Bay of Fundy Tidal Barriers GIS Database Development

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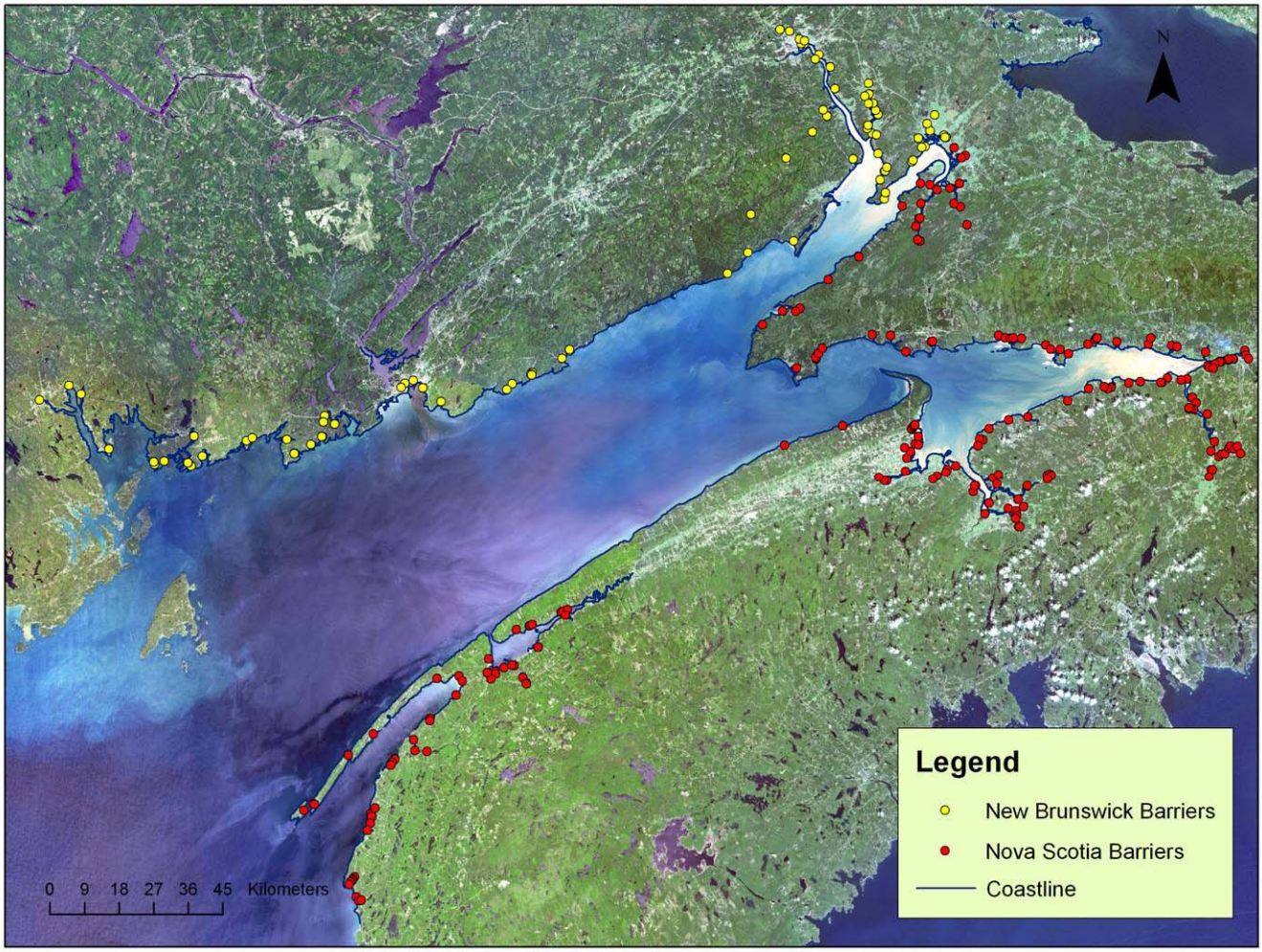

In partnership with
Bay of Fundy Ecosystem Partnership (BoFEP), Inc.
&
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Ecosystem Science and Information Division
Environment Canada Atlantic Region

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PROJECT OVERVIEW

Over the last century, the majority of rivers entering into the Bay of Fundy have been highly modified through the construction of tidal barriers. The construction of these barriers resulted in either partial or complete obstruction to tidal flow in many areas around the Bay. Tidal barriers effectively decrease turbulent energy in the tidal system causing sediments and other particles to drop from suspension and accumulate as deposits of mud, sand and silt. In other areas, localized erosion is initiated either directly upstream or downstream of a partially restrictive barrier. Ecosystems inhabiting this zone, such as mudflats and salt marshes, are some of the first environments to feel the effects of coastal modification. These changes have cascading impacts on intertidal ecosystems, some negative and others positive. Overall however, the cumulative impacts of tidal barriers on intertidal ecosystems of the Bay of Fundy are unknown. This is of particular concern with increasing interest in removing or modifying tidal barriers in an effort to 'return the tides'. Without a solid baseline of past and present 'states' of these systems, assessing or predicting the success of restoration activities is difficult.

