the wave climate, water levels, material availability and physical model study, as well as consideration of construction issues has been undertaken to support preliminary design development for the island perimeter (construction access roads, stone headlands and beaches).

The preliminary designs are based on the estimated 20-year storm event as noted in Section 5.0 consisting of:

- Hs/Tp = 3.3 ft / 6 s along the "exposed" NE side of the islands; and
- Hs/Tp = 2.0 ft / 4 s along the "sheltered" SW side of the islands.

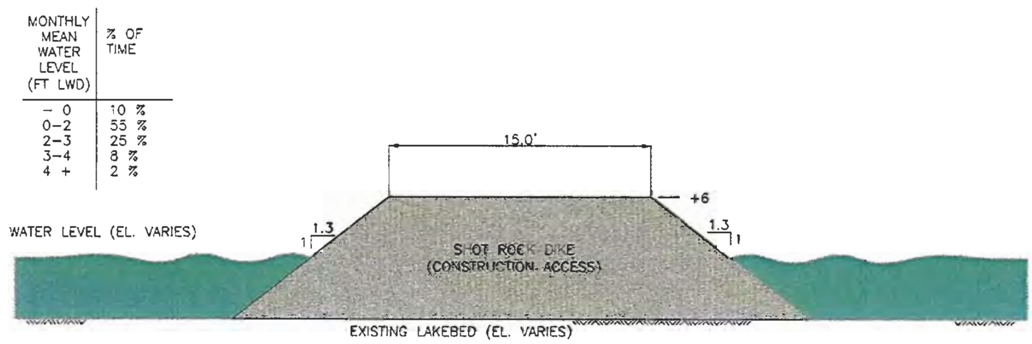
9.3.1 Construction Access Road

Depending on the mode of material delivery and construction methodologies adopted, a construction access road may be required. This construction access road would extend from the mainland to Western Island as indicated on Figure 10.1. This structure would likely be constructed of quarry run or shot rock, with its crest width established by equipment requirements and a crest height several feet above prevailing lake levels at the time of construction. At this time, a minimum crest width of 15 ft and a crest elevation of +6 ft LWD have been assumed. Refer to Figure 9.5. The crest width of 15 feet has been selected to allow two-way truck traffic and provide space for loaders and excavators to continuously place stone as delivered by trucks.

Because this is a temporary construction access road, it is proposed that armor stone not be placed on the exposed perimeter as a cost saving measure. It is likely that periodic maintenance will be required along this perimeter following significant storm events. During long periods of time when the access road is not required, temporary gaps will be provided in the road to deter predator and pedestrian access to the islands.

Whether the temporary construction access road is required or not some form of road will be required to create a series of island berms to significantly reduce the potential for flow between the west island and the shore, restoring a condition that existed before the Cat Island Chain was eroded (i.e. where the area between the west island and the shore consisted of dense emergent vegetation and low flows). This is necessary to achieve the required water clarity conditions, to the southwest of the west island along the shore, for restoration of aquatic vegetation (see Section 8).

A similar cross section will also be utilized to provide access for the construction of the island perimeter stone revetments, headlands and extended jetties. These structures will remain in place and become an integral part of the final island perimeter and beach containment system.



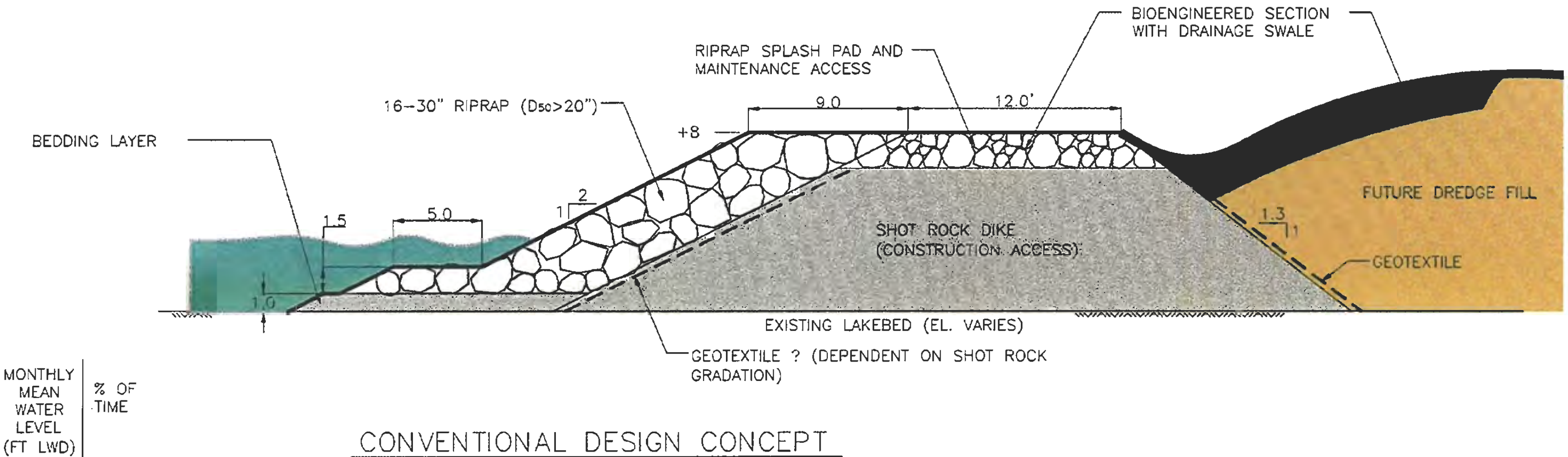
Note: Elevations are in ft, LWD

Figure 9.5 – Construction Access Road – Preliminary Design

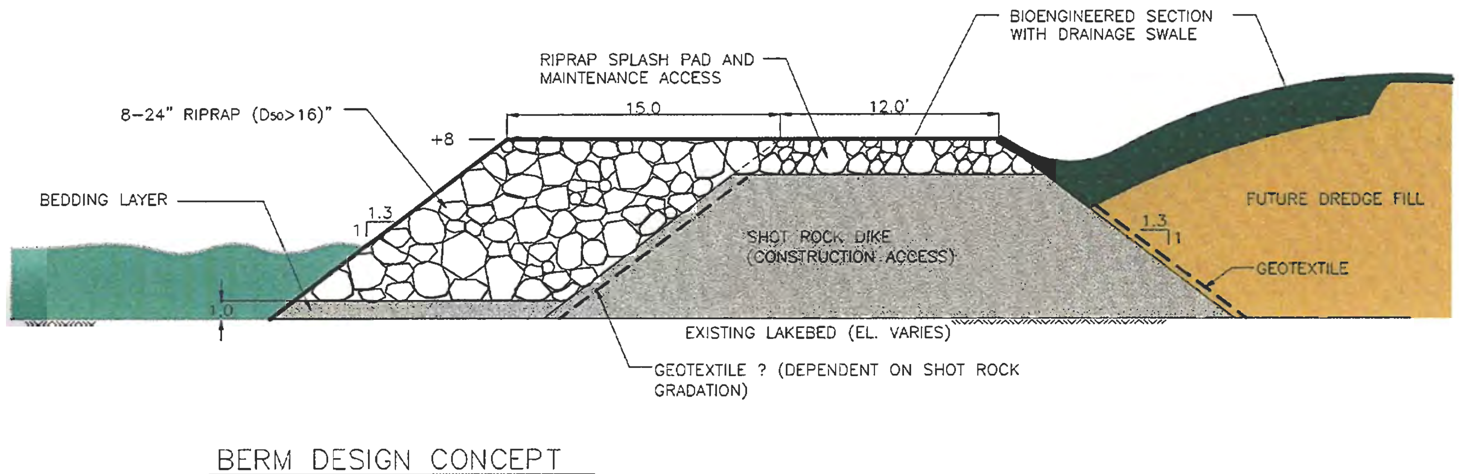
During the final design phase it may possible to optimize this cross section. If special construction sequencing and material delivery scheduling is utilized there are opportunities to reduce the width and/or crest height of this section and therefore reduce cost. This may be accomplished though the refinement of the revetment design to allow excavators to place stone while trucks maintain delivery of materials and/or the use of a one way roadway system with periodic bump-outs to allow trucks to pass. If the construction road is placed during periods of low water it may be possible to reduce the crest height, which will also reduce stone quantities and costs.

9.3.2 Stone Revetment/Headland Cross-Sections

Two alternative revetment and headland cross-sections have been developed, including a "conventional" design concept and a "berm" design concept. The latter allows the use of smaller riprap with a wider gradation, but requires an increase in the overall quantity of riprap. Figure 9.6 presents these two alternative cross-sections.



MONTHLY MEAN WATER LEVEL (FT LWD)	% OF TIME
– 0	10 %
0–2	55 %
2–3	25 %
3–4	8 %
4 +	2 %



Note: Elevations are in ft, LWD.

Figure 9.6 – Revetment/Headland Cross-Sections – Preliminary Design Concepts

The conventional design has an outer slope of 2:1, while the berm design has an outer slope of 1.3:1 (assumed angle of repose). These steep slopes are intended to minimize quantities and equipment reach requirements. However, flatter slopes could certainly be considered to provide easier access to/from the water for wildlife. With the berm design, the slope will evolve naturally to have milder sections as it is exposed to wave attack at different lake levels.

Both designs have a crest elevation of +8 ft LWD. This elevation has been selected, on the basis of the physical model results, to prevent damage to the structure or erosion of sand dredge material behind the structure due to wave overtopping.

The advantage of developing two stone revetment/headland designs is that it provides the opportunity to bid both alternatives and select the lowest cost solution. It may be possible that the berm concept will be less expensive to construct then the conventional design. Although there is a greater quantity of stone to transport to the site with the berm design, it may be less expensive to produce the stone due to the wider gradation. Stone placement is also less time consuming than the conventional design.

It should be recalled that the cross section profile of the berm concept re-shapes during initial storm events and assumes a somewhat “S” curved profile. See the Physical Model Section 4. The conventional design is intended to retain its original constructed slope and shape.

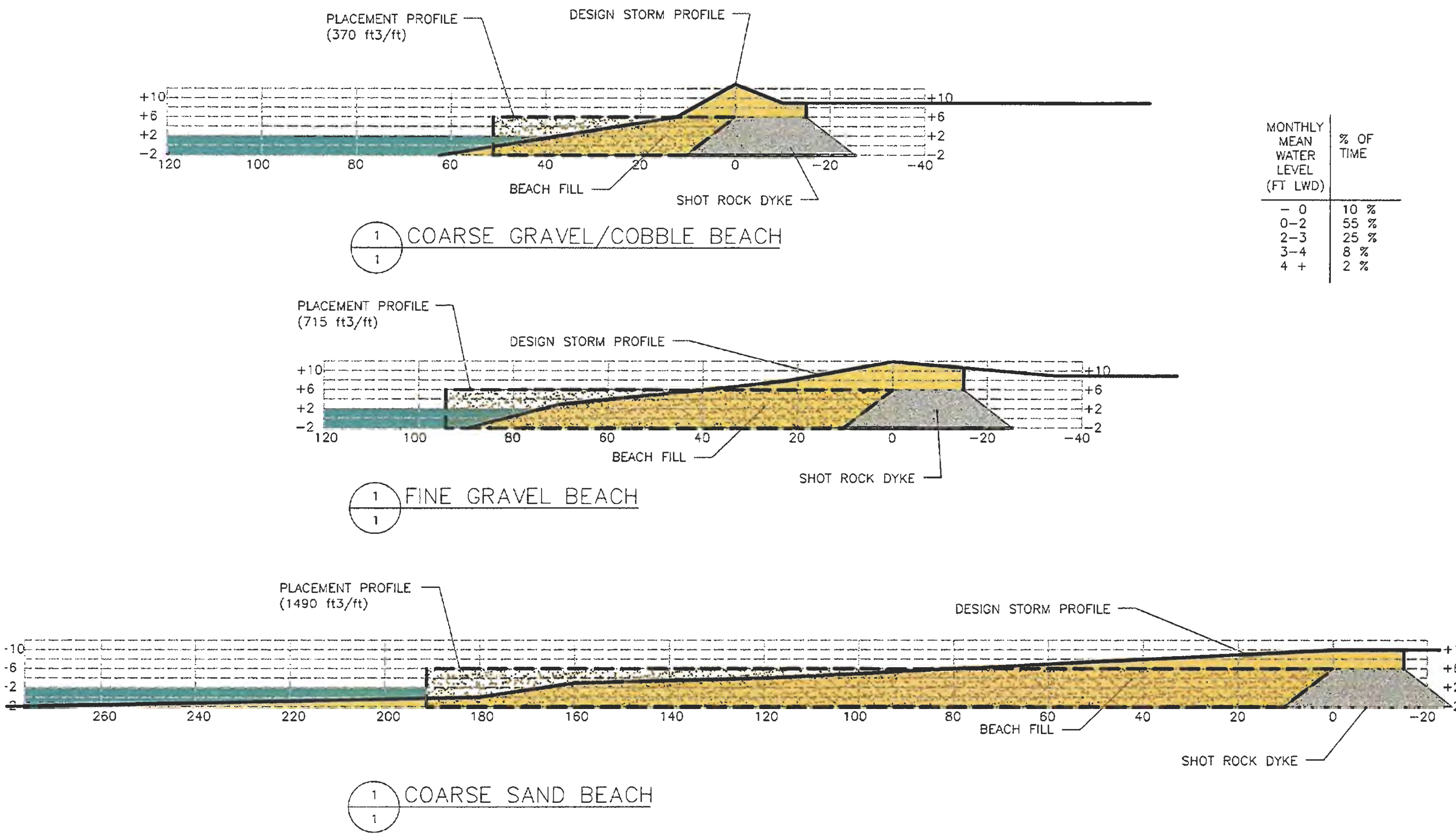
Following the placement of the armor stone on the exposed perimeter slope of the revetment/headland, additional armor stone will be placed on the surface of the construction access road to provide a splash apron. This splash apron has been incorporated to allow the over-all crest height of the revetment to be lowered to reduce cost. During extreme storm events wave overtopping may occur. Excess water from overtopping would be collected in a shallow swale landward of the revetment structure and drain back to the lake. This swale would be bio-engineered during the final design process to withstand overtopping events and reduce erosion of the dredge sand fill. In addition, the splash apron may also be bio-engineered to support plant life during the majority of the time and to regenerate vegetation following extreme storm events.

Both cross-sections show a geotextile filter fabric between the riprap cover layer and the underlying materials. The requirement for a filter layer (geotextile or granular) between the riprap and the quarry run/shot rock core will depend on the gradation of this material, in particular the presence of fines in the rock fill.

9.3.3 Imported Material Beach Cross-Sections

Figure 9.7 presents cross-sections of beach fill placement profiles and estimated storm beach profiles for three different beach fill materials, including:

- Coarse gravel/cobbles (well sorted, $D_{50} > 1$")
- Clean fine gravel (well sorted, $D_{50} \sim 3/8$-1")
- Coarse sand or mixed sand-gravel (material with a significant percentage < 3/8")



MONTHLY MEAN WATER LEVEL (FT LWD)	% OF TIME
– 0	10 %
0–2	55 %
2–3	25 %
3–4	8 %
4 +	2 %

Note: Elevations are in ft, LWD.

Figure 9.7 – Beach Fill – Suggested Placement Profiles and Estimated Storm Profiles

The estimated storm beach profiles are based on the physical model results for a 20-year design event at a 5 to 10-year water level (+6 ft LWD).

9.3.4 Dredge Sand Beach Sections

Along the southwest side of the proposed islands a flatter slope is anticipated, due to the fine sediments of the dredge sand material. The COSMOS numerical model of coastal processes was applied to investigate the cross-shore stability of fine sand beaches on the lee side of the islands. It is important to evaluate the stability of the dredged sand without protection on the lee side of the island during extreme wave attack. The COSMOS model is a deterministic profile model of coastal processes and simulates: wave transformation (shoaling, refraction, friction losses, breaking, wave decay and reformation, run-up and overtopping), hydrodynamics (longshore and cross-shore steady currents including undertow and non-linear orbital velocities) and erosion/sedimentation (considering bed and suspended load, erosion of glacial sediment and a consideration of erosion resistance surfaces).

For application to the lee side of the island, an extreme storm condition (24 hours with an Hs of 2 ft and a period of 3 s) was modeled for three different lake level scenarios corresponding to moderate to very high lake levels (+3, +4 and +5 ft LWD). The model tests were completed for two different assumptions on D50 of the dredged sediment (0.1 mm and 0.15 mm). The assumed initial nearshore/beach profile consisted of a slope of 1:200 below +2 ft and a graded 1:15 slope above +2 ft. The results, showing profile change for the 24-hour period, are shown in Figures 9.8 and 9.9. The results demonstrate that erosion of the upper and steeper 1:15 slope only commences for lake levels of +4 ft or greater. For the model test with a D50 of 0.15 mm the eroded sediment is transported no further than about 80 ft (25 m) beyond the toe of the steep slope (i.e. out onto the flatter slope beyond). For the test with the finer D50 of 0.1 mm, most of the sediment that is transported offshore is confined to within 100 ft (30 m) of the toe of the steep slope, however a small amount is transported further offshore. This numerical model estimates were used to develop the required length and form of the beach containing structures on the southwest side of the islands and also to confirm that losses of beach sediment from the islands would be minimal under extreme storm conditions.

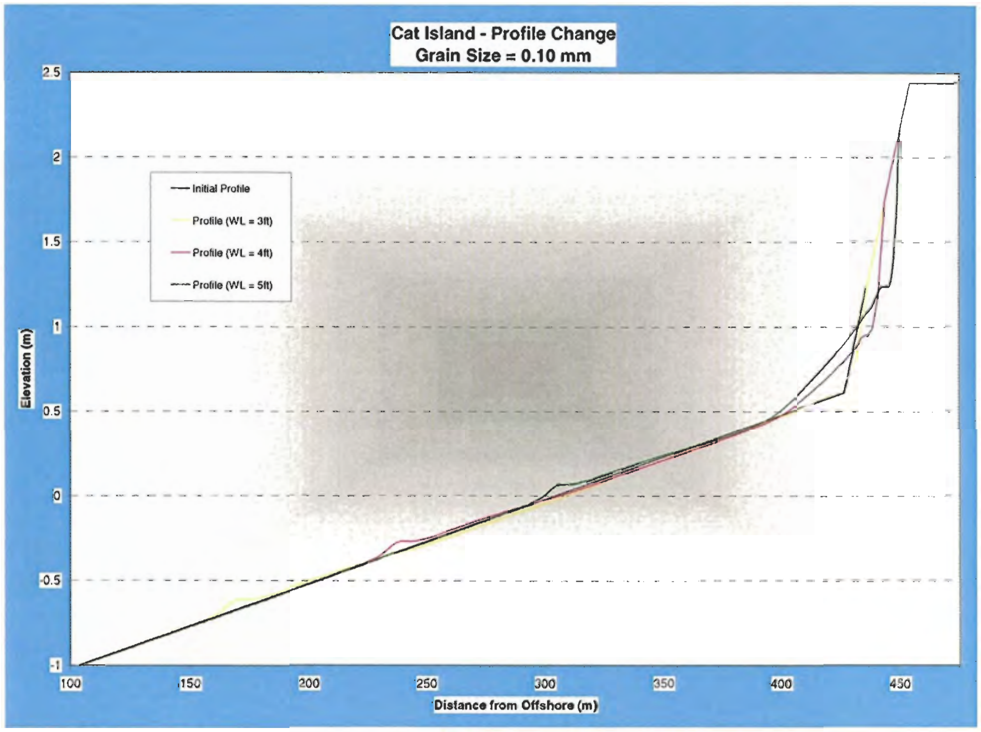


Figure 9.8 – Dredge Material Beach Section Profile Change (d = 0.10 mm)

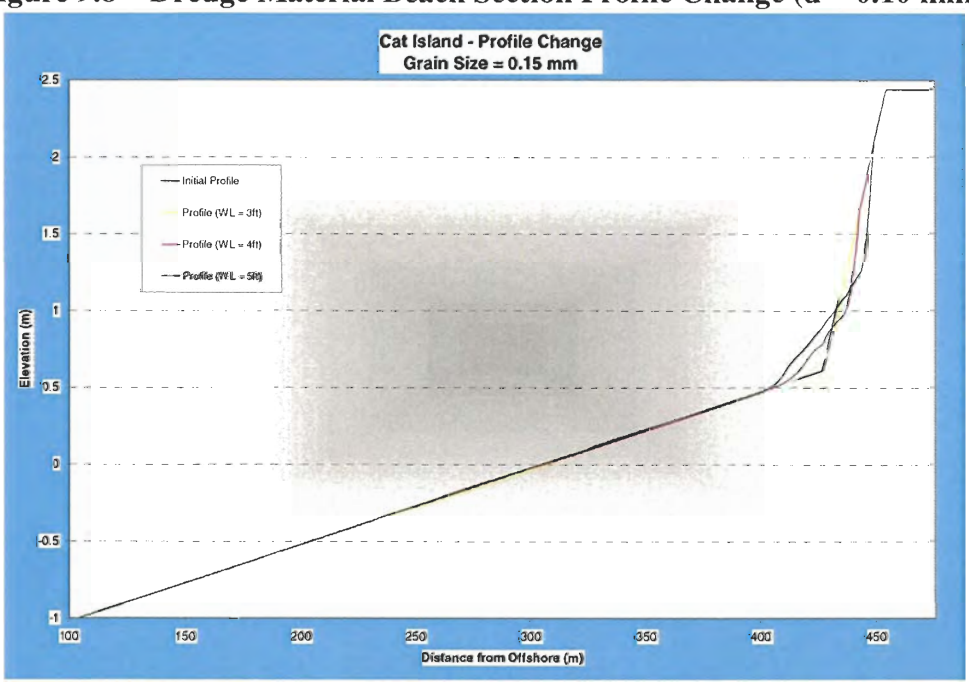


Figure 9.9 – Dredge Material Beach Section Profile Change (d = 0.15 mm)

9.4 Habitat Considerations for Layout & Sections

The updated island design development plan includes a variety of different substrates and slopes to provide a variety of habitat opportunities. The beaches shown include a variety of materials and slopes, along with opportunities to create wetland lagoons, deadfall areas, native rock outcrop areas and island berms.

A goal of the project is to re-create the sheltered area southwest of the proposed islands to promote restoration of submerged and emergent vegetation communities. As indicated in Sections 7 and 8, a connection to the shoreline is necessary to provide the protection required. After the construction period, the construction access road could be altered to provide a series of islands with varying elevations and substrate to provide this protection.

10.0 CONSTRUCTION ISSUES

The primary issues that impact construction and restoration of the Cat Island Chain include:

- Construction Access and Sequencing;
- Material Availability and Costs.

10.1 Construction Access & Sequencing

10.1.1 Land Based Construction –Preliminary Plan

Land based construction involves providing a construction access road from the mainland to the islands for the delivery of construction materials by trucks. Figure 10.7 in displays the possible progression of the project for both the Preliminary and Revised Plan if constructed from land.

In order to provide land-based construction access to the west island, an access road from the mainland is required. A preliminary alignment is indicated on Figure 10.1.

A detailed topographic survey and geotechnical investigation will be required during the final design process to align the access road in an optimum location, refine estimated material quantities and determine if settlement of existing soils can be expected.