In addition, cycles of progradation and retreat have been documented on a number of marsh and intertidal systems. These cycles have been linked to changes in sea level and in the tidal prism due to human activities such as tidal barrier construction or dredging, changes in wind/wave climate, sediment supply, cliff morphology, intertidal sedimentation and changes in the location of the major tidal channel. One of the most effective ways of documenting these changes is through the analysis of rectified aerial photographs within a GIS system. This is the preliminary stage that is required before any true questions regarding the 'why' of these changes are addressed.

The purpose of this collaborative research project was to integrate the Bay of Fundy Tidal Barrier Audits into a comprehensive digital spatial database being developed in a concurrent project with Environment Canada. Together, they will be used as a baseline to assess the cumulative impacts of tidal barriers in the Upper Bay of Fundy and serve as a platform for future research. This portion of the project will focus on data that is of particular interest for salt marsh restoration initiatives. Baseline data currently integrated into the database include: 1:10,000 planimetric (NS,NB), property management units and type classification (NS), watershed boundaries (NS,NB), digital elevation model (NS, NB), Landsat 7 ETM – 30 m resolution imagery as well as digital orthophographs (4m resolution) for NB and orthorectified aerial photographs (1 m resolution) for portions of NS, particularly the Southern Bight of the Minas Basin. The full GIS will be available to researchers and government agencies as long as the potential users have secured appropriate licensing permission from the data providers if those data are not freely available. The geographical coordinates of tidal barriers inventoried for both NS (216 sites) and NB (91 sites) have been integrated into the GIS. Full fact sheets and summaries of the audits were prepared in conjunction with the EAC for NS and will be available this summer on-line as downloadable PDFs. Basic attribute information and maps for NB barriers will also be available within the GIS framework however completion of complete fact sheets available to the public is not feasible within the time frame of the project this year.

TABLE of CONTENTS

ACKNOWLEDGEMENTS……..2

I. INTRODUCTION.....4
1.1 General impacts of barriers…….4
1.2 Overview of tidal barriers……..…..4
1.3 GIS project…….……5

II STUDY AREA……..6

III METHODOLOGY……8
3.1 Overview…….8
3.2 Baseline data……8
3.3 Digital Imagery……..12
3.4 Integration of tidal barrier audit data……14

IV RESULTS.....15
4.1 GIS layers……15
4.2 Fact Sheets……..17
4.3 Preliminary historical imagery assessment……19

V RECOMMENDATIONS and FUTURE DIRECTIONS……..20

VI REFERENCES and RESOURCES…….22

APPENDIX A: Data sources…….24

APPENDIX B: Property ownership classification codes……..25

APPENDIX C: AML and VBA……26

APPENDIX D: Web interface……27

APPENDIX E: Examples of tidal barrier fact sheets……31

APPENDIX F: Inventory and assessment of available historical images……32

INTRODUCTION

1.1 General Impacts of Tidal Barriers

Figure 1: *Aerial photograph of causeway across Petitcodiac River in Moncton, NB (www.petitcodiac.com)*

Depending on the degree of restriction, tidal barriers will cause modifications to the flow regime and subsequent biological, physical and chemical processes in the surrounding area (Wells, 1999). In extreme cases (e.g. Petitcodiac river – Figure 1 - or Windsor Causeway), the impacts of these barriers can be quite dramatic (Figure 1), completely modifying the surrounding ecosystems. Although the impacts of these large structures is very visible, the cumulative impact of hundreds of smaller, less noticeable barrier structures causing partial or complete obstruction to flow is unknown. Potentially, their cumulative impact may exceed that of the larger tidal barriers mentioned earlier. Small barriers can just as easily reduce the area of estuarine habitat, including freshwater flow and alter flow dynamics, causing erosion or scouring of surrounding banks or increased sedimentation (e.g. Wells, 1999). In addition, areas formerly inhabited by salt marsh vegetation may now have converted to fresh water wetlands or dry land, eliminating an important nutrient source and nursery area to support the region's estuarine ecosystems, including fisheries. These smaller barriers however, are in most cases the most easily repaired (Figure 2) or removed to effectively restore tidal flow for restoration of salt marsh habitat and subsequent biophysical processes (e.g. Harvey, 2000). The need to effectively and systematically locate and assess the smaller tidal barriers in the Bay of Fundy stimulated the initiation of the Tidal Barrier Audits.