In addition to providing access for construction vehicle and material delivery, this access road provides wave protection for Peter's Marsh and most importantly, significantly reduces the flow of sediment-laden water into this area (i.e. providing the necessary water clarity conditions for the recovery of aquatic vegetation as described in Section 8).

Following the construction of the access road, the Preliminary Plan includes construction of containment berms, construction access, stone revetments/headlands and beach protection for the entire perimeter of the west island to accept dredge sand material. In addition, a construction access road or "spine" will be extended from the west island to the east island and the marine terminal.

This construction spine follows the final northeastern alignment of central and east islands. A permanent dredge pipeline can be incorporated into the spine to transport dredged sand material from the marine terminal to each island.

The construction spine provides protection from wave activity for the entire Duck Creek Wetland Area during the initial construction phase. As an option to create additional habitat during the initial construction phase the northeast perimeter of central and east islands can be constructed to their final design configuration including stone headlands and gravel beaches.

This spine also provides the opportunity for marine delivery of island construction materials by self-unloader boats and barges. By providing both land and water based delivery of island construction material, a competitive bidding environment can be maintained throughout the construction of the entire island chain. If a marine terminal is constructed, dredging will be required to provide access from the existing navigation channel to the east island. This dredge material, if suitable, could be used to create a construction staging area to accept stone materials for revetment, headland and beach construction.

Temporary circulation structures will be provided through the construction access road at the location of the future gaps between the island to promote water circulation until central and east island are constructed. Once the two westerly islands are complete the road and culverts between the islands will be removed and final habitat and scour protection in the gaps between the islands will be implemented.

It is assumed that the maintenance dredging of the navigation channel is likely to be performed by a hydraulic cutter suction dredge. The dredge vessel would be located at the dredging site and material will be pumped to the dredge pipeline located on or within the construction spine and distributed to the islands for disposal.

If a hopper dredge is to be used, the dredge vessel will excavate material, then dock at the east island and pump dredged sand though the dredge pipeline for island disposal. In this case, a hopper dredge terminal will need to be created. This will involve dredging of the area between the east Island and the existing Navigation Channel. It will also require creation of temporary mooring structures or possibly a bulkhead wall.

If the dredge pipeline is not used and the method of dredging is by hopper dredge, then an access channel to the current island being filled will need to be excavated. This would require that a significant amount of material be dredged. If the material was suitable, it could be placed within the islands, however, this would reduce storage capacity. If unsuitable for placement in the islands it would be costly to transport and dispose of this material at an alternate site. The dredge access channel would required routine maintenance and may have an adverse impact on the perimeter design and construction operations. Therefore, it is recommended that the sand be pumped from the east island or closer to the area of dredging through pipelines to each of the islands.

If dredged sand is delivered to the island hydraulically, dozers will be required to construct sand berms and weirs to contain and dewater the dredged material. Following the dewatering process the dozers will be required to establish the final design grades.

It may desirable to phase the filling of each island based upon budget constraints or anticipated maintenance dredging and construction schedules. Each of the islands could easily be phased by incorporating secondary containment berms. The berms would need to be located to include the appropriate headlands to contain the beach cells that provide the required shore protection and containment for the area being filled.

Once initial filling is complete on the west island is can be vegetated and detailed habitat improvements can be incorporated. The dredge pipeline can be salvaged or abandoned. Construction access, containment berms, headlands and beaches can be constructed for the central island to allow filling to begin (alternatively the skeleton of two or three of the islands could be created in the initial construction phase). As with the west island, the central island could be phased, if desired. The delivery and placement of dredged sand and the dewatering and the filling process would be similar to that described for the west island.

A similar construction sequence can be implemented for the construction of the east island.

Land-based construction would generate significant truck traffic through local neighborhoods during the delivery of stone materials for the duration of island perimeter construction. A northerly location for the mainland connection of the construction access road is suggested to avoid more populated neighborhoods located to the south.

As the construction of the three islands perimeters is completed, the construction roads in the gaps between the islands can be removed and partial lengths of the construction access road to the mainland can be removed to deter predator and pedestrian access to the islands. The excess material can be utilized to reshape and create additional island habitat (as required to promote aquatic vegetation recovery in Peter's Marsh as noted above and in Section 8).

Once island construction is complete, the management of the marine terminal should include provisions to deter recreational boaters from accessing the east island, however, it will be important to maintain some access opportunities to the island for long-term maintenance and monitoring purposes.

10.1.2 Water-Based Construction –Preliminary Plan

Figure 10.7 displays the possible progression of the island construction based upon water-based access only. The existing Navigation Channel, located at the eastern end of the project, could be utilized to provide water-based access for material delivery to the site and off loading construction equipment. Depths maintained in the existing channel could allow the delivery of construction materials (stone) in bulk quantities by self-unloader boat and barges. This could provide construction savings compared to the cost of materials delivered by trucks.

Water-based construction would require dredging to provide access between the existing Navigation Channel and the east island. As discussed above in the land based construction scenario, the construction of this access would create additional dredge spoil material that would likely be costly and present other adverse impacts to the project. Currently, the proposed marine terminal is located within the existing Lake Bed Grant being proposed. If the Lake Bed Grant limits could be revised to allow the terminal to be positioned closer to the navigation channel, cost savings would result.

Following the initial construction of the marine terminal, and construction staging area the perimeter construction spine, access roads, headlands and beaches could be constructed for the west island to accept sand dredge materials. The west island could be phased and filling could be proceeding as previously discussed.

Key disadvantages of relying entirely on water based access for construction include: entire protection for the Duck Creek Wetland area is not provided until the western island "shell" is complete, the Peter's Marsh area is not protected from waves and sediment laden flows and construction materials are limited to water based delivery only.

Advantages of relying entirely on water-based construction include: no truck traffic though local neighborhoods; and pedestrian or predator access to the islands from the mainland is restricted.

10.1.3 *Land-based and Water-based Construction – Revised Plan*

Combined land-based and water-based construction for the Revised Plan is similar to the Preliminary Plan with the following exceptions: the entire southwest perimeter of the Islands in the revised Plan are not entirely contained and consist of dredged sand material rather than imported coarse sand or gravel material. Some additional detail has been added to specific northeast beach cells for to introduce more diversity in island habitat creation.

Because of the relatively unknown physical characteristics of the dredge sand material the long-term stable slopes of these exposed beaches is difficult to predict. Therefore the monitoring of these beaches and an "Adaptive Design" approach is suggested.

During filling of the first island it will be important to monitor the grain size of the dredged sand being deposited, the profile of the existing lake bottom prior to filling and the profile of the new beach during filling and following key storm events. Once a stable profile can be determined, the lengths and crest heights of the beach containment structures can be determined and the need for central containment structure on the west and central islands can be assessed. The central headlands located in the southwest sides of the west and central islands could possibly be built before or after filling of the respective island.

A detailed monitoring plan should be developed as part of the final design process.

It may also be possible to obtain grain size information on sand material prior to dredging to efficiently manage placement, e.g. perhaps the west island is most suitable for fine materials while the east island may be more suitable for coarser materials.

10.2 Material Availability & Costs

A materials investigation was conducted to identify possible stone sources and establish budget costs. Several local quarries were contacted as well as several remote quarries that have marine loading facilities for self-unloader boats and barges.

Tables 10.1 and 10.2 represent material, delivery and placement costs generated from this investigation.

Table 10.1 Estimated Material In-place Costs - Land Based Construction

Item	Origin	Material On Site $/ton	Placement $/ton	Total Cost $/ton	Budget Price $/ton
Conventional Armor	Local Quarry	$15.00	$15.00	$30.00	$30.00
Berm Armor	Local Quarry	$15.00	$10.00	$25.00	$25.00
Coarse Gravel / Cobble	Local Quarry	$5.50	$5.00	$10.50	$12.00
Fine Gravel	Local Quarry	$6.50	$5.00	$11.50	$12.00
Coarse Sand	Local Quarry	$6.75	$5.00	$11.75	$12.00
Construction Access Road	Local Quarry-Shot Rock	$6.50	$5.00	$11.50	$12.00

Table 10.2 Estimated Material In-place Costs - Water Based Construction

Item	Origin	Material On Site $/ton	Placement $/ton	Total Cost $/ton	Budget Price $/ton
Conventional Armor	Local Quarry & Barge	$25.00	$15.00	$40.00	$40.00
Berm Armor	Local Quarry & Barge	$25.00	$10.00	$35.00	$35.00
Coarse Gravel / Cobble	Michigan Limestone Self Unloader	$8.00	$5.00	$13.00	$14.00
Fine Gravel	Michigan Limestone Self Unloader	$8.00	$5.00	$13.00	$14.00

Coarse Sand	Michigan Limestone Self Unloader	$7.25	$5.00	$12.25	$14.00
Construction Access Road	Michigan Limestone - Coarse Gravel / Cobble	$8.00	$5.00	$13.00	$14.00

Complete itemized statements of probable construction costs have been created for both the Preliminary and Revised Plan as well as Land based and Water based construction. They are included in Appendix I. A summary of the estimates is included in Tables 10.3 and 10.4.

Table 10.3 - Statement of Probable Construction Cost Summary
Land Based Construction

Item	Cost Preliminary Plan	Cost Revised Plan
Construction Access Road	$ 0.8 M	$ 0.8 M
West Island	$ 5.8 M	$ 3.6 M
Central Island	$ 5.2 M	$ 4.1 M
East Island	$ 5.5 M	$ 5.8 M
Gaps	$ 1.1 M	$ 1.1 M
Miscellaneous - Mobilization, Removing Temporary Construction Access Roads	$ 2.9 M	$ 2.9 M
Total Project Cost	**$ 21.2M**	**$ 18.2 M**

* Notes: Itemized summary totals do not match the total project cost exactly due to rounding. One option for the construction is creating the west island and construction spine with dredge pipeline of the central and eastern islands at the start of the project. The total cost for creating this construction spine and pipeline is $5.4 M for the

preliminary plan and $6.0 M for the revised plan. If this option were exercised, the cost of the central and east island would lower approximately by the cost of the construction spine with pipeline.

Table 10.4 - Statement of Probable Construction Cost Summary Water Based Construction

Item	Cost Preliminary Plan	Cost Revised Plan
Marine Terminal	$ 3.5 M	$ 3.5 M
East Island	$ 6.8 M	$ 6.8 M
Central Island	$ 6.4 M	$ 4.9 M
West Island	$ 7.1 M	$ 4.3 M
Gaps	$ 1.3 M	$ 1.3 M
Miscellaneous - Mobilization, Removing Temporary Construction Access Roads	$ 1.6 M	$ 1.6 M
Total	**$ 26.6 M**	**$ 22.6 M**

* Notes: Itemized summary totals do not match the total project cost exactly due to rounding.

It is assumed that the dredging quantities from the Federal Navigation Channel will equal or exceed 80,000 cubic yards every three years. It is anticipated that a hydraulic cutter suction dredge will be implemented for the project.

10.3 Schedule

The anticipated start date for construction is Spring 2006. The typical construction season in the Great Lakes area extends between April 15 and October 15. Average construction rates anticipated for this project are as follows:

- Placing Construction Access Road/Spine 1,200 tons / day
- Placing Imported Beach Material 1,200 tons / day
- Placing Armor Stone 800 tons / day
- Installing Circulation Culverts 2 / day
- Installing Steel Sheet Pile Wall 20 sheets / day
- Installing Mooring Pile Clusters 2 / day
- Excavation 3,000 cubic yards / day

These rates are based upon average construction schedules. The rates may be accelerated as needed. Based upon these rates land and water based construction schedules are indicated in Tables 10.5 and 10.6.

Table 10.5 - Anticipated Construction Schedule
Land Based Construction

Item	Days to Complete Preliminary Plan	Days to Complete Revised Plan
Construction Access Road	58 days	58 days
West Island	250 days	179 days
Central Island	210 days	137 days
East Island	151 days	172 days
Island Gaps & Berms	58 days	58 days
Total	**730 days**	**604 days**

Table 10.6 - Anticipated Construction Schedule
Water Based Construction

Item	Days to Complete Preliminary Plan	Days to Complete Revised Plan
Marine Terminal	88 days	88 days
East Island	261 days	246 days
Central Island	227 days	203 days
West Island	250 days	179 days
Island Gaps & Berms	58 days	58 days
Total	**884 days**	**774 days**

11.0 SUMMARY

The primary goals of the Cat Island Chain Restoration project are to restore the aquatic vegetation in the lee of the island chain in addition to restoring Cat Island habitat, while providing capacity for dredged material from the Federal Shipping Channel. The purpose of this report is to document design development activities for the restoration of the Cat Island Chain. The following points summarize the key elements of the investigation and design activities:

- Bathymetry data, GIS data, sediment and water characteristics were obtained for this project. These data are described in Section 2 of the report and were utilized in the analysis completed for this investigation.

- A geomorphic analysis presented in Section 3 providing a description of the shoreline and lakebed evolution for the southwestern part of Green Bay. The analysis provides historic plan outlines of both the Cat Island Chain, and the Duck Creek wetland area.

- A physical model study was completed to support this design development and is described in Section 4. The study included stability analysis of various revetments and beach types. Stable material sizes and slopes are provided in Section 4. Overtopping analysis was performed to provide guidance on crest elevations for the islands. The revetments are proposed at a crest elevation of +8 ft, LWD. The imported beach sections are proposed with a placement crest of +6 ft, LWD. Over time they are anticipated to develop a storm berm profile with a crest of +10 ft, LWD.

- Numerical wave modeling was performed to define a design wave climate for the islands. The numerical modeling is described in Section 5. The model WAVAD was used to simulate wind-wave generation for the entire Green Bay. The model STWAVE was used to transform waves from deep water to the Cat Island Chain and further into the bay. A design significant wave height for the exposed side of the Cat Island Chain with a return period of 20 years, is 3.3 ft.

- A hydrodynamic model (MIKE21 HD) was developed for use in simulating the effects of wind generated surge and associated currents around the Cat Island Chain. The model application and results are described in Section 6. Wind and water levels were applied to the nested model system of Green Bay. The model successfully predicted measured extreme and typical surge events. Results indicated a maximum velocity of 2.3 to 2.6 ft/s (0.7 to 0.8 m/s) might occur in the gaps between proposed islands.

- A numerical model of sediment dynamics (MIKE21 MT) in the lower bay was setup and tested as presented in Section 7. The model simulated the two key sources for suspended sediment including plumes discharged from the Fox River and Duck Creek together with sediment re-suspended from the lakebed. The model of sediment dynamics was linked to the hydrodynamic model to define advection/dispersion of the sediments within the bay. Model simulations were completed five representative events include rainfall (i.e. plume discharge only), wind-wave re-suspended sediment only (i.e. no plumes from the river) and a combined event. Each of the simulations was completed for different phases of island construction. It was found that the re-introduction of the islands will only slightly influence water clarity impairment associated with the advection/dispersion of sediment plumes discharged from Fox River and Duck Creek. However, there is a significant improvement in water clarity for conditions of wave re-suspension of lakebed sediments after the islands are re-created. The reduction of wave re-suspension related turbidity is probably most important for recovery of the aquatic vegetation as these events occur more often and result in higher turbidity levels. There may be a need to reduce watershed loading of sediments from Duck Creek and Fox River to levels equivalent to those that existed prior to 1970 (if this has not already been achieved) in order to successfully promote recovery of the aquatic vegetation in Peter's Marsh, Peats Lake and the Duck Creek wetland areas.

- One of the most important objectives of this project is to provide the necessary conditions for recovery of the aquatic vegetation between the Cat Island Chain and the lower Green Bay shore. An analysis of the existing conditions and the conditions after construction of the islands is presented in Section 8 of this report. The analysis considered several criteria required to promote the survival (and recovery) of aquatic vegetation including the two key criteria: water clarity (addressed through the modeling of sediment dynamics) and the ability of the plants to withstand wave attack. Water clarity was found to be the key limiting condition for recovery of aquatic vegetation and the role of re-introduction of the Cat Island Chain in improving these conditions is discussed in the bullet point above.

- As a result of the above analysis, a design development plan was obtained with input from the US Army Corps of Engineers, US Fish & Wildlife, Wisconsin Department of Natural Resources, Brown County, University of Wisconsin-Green Bay and UW Sea Grant. The progression of the development of the design is described in Section 9 of this report. The plan and sections are included Section 10.

- The preliminary and revised plans were designed so that their storage capacities were similar, as comments from stakeholders indicated that the capacities were acceptable. In the final design stage, there remains opportunity to optimize or expand the storage capacities of each island. The storage capacities each island are 630,000 cy for the west island, 720,000 cy for the central island 1,000,000 cy for the east island. The total storage capacity for the entire island chain is estimated to be 2,350,000 cy.

- The construction plan including approaches and sequencing is discussed in Section 10. Also included in this report section are preliminary estimates of probable construction costs, and schedules for the island construction. Total probable construction costs for the plans are summarized in Table 11.1

Table 11.1 - Summary Estimates of Probable Construction Costs

	Preliminary Plan		Revised Plan	
	Land Based Construction	Water Based Construction	Land Based Construction	Water Based Construction
West Island	$ 5.8 M	$ 7.1 M	$ 3.6 M	$ 4.3 M
Central Island	$ 5.2 M	$ 6.4 M	$ 4.1 M	$ 4.9 M
East Island	$ 5.5 M	$ 6.8 M	$ 5.8 M	$ 6.8 M
Total Cost*	$ 21.2 M	$ 26.6 M	$ 18.2 M	$ 22.6 M

Total Cost includes items such as Island Gaps, Mobilization and Removal of Temporary Construction Access Roads.

- The U.S. Fish & Wildlife Service has provided comments on this report. Baird has created responses to each and they are included in Appendix J.

12.0 CONCLUSIONS AND RECOMMENDATIONS

As a result of the analysis described in this report, the following conclusions and recommendations can be made related to the design and construction of the Cat Island Chain restoration project:

- It would be advantageous for the restoration of emergent and submerged vegetation in the Duck Creek wetland area to construct the west island first, followed by the central island and the east island. This would provide immediate protection from the large waves generated from winds blowing over the long fetch to the northeast (and the related re-suspension of sediment and impact to water clarity).

- It is recommended that consideration be given to the initial construction of an access road linking the shore and all the islands to provide the maximum possible protection to the lower bay in the lee of the islands, immediately. This layout of this access road has been developed to form the core of the protection for the exposed side of the three islands.

- Furthermore, the creation of a land-based construction access road between the west island and the shore will provide the necessary restriction to the sediment laden flows into the Peter's Marsh area, creating the necessary condition to promote restoration of aquatic vegetation. This road can be reshaped to create additional habitat islands at the termination of the project at the same time as maintaining the restriction to flow (a condition that existed prior to the erosion of the Cat Island Chain in the early 1970s).

- It may be advantageous to incorporate a dredge pipeline within the initial construction access road noted in the second point. This could be used to facilitate the transport of dredged material to each of the islands from the dredge location whenever as it becomes available and reduce the need for mobilization and demobilization of dredge pipe for each operation.

- Through consultation with the key stakeholders it was determined that the southwest facing or lee side of the islands should consist of exposed dredged fill material. This will allow for the development of mild sloping fine sand beaches that would have been typical of the islands before they were severely eroded in the early 1970s. Monitoring of the performance of the dredge material beaches on the lee side of the islands will be necessary to inform possible design adaptation as the project proceeds.

- Current preliminary statements of probable construction costs indicate a savings in starting with land-based construction. This may change as the project evolves over time and it is recommended to keep future water based construction options open to provide a more competitive bidding environment.

- The project is anticipated to progress into the final design stage following this design development phase. Construction bidding documents will be created as a result of this next stage. Following the final design phase a construction-monitoring plan should be implemented.

- As indicated in the summary, the U.S. Fish & Wildlife Service has provided comments on this report. The comments and Baird responses are provided in Appendix J. The comments include items that should be addressed in the final design phase.

- The design development analysis and plans created allow for further optimization during the final design phase. Areas of possible optimization include:

    - Increase storage capacity of the islands by location and orientation of dredged material beaches.

    - Optimize structure cross-section design based on gradations obtained from quarry visits and test blasts of shot rock.

    - Include bio-Engineered sections in final design plans and specifications where wave and current climates allow.

    - Create a detailed grading plan to optimize storage capacity.

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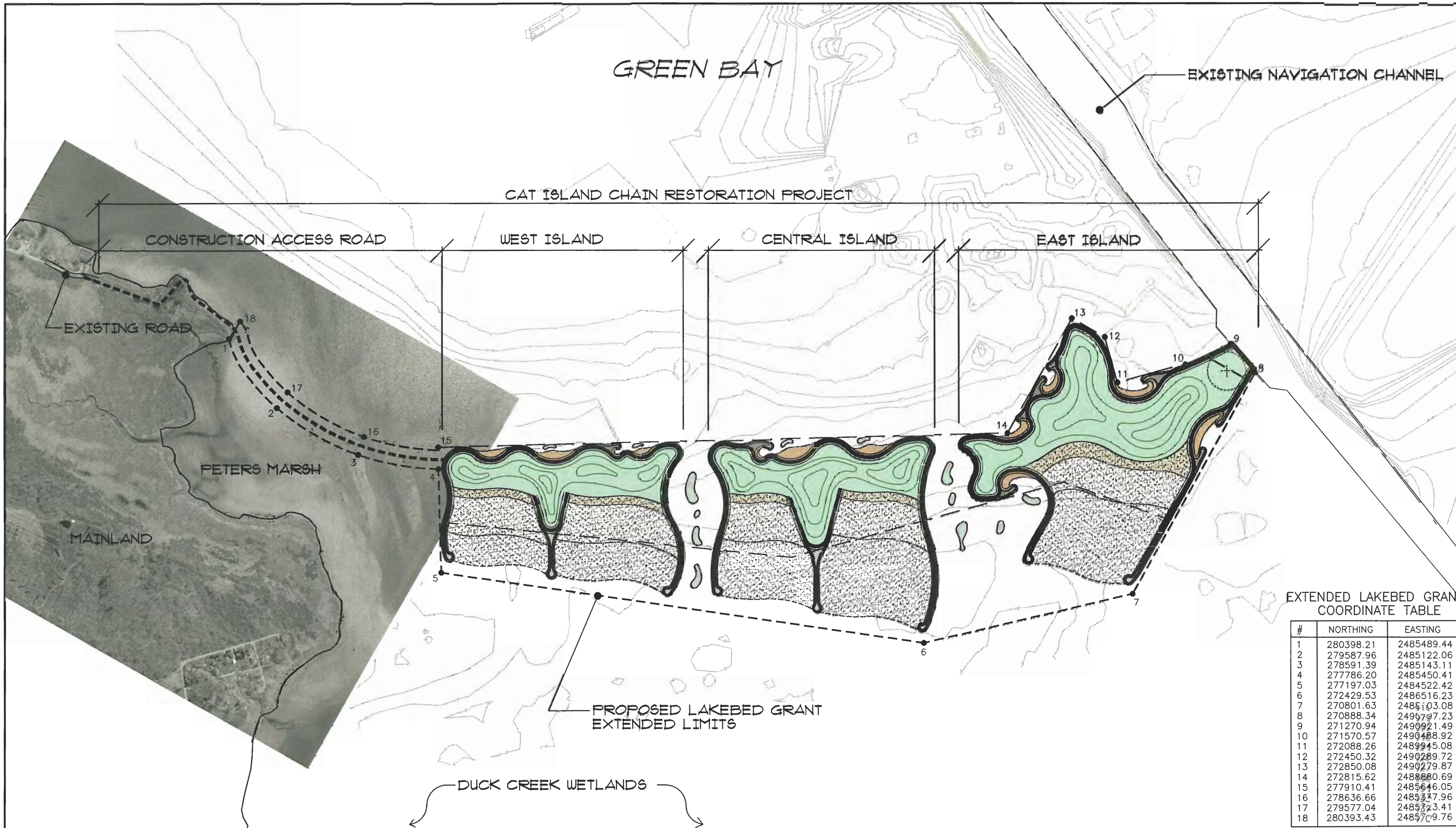