1.2 Overview of the Tidal Barrier Audits in the Bay of Fundy

Figure 2: *Close up of the old, double chambered, wooden culvert (CCCB 13C) at Christie Brook (River Hebert, NS). Classification: partial restriction.(Hynes et al., 2005)*

In 2000, a major initiative was undertaken by the Conservation Council of New Brunswick and in 2001 joined by the Ecology Action Center of NS to conduct a comprehensive audit of tidal barriers in the Bay of Fundy. Conducting an audit of tidal crossings is a critical initial step in the restoration process, identifying and highlighting potential areas requiring restoration and to some extent the feasibility of this restoration (e.g. removal of a causeway vs replacing a culvert or repairing an aboiteau). It generally consists of three phases: I (locating and visual assessment), II (quantitative data re tides) and III (analysis and recommendations). In 2001 the Salt Marsh and Restricted Tidal Systems Working Group (SMARTS) of BoFEP assisted in the evaluation

and modification of the initial CCNB audit methodology which used the *Tidal Barrier Handbook* (Puriton and Mountain, 1998) to better incorporate the macrotidal conditions of the Fundy region. The general assessment included a classification of the type of crossing and evaluation of the degree of restriction using quantitative (e.g. difference in tidal height upstream and downstream) and qualitative (e.g. bank scour, differences in type of flora and fauna). At this time, it was suggested that GPS coordinates be recorded. More detailed accounting of the methodology used may be found in any of the following audit reports (McCullen, 2000; Koller, 2001; Bowron and Fitzpatrick, 2001; Dalton *et al*., 2002: Hynes *et al*., 2004a and 2004b) as well as a detailed accounting of their findings.

1.3 GIS Project

1.3.1 *Rational*

Over the last century, the majority of rivers entering into the Bay of Fundy have been highly modified through the construction of tidal barriers. The construction of these barriers resulted in either partial or complete obstruction to tidal flow in many areas around the Bay. Tidal barriers effectively decrease turbulent energy in the tidal system causing sediments and other particles to drop from suspension and accumulate as deposits of mud, sand and silt. In other areas, localized erosion is initiated either directly upstream or downstream of a partially restrictive barrier. Ecosystems inhabiting this zone, such as mudflats and salt marshes, are some of the first environments to feel the effects of coastal modification. These changes have cascading impacts on intertidal ecosystems, some negative and others positive. Overall however, the cumulative impacts of tidal barriers on intertidal ecosystems of the Bay of Fundy are unknown. This is of particular concern with increasing interest in removing or modifying tidal barriers in an effort to 'return the tides'. Without a solid baseline of past and present 'states' of these systems, assessing or predicting the success of restoration activities is difficult.

In addition, cycles of progradation and retreat have been documented on a number of marsh and intertidal systems. These cycles have been linked to changes in sea level and in the tidal prism due to human activities such as tidal barrier construction or dredging, changes in wind/wave climate, sediment supply, cliff morphology, intertidal sedimentation and changes in the location of the major tidal channel. One of the most effective ways of documenting these changes is through the analysis of rectified aerial photographs within a GIS system. This is the preliminary stage that is required before any true questions regarding the 'why' of these changes are addressed.

1.3.2 *Partnerships*

This project incorporates a suite of collaborative research partnerships between the Department of Geography and the Maritime Provinces Spatial Analysis Research Center (MP_SpARC) at Saint Mary's University and Bay of Fundy Ecosystem Partnership (BoFEP), Inc. as well as the Ecosystem Science and Information Division of Environment Canada (Atlantic Region).

1.3.3 *Project Purpose and Objectives*

The purpose of this collaborative research project was to develop a comprehensive digital spatial database to integrate a series of environmental indicators over time, which can serve as a baseline to assess the cumulative impacts of tidal barriers in the Upper Bay of Fundy. In addition, these data will serve as a baseline to assess present and future states of intertidal ecosystems in the Bay of Fundy and identify areas for future research. The research focuses on the Upper Bay of Fundy with the Southern Bight of the Minas Basin being used as a case example of the application of such a

database. Objectives 1-3 will be addressed directly through this project whereas Objectives 4-6 represent a scoping exercise for future research and collaboration:

1. To integrate empirical data collected from the Bay of Fundy Tidal Barrier Audits performed by the CCNB (New Brunswick) and the EAC (Nova Scotia) into an ArcGIS geodatabase. The goal is to provide a coherent view of the extent and local physical impact of existing tidal barriers. All data, including photographs, collected during the previous surveys will be standardized and linked spatially to the database. This database will be made available to the general public with the assistance Environment Canada's media lab[1].

2. To create a geodatabase incorporating all available terrestrial layers include landuse (forestry, agriculture, urbanization), infrastructure (roads and rail), dykelands, vegetation and soil cover. Final layers will depend on licensing arrangements. Priority will be placed on acquiring data within the Minas Basin Bight area. [2]

3. To determine the current and historical spatial extents and changes in intertidal habitat (mudflats and salt marshes) using aerial photography, remote sensing images (e.g. Ikonos, Landsat, Radarsat) and existing GIS in the Minas Basin Bight at low tide.