EXTENDED LAKEBED GRANT COORDINATE TABLE

#	NORTHING	EASTING
1	280398.21	2485489.44
2	279587.96	2485122.06
3	278591.39	2485143.11
4	277786.20	2485450.41
5	277197.03	2484522.42
6	272429.53	2486516.23
7	270801.63	2488103.08
8	270888.34	2490797.23
9	271270.94	2490921.49
10	271570.57	2490488.92
11	272088.26	2489945.08
12	272450.32	2490289.72
13	272850.08	2490279.87
14	272815.62	2488880.69
15	277910.41	2485646.05
16	278636.66	2485337.96
17	279577.04	2485323.41
18	280393.43	2485709.76

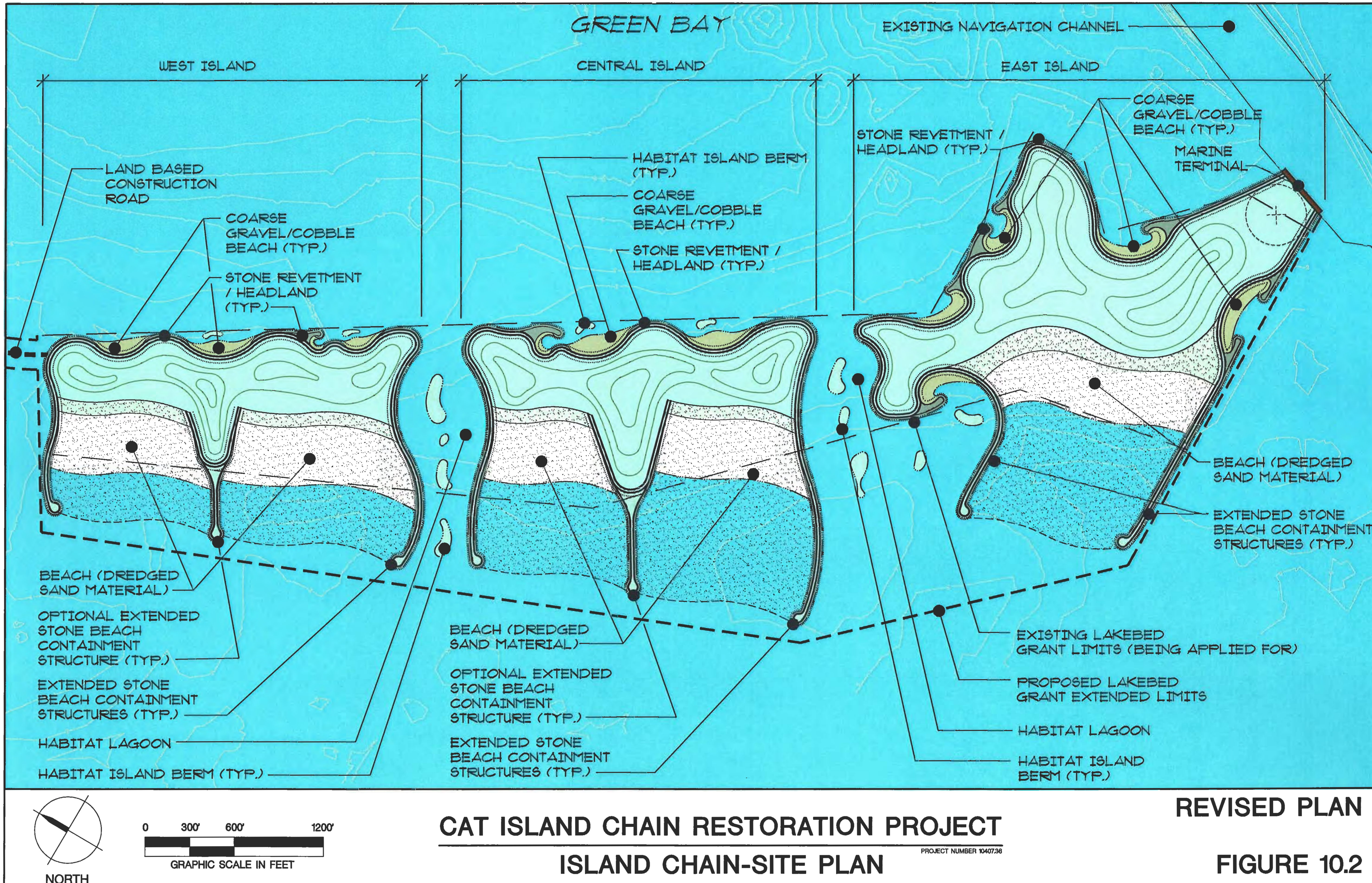
CAT ISLAND CHAIN RESTORATION PROJECT

OVERALL SITE PLAN

PROJECT NUMBER : 10407.36

REVISED PLAN

FIGURE 10.1



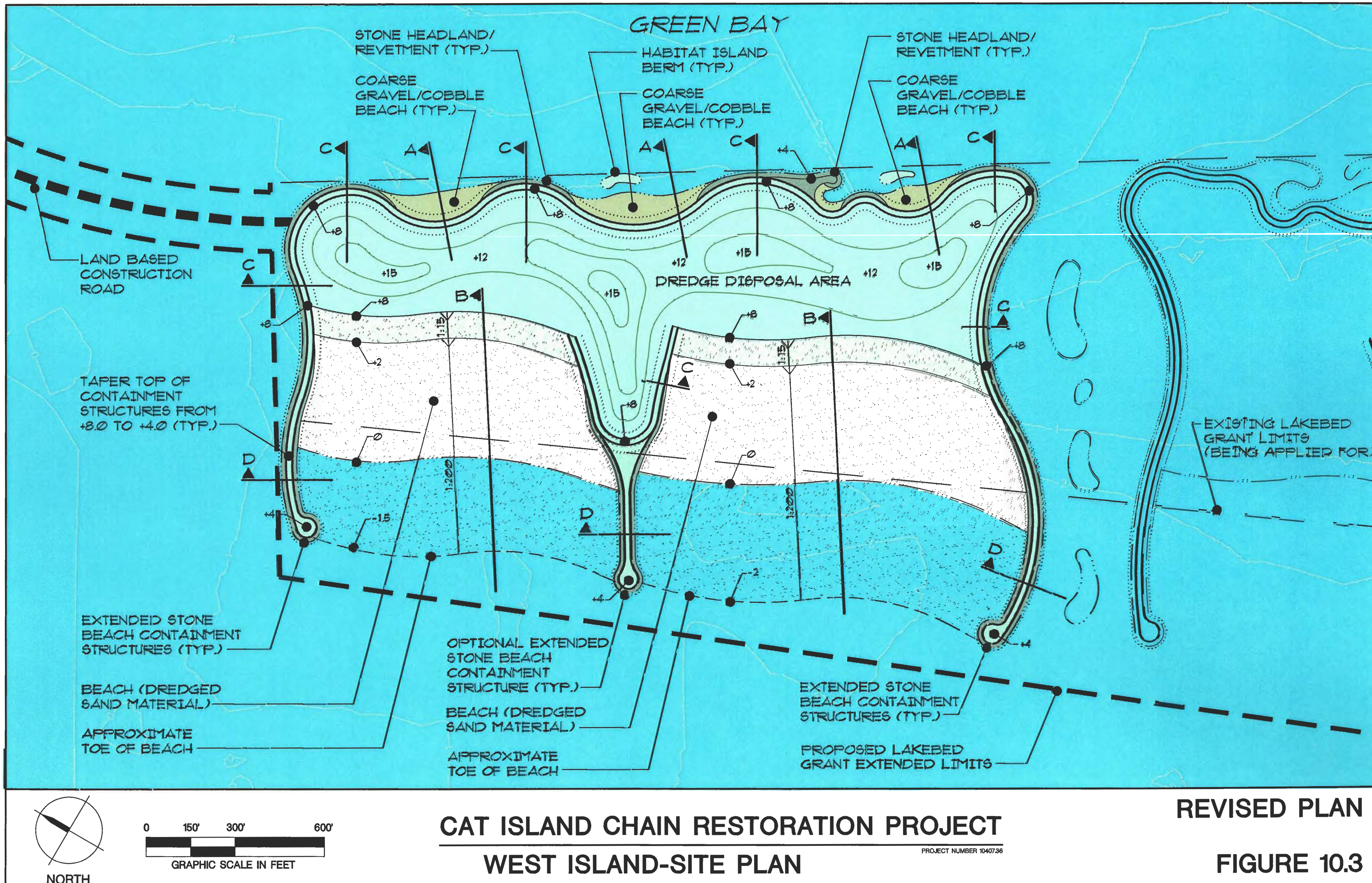
CAT ISLAND CHAIN RESTORATION PROJECT

PROJECT NUMBER 10407.36

ISLAND CHAIN-SITE PLAN

REVISED PLAN

FIGURE 10.2



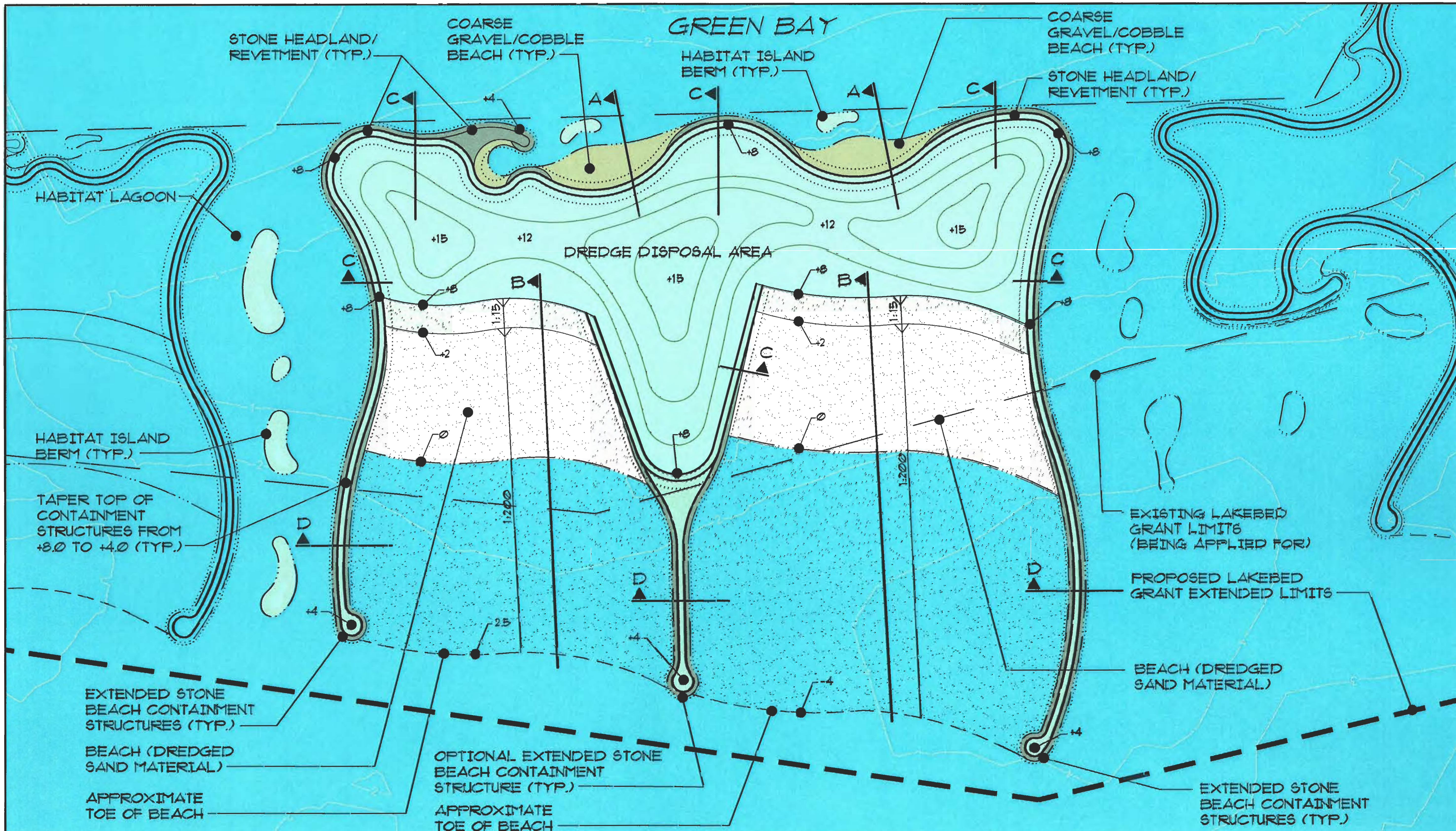
CAT ISLAND CHAIN RESTORATION PROJECT

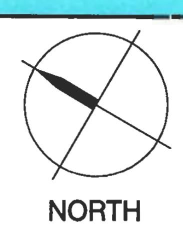
PROJECT NUMBER 1040736