4. To identify potential spatial relationships which will serve as a platform for future research on cumulative change and effects of restoration.

5. To begin a scoping exercise to identify existing coastal information layers which are not currently in a GIS format (e.g. shorebird counts, mudflat sediment composition, water quality assessment) but do contain spatial referencing information.

6. To assess the project and provide recommendations for a scoping exercise to evaluate the contribution of the geodatabase to existing partners and identify potential future collaborations.

STUDY AREA

Figure 4 depicts the geographical extent of GIS data to be incorporated into the geospatial database. Where possible (e.g. freely available), data were integrated for both NS and NB however, specific focus was placed on the Southern Bight of the Minas Basin in NS (Figure 3) for data that needed to be purchased or were only available through strict licensing agreements.

The Bay of Fundy is a large macrotidal embayment situated on the east coast of Canada between the provinces of New Brunswick and Nova Scotia (Figure 3). Two main branches extend off the central Bay: Minas Basin to the east, which is dominated by large accumulations of sand; and Chignecto Bay to the northwest, which is characterized by large accumulations of silt. The Bay of Fundy is

[1] The general public will be able to select barriers graphically from a base map of Nova Scotia and New Brunswick however will only have access to PDF layers of GIS and Tidal Barrier data due to digital data licensing restrictions. These files will be housed at Environment Canada, Dartmouth and data will be served via the BoFEP website. The full geodatabase will be housed at Saint Mary's University. Access to researchers will be negotiated on an individual basis dependent on academic data licensing restrictions.

[2] It is assumed that Environment Canada will negotiate individual licensing arrangements as needed for access to restricted digital data contained within the geodatabase. The original geodatabase will be generated using academic licensing agreements with relevant organizations (e.g. Nova Scotia Geomatics, DNR, etc..) and publicly available data.

located in the Appalachian region (Amos *et al.*, 1991), an area of deformed sedimentary and volcanic rocks. There is great variability in local relief due to the effects of glacial and fluvial erosion on rock outcrops of differing resistance. Essentially, Chignecto Bay is a glacially excavated, elongated macro-tidal estuary (Amos *et al.*, 1991) with blankets of transgressive, silty, glacial and postglacial unconsolidated sediments in the upper reaches. Chignecto Bay may be divided into three regions: 1) Chignecto Bay, 2) Shepody Bay, and 3) Cumberland Basin. The Minas Basin is a large, triangular basin at the head of the Bay of Fundy. Towards its eastern end, a promontory called Economy Point defines the outer limit of the eastern portion known as Cobequid Bay (Figure 3). The seaward boundary of the Southern Bight of the Minas Basin is defined roughly by a line from

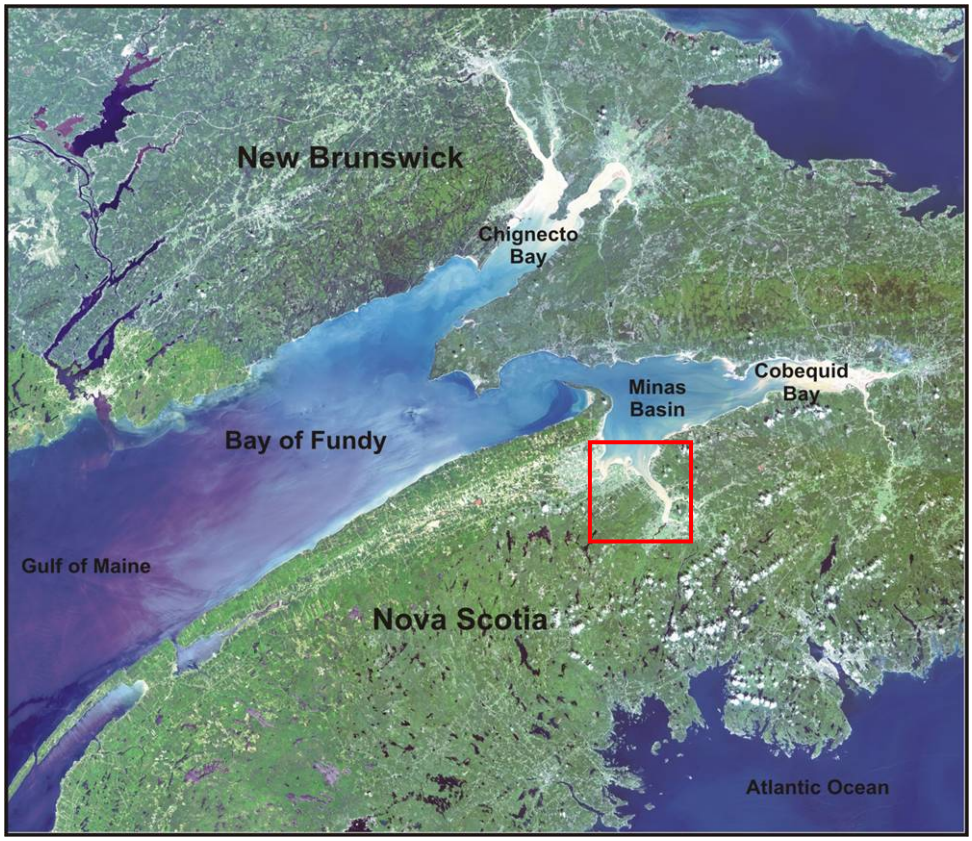

Figure 3: *Landsat Enhanced Thematic Mapper (ETM+), 30 m resolution used to illustrate study area of the Bay of Fundy. Smaller, red box illustrates the Southern Bight and study area for more detailed analysis.*

Cape Blomidon to the vicinity of Cambridge (Hants Co.). It includes the Cornwallis and Avon Estuaries, the smaller Gaspereau Estuary, and three rivers (Canard, Habitant and Pereau).

European settlers arriving at the upper Bay of Fundy region in the 17th century would have been greeted by large expanses of salt marsh. The shape of the basin created a sheltered embayment with abundant supplies of fine sediment, ideal for the development of large tracts of salt marsh along the coast. Recognizing the rich agricultural potential of these marshes, early settlers quickly applied their homeland experience in reclamation and dyking to the marshes of the upper Fundy region. Since the 1900s, barriers have been built to allow for road or rail crossings, creation of headponds for generation of hydro or tidal power and recreational areas as well as the control of water levels and water flows for flood control, logging and industrial activities (Wells, 1999; Daborn *et al.*, 2004). Forty-four large and medium-sized rivers flow into the Bay of Fundy (Wells, 1999), 18 of which are found in NB and 26 in NS. The tidal barrier audit was responsible for assessing the degree of restriction for all tidal crossings in the region.

METHODOLOGY

3.1 Overview

The development of a comprehensive digital spatial GIS database for the Bay of Fundy is an on-going initiative that is being coordinated through Saint Mary's University and builds upon partnerships between academic institutions (Saint Mary's, Mount Allison, Acadia University), government agencies (Environment Canada, Canadian Wildlife Service, Department of Agriculture and Fisheries) and non-government organizations (Bay of Fundy Ecosystem Partnership BoFEP, Ecology Action Centre, Conservation Council of New Brunswick). All data that was incorporated within the geospatial database was transformed to the following coordinate system:

NAD 1983 Zone 20
Transverse Mercator
False Easting: 500000.000000, False Northing: 0.000000
Central Meridian: -63.000000
Scale Factor: 0.999600
Latitude of origin: 0.000000
North American 1983, CSRS 98

Data originally in Geographic Coordinates (Lat/Long), NAD 1927, ATS77 MTM were transformed to NAD 1983 CSRS 98 using the appropriate transformation algorithms in ArcGIS. It is understood that individual licensing arrangements might be needed for collaborators (other than Environment Canada) for access to restricted digital data contained within the geodatabase. Because of this fact, the majority of data that are included within the original geodatabase will be generated using academic licensing agreements with relevant organizations (e.g. Nova Scotia Geomatics, DNR, etc..), publicly available free data (e.g. Geogratis) or purchased by proponents (e.g. aerial photographs for Nova Scotia purchased by Dr. D. van Proosdij and Env. Canada) even if these might not be the most detailed information available. Detailed metadata are provided for each layer incorporated within the GIS and data sources are summarized in Appendix A. Only the final PDF tidal barrier fact sheets and associated maps are available to the general public over the Internet.

3.2 Baseline Data

Initially, all *available terrestrial layers include landuse (forestry, agriculture, urbanization), infrastructure (roads and rail), dykelands, vegetation and soil cover* (Objective 2) were to be incorporated into the geospatial database. However, after consultation with members of the Bay of Fundy Ecosystem Partnership at the 6th annual meeting (September 29- Oct 2) in Cornwallis, Nova Scotia the type of layers to be included was revised. The general feeling of those who would use the audit data and are working on restoration projects thought that it is better to be more focused in some aspects rather than have lots of superficial and superfluous data (eg. many terrestrial layers). The primary need identified from the BoFEP community was to be able to quickly access data regarding a particular tidal barrier in the region. The following types of information were deemed critical: barrier fact sheet (indicating type, degree of restoration, condition, date of replacement[3]), property ownership (Property ID and type of ownership), aerial photos and a high resolution DEM landward of the barrier to calculate area which would be flooded and potentially restored. This last variable is recognized as being critical to restoration efforts; however, it would require intensive field work. This project incorporates DEM data where available and provides as much air photo

[3] Consultation with Bob Pett of Nova Scotia Department of Transportation determined that most culverts did not have set replacement dates.

coverage as possible. Flood zones may be delineated based on vegetation and general topography in the future. In addition, additional layers may be added as needed.