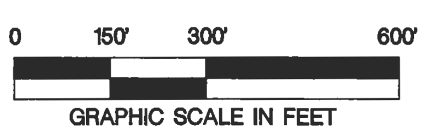
WEST ISLAND-SITE PLAN

REVISED PLAN

FIGURE 10.3







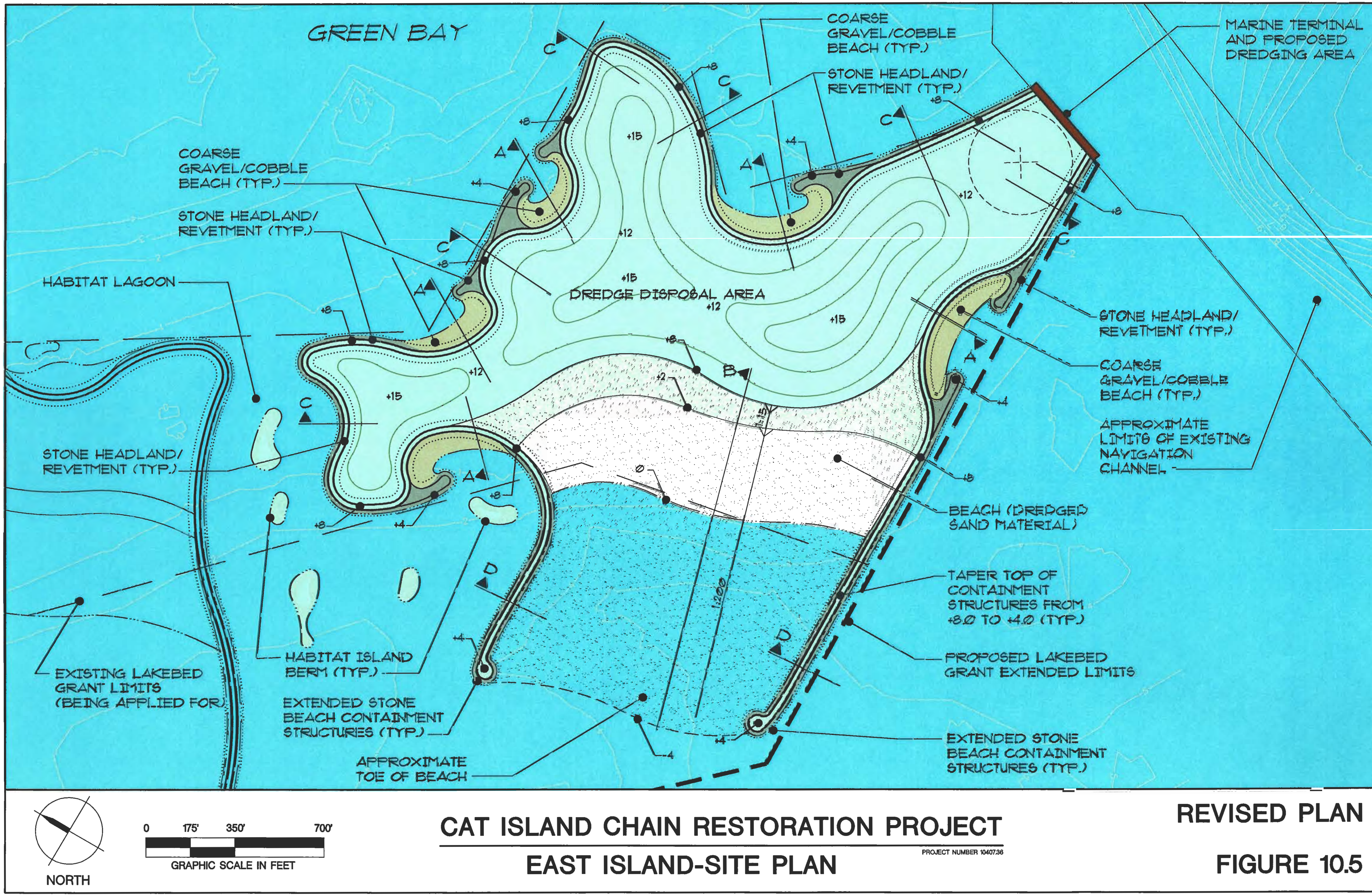
CAT ISLAND CHAIN RESTORATION PROJECT

PROJECT NUMBER 10407.36

CENTRAL ISLAND-SITE PLAN

REVISED PLAN

FIGURE 10.4



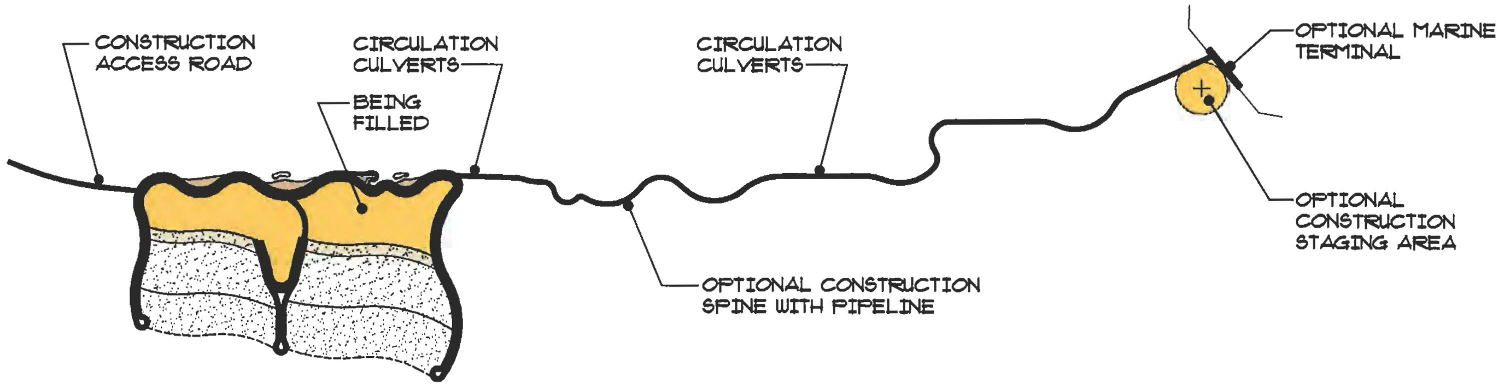
CAT ISLAND CHAIN RESTORATION PROJECT

EAST ISLAND-SITE PLAN

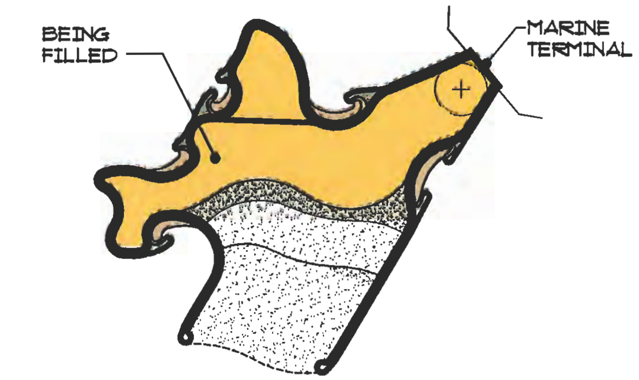
PROJECT NUMBER 10407.36

REVISED PLAN

FIGURE 10.5



WEST ISLAND - LAND BASED CONSTRUCTION



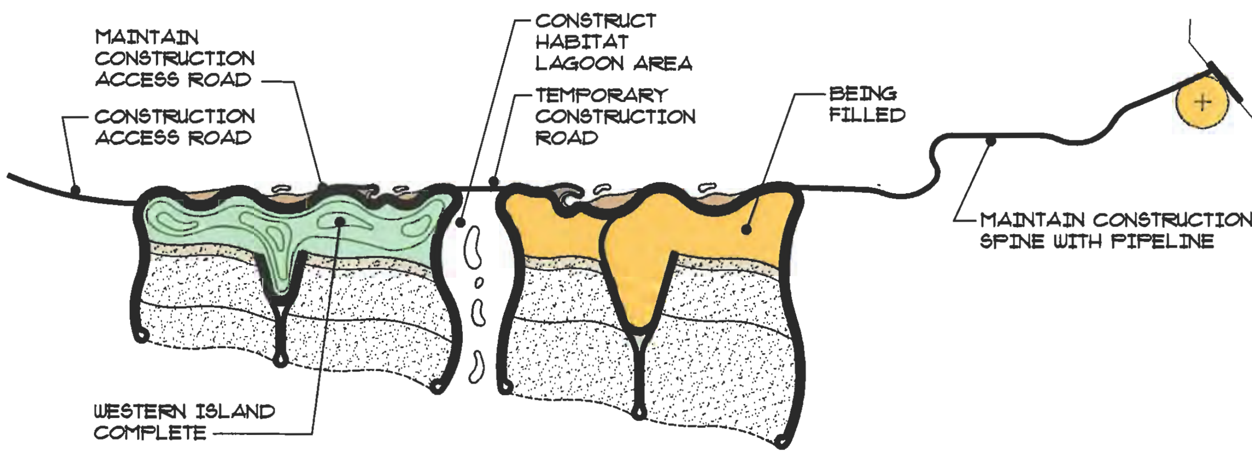
EAST ISLAND - WATER BASED CONSTRUCTION

LAND BASED CONSTRUCTION NOTES (UPON COMPLETION OF EAST ISLAND)

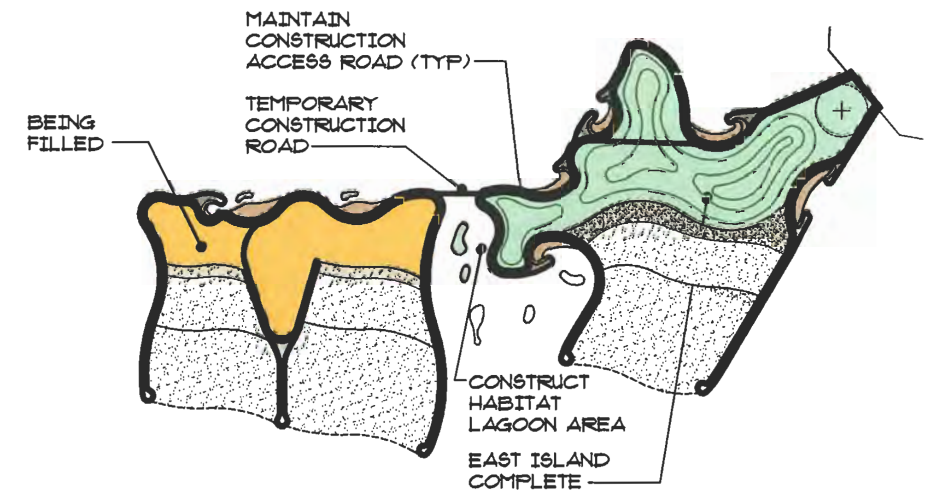
1. REMOVE TEMPORARY CONSTRUCTION ACCESS ROAD CONNECTIONS BETWEEN ALL ISLANDS.
2. REMOVE SECTIONS OF LAND BASED CONSTRUCTION ACCESS ROAD AND CREATE HABITAT ISLANDS.
3. ABANDON EASTERN ISLAND DREDGE PIPELINE.
4. SECURE MARINE TERMINAL TO DISCOURAGE RECREATIONAL BOAT USE.

WATER BASED CONSTRUCTION NOTES (UPON COMPLETION OF WEST ISLAND)

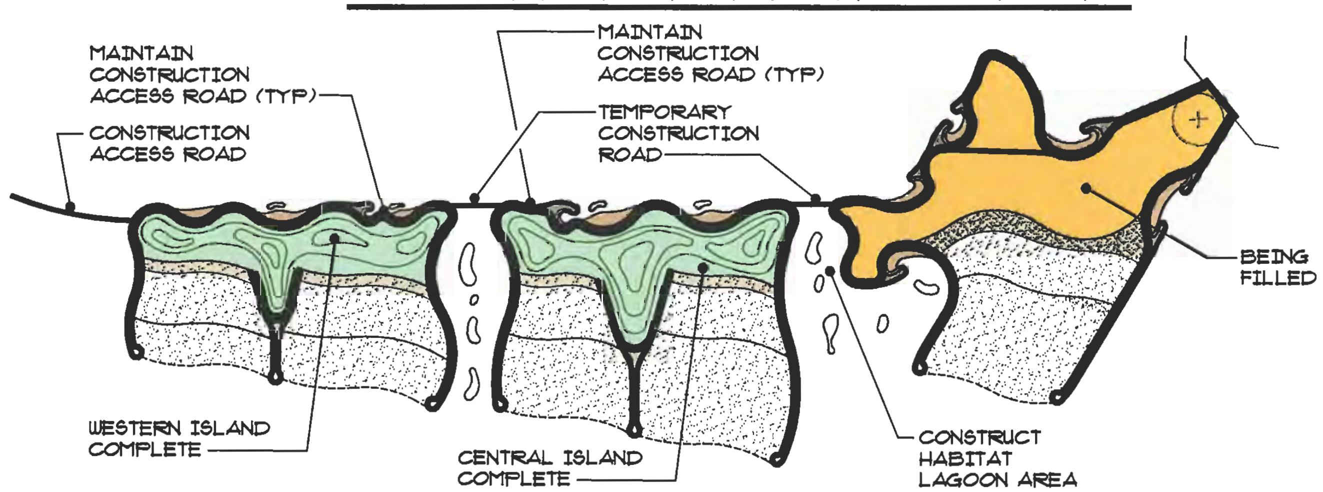
1. REMOVE TEMPORARY CONSTRUCTION ACCESS ROAD CONNECTIONS BETWEEN ALL ISLANDS TO DETER PEDESTRIAN AND PREDATOR ACCESS.
2. ABANDON DREDGE PIPELINE.
3. SECURE MARINE TERMINAL TO DISCOURAGE RECREATIONAL BOAT USE.



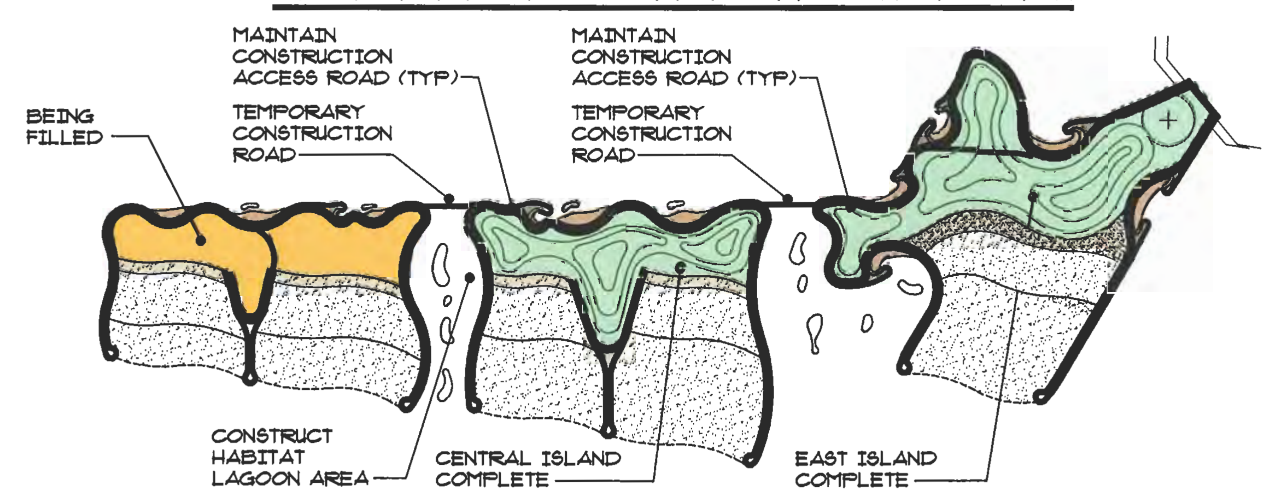
CENTRAL ISLAND - LAND BASED CONSTRUCTION



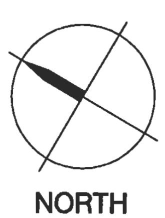
CENTRAL ISLAND - WATER BASED CONSTRUCTION