3.2.1 Planimetric

In order to effectively integrate the Geographic Information System (GPS) coordinates collected through the Tidal Barrier Audits, a detailed digital planimetric base layer of the Fundy coastal regions of New Brunswick (NB) and Nova Scotia (NS) needed to be created. Over 500 individual 1:10,000 digital topographic tiles were merged together and individual features of interest (roads, rivers, urban areas, coastal areas and transmission lines) were selected based on feature code and exported as individual shapefiles. The planimetric data serve two fundamental purposes: it creates a map to house the barrier data and it serves as vector data to be used for georeferencing and orthorectifying aerial photographs.

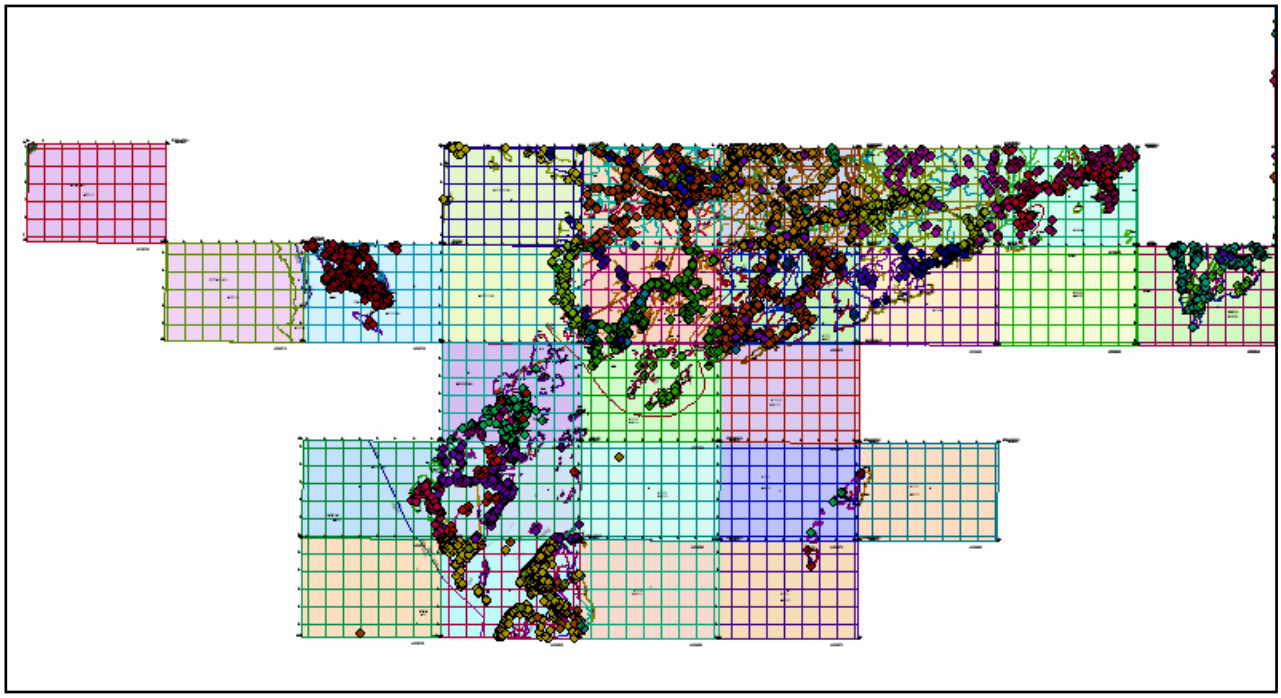

Figure 4: *Example of 1:10,000 digital map sheets for southern portion of NB from Service New Brunswick. Data in the raw form is very cluttered and must be 'cleaned' prior to use.*

However, the methods of acquisition and transformation of the data differed between NS and NB. Nova Scotia 1:10,000 map sheets were downloaded as zipped .EOO files from Nova Scotia Geomatics at http://www.gov.ns.ca/snsmr/land/products/geographic_access.asp. Only the files adjacent to the shoreline were selected. These data were converted from ArcInfo interchange files to ArcMap coverages using Arc Toolbox. Coverages were merged using the Geoprocessing Wizard in ArcMap to produce a full seamless planimetric base layer. NS data were transformed from ATS 77 MTM Zone 5 to UTM Zone 20 NAD 1983 CSRS 98 using Arc Toolbox and a grid shift file. Data for NB were gathered using a similar procedure however the format of the data was different and required additional modification. Each zipped folder contained several files including .gxf, .hxf and .rxf files which were all changed to a .dxf format. In addition, the NB data had to be transformed from a New Brunswick Double Stereographic Projection and a NAD 83 CSRS 98 datum to UTM Zone 20 NAD CSRS 98 to perfectly merge with the NS shapefile created earlier.

This initial planimetric map contained too much detail to distinguish individual layers (Figure 5a) therefore features of interest (e.g. roads, rivers, treeline, coastline, urban areas, transmission lines and dykelands) were selected based on feature code and exported as individual shapefiles (Figure 5b) enabling the user to turn layers on and off as needed.