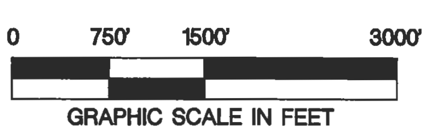


EAST ISLAND - LAND BASED CONSTRUCTION



WEST ISLAND - WATER BASED CONSTRUCTION





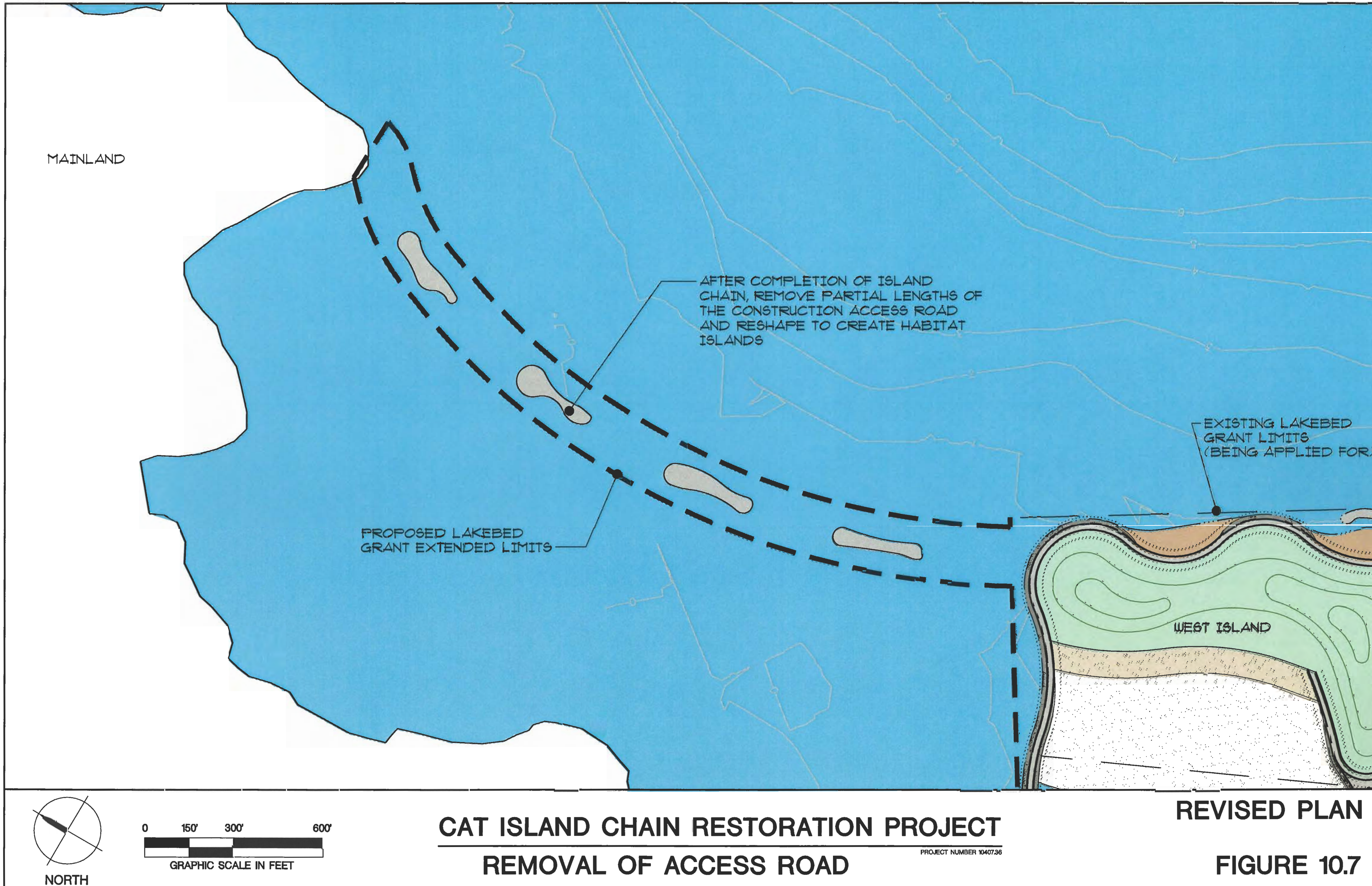
CAT ISLAND CHAIN RESTORATION PROJECT

CONSTRUCTION ACCESS / SEQUENCING PLAN

PROJECT NUMBER 10407.36

REVISED PLAN

FIGURE 10.6



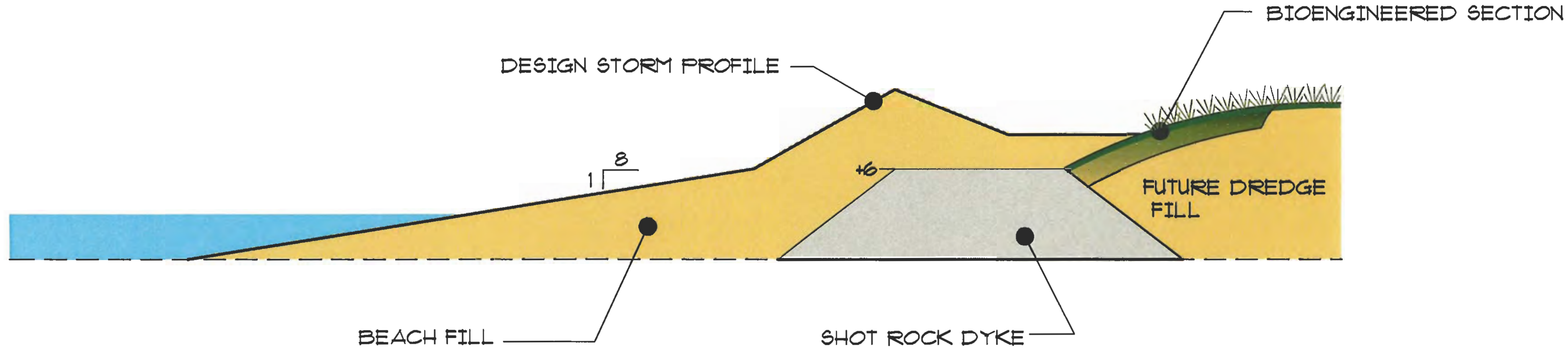
CAT ISLAND CHAIN RESTORATION PROJECT

PROJECT NUMBER 10407.36

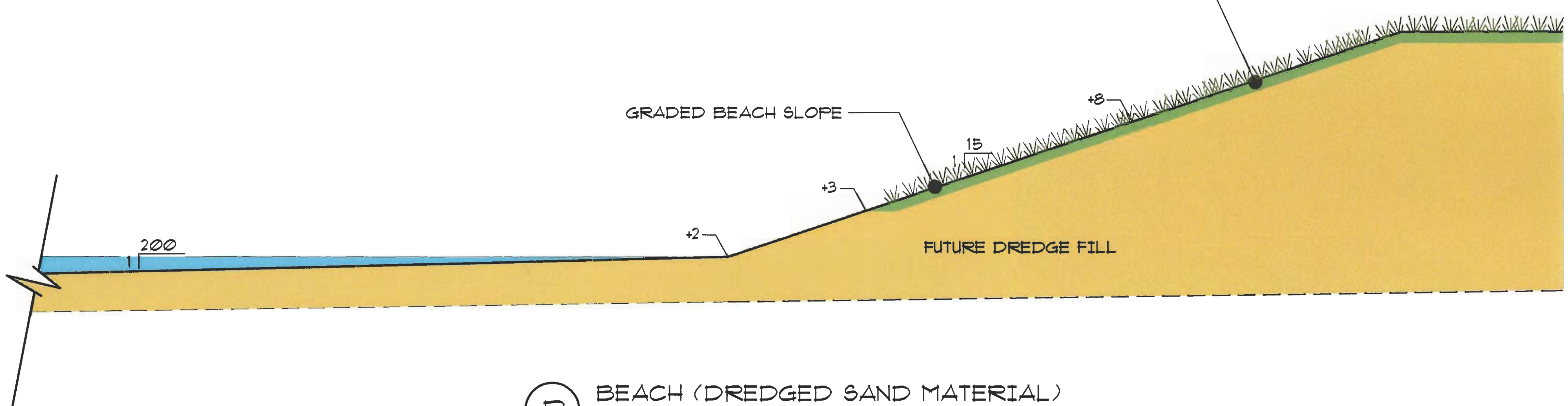
REMOVAL OF ACCESS ROAD

REVISED PLAN

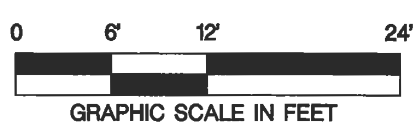
FIGURE 10.7



A COARSE GRAVEL/COBBLE BEACH



B BEACH (DREDGED SAND MATERIAL)
VERTICAL EXAGGERATION = 5X



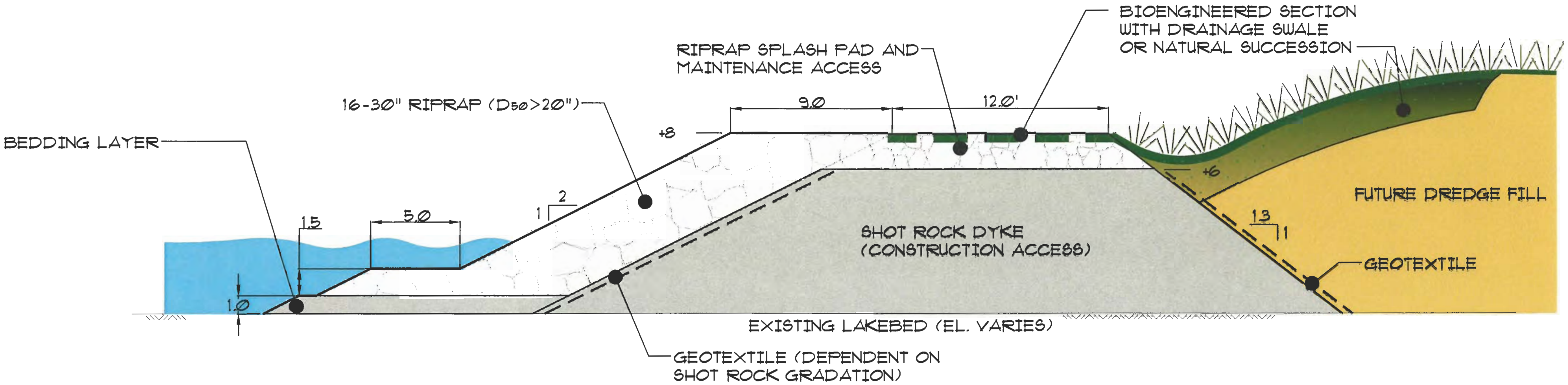
CAT ISLAND CHAIN RESTORATION PROJECT

PROJECT NUMBER 1040736

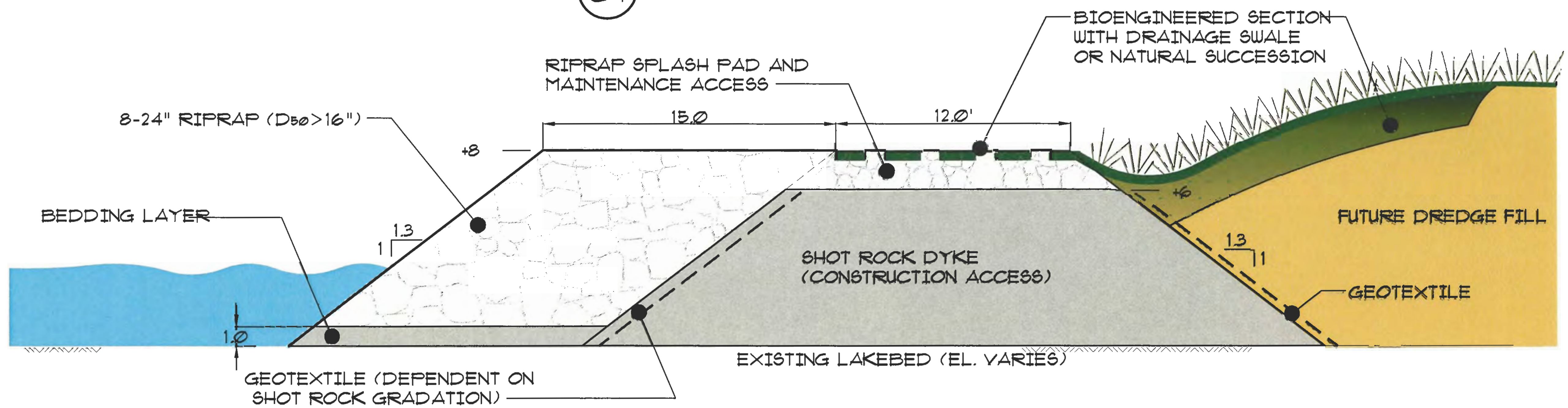
TYPICAL SECTIONS

REVISED PLAN

FIGURE 10.8



C1 CONVENTIONAL DESIGN CONCEPT



C2 BERM DESIGN CONCEPT

NORTH

0 3' 6' 12'
GRAPHIC SCALE IN FEET

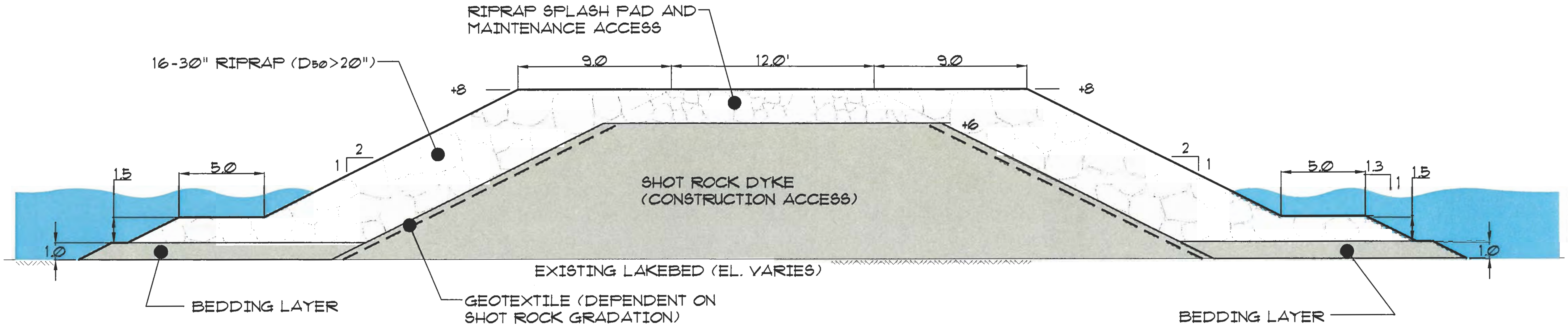
CAT ISLAND CHAIN RESTORATION PROJECT

PROJECT NUMBER 10407.36

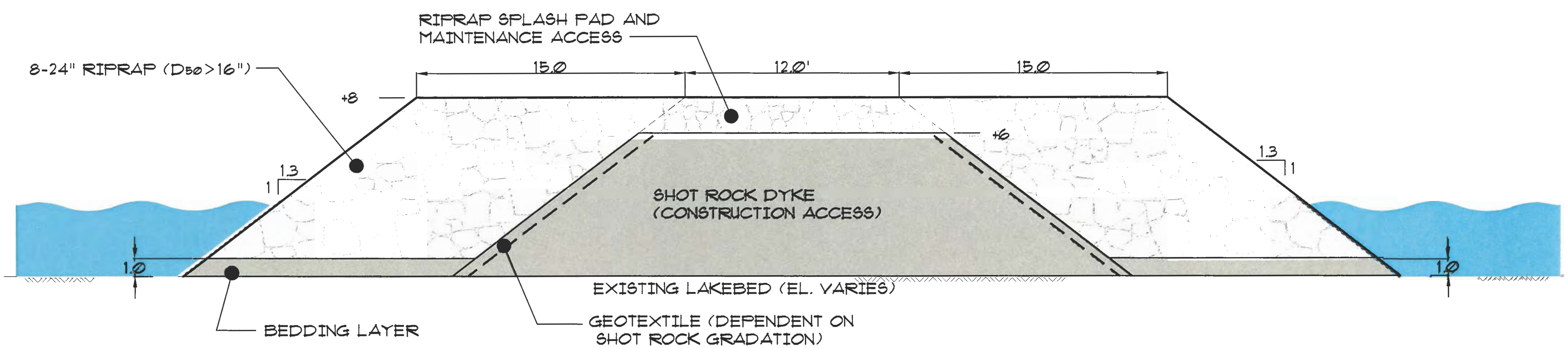
TYPICAL SECTIONS

REVISED PLAN

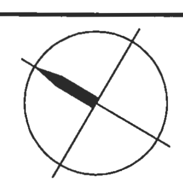
FIGURE 10.9

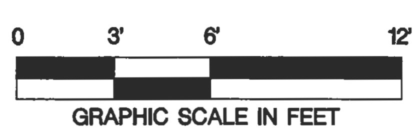


D1 CONVENTIONAL DESIGN CONCEPT



D2 BERM DESIGN CONCEPT





CAT ISLAND CHAIN RESTORATION PROJECT

PROJECT NUMBER 10407.38

TYPICAL SECTIONS

REVISED PLAN

FIGURE 10.10