Figure 5: a) *Avon river planimetric file without individual features is difficult to identify. This makes georeferencing and orthorectification very difficult.*

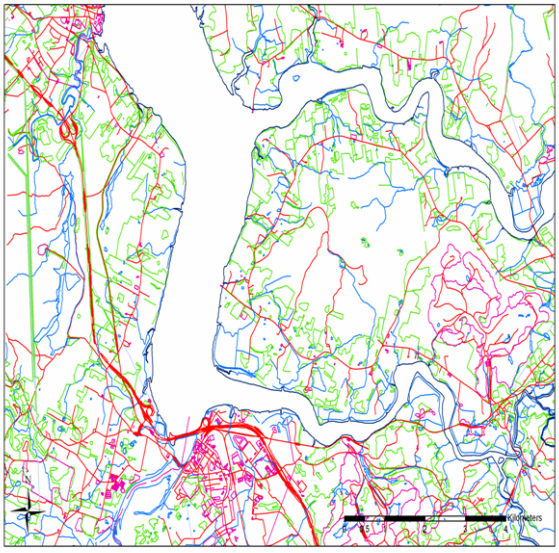

Figure 5: b) *Avon river planimetric file with individual features. This makes a more suitable map for georeferencing and can be easily manipulated.*

3.2.2 Property Management Units

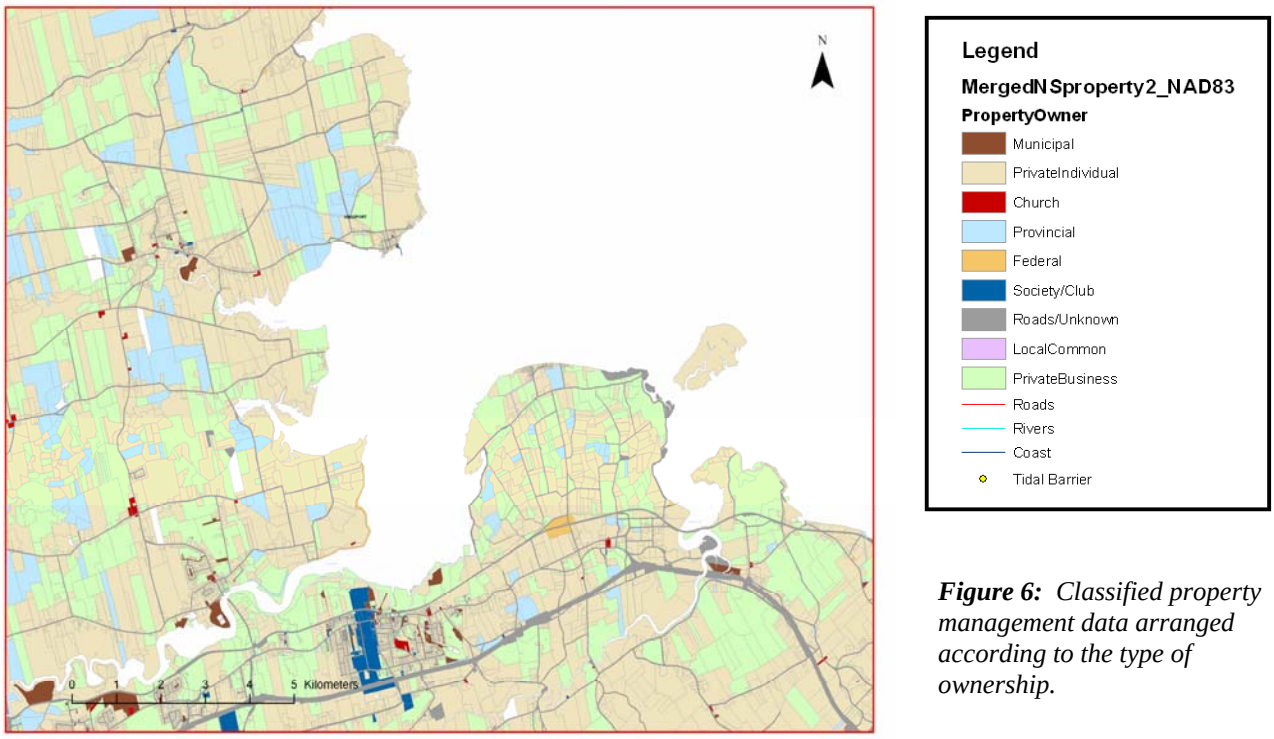

Figure 6: *Classified property management data arranged according to the type of ownership.*

In order to properly classify the properties, a table join had to be created between the *PIDName.dbf* file and Property shapefile using the PID fieldname as the primary key. The owners were then categorized as: Municipal, Provincial, Federal, Private Individual, Private Business, Church, Society/Club, Local Common, Roads/Unknown (Appendix B) and saved as individual shapefiles (Figure 6).

3.3.3 Watershed Boundaries

Nova Scotia watersheds were supplied by Environment Canada and were dissolved into three levels, Primary, Secondary and Tertiary. The Primary watershed was created with the use of the Geoprocessing Wizard in Arc Map. The primary layer was dissolved based on the "primary" feature attribute. It was then joined with the *NSPrimary_sheds.csv* file to properly label the primary watersheds. The Secondary watersheds were created by concatenating the Primary and Secondary feature class using the Arc Map field calculator (Appendix C). The COMBINED field was created and a dissolve was conducted on this field. This file was then joined with *NSsecondaryWaterNames.csv* in order to display watershed names. The Tertiary watershed was created in the same manner as the Secondary watershed except that the Primary, Secondary and Tertiary are used in the Field Calculator script (Appendix C). There are no Tertiary watershed names available. The three completed Nova Scotia watershed files are named: *NSprimaryWater, NSsecondaryWater2, and NStertiaryWater.* Watershed boundaries for NB were also completed using a similar methodology.

3.3.4 Digital Elevation Model

A digital elevation model (DEM) was constructed for NS and NB within ArcGIS using the 1:10,000 DEM data. The DEM was created by Matt Mahoney at Environment Canada and provided elevation data critical for future research (Figure 7). Although the resolution of these data is not sufficient to accurately model flooded areas at any of the tidal sites, they are quite useful for identifying former marshland areas and coastal habitats.

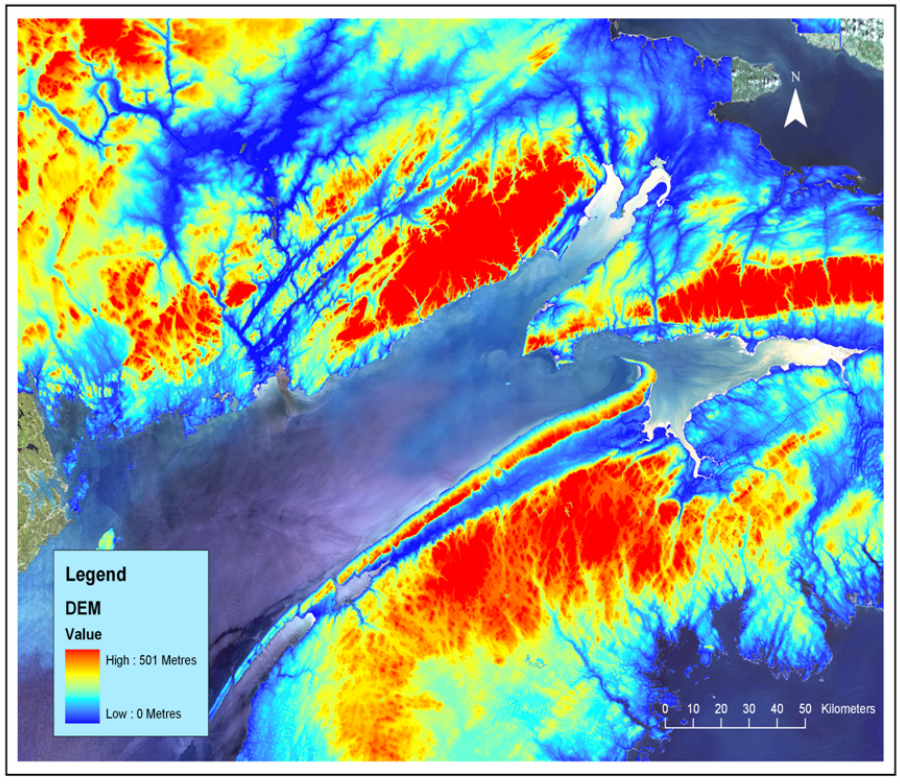

Figure 7: *Digital elevation model (DEM) of NS and NB at 20 m resolution created by Matt Mahoney Environment Canada.*

3.3 Digital Imagery

3.3.1 Aerial photography

All available aerial photographs were integrated into ArcGIS however the process differed between NB and NS. New Brunswick aerial photographs were supplied by Service New Brunswick and were already in digital format in 1:10,000 sheets consisting of six, rectified and mosaiked aerial photographs. Although available free of charge, the resolution of the images was only 4 m and date back to 1996. However they can provide a good overview of the type of landuse activities surrounding different tidal barriers when used as a base layer. The 1-m resolution orthophotos are available for download from Service New Brunswick if desired in compressed format. Due to the format of the data (e.g. tiled with no feducial marks) a different AML code *(&r merge.aml***)** was implemented to merge these files together (Appendix C). Using Arc Catalogue, each air photo tile was defined as having a New Brunswick Double Stereographic projection and a NAD 83 CSRS 98 datum. These files were transformed on the fly in ArcMap when integrated with the NS data and can be transformed permanently to UTM grid zones 20 and 19 if desired. Additional consultation with proponents is required to confirm the grid zone to be used.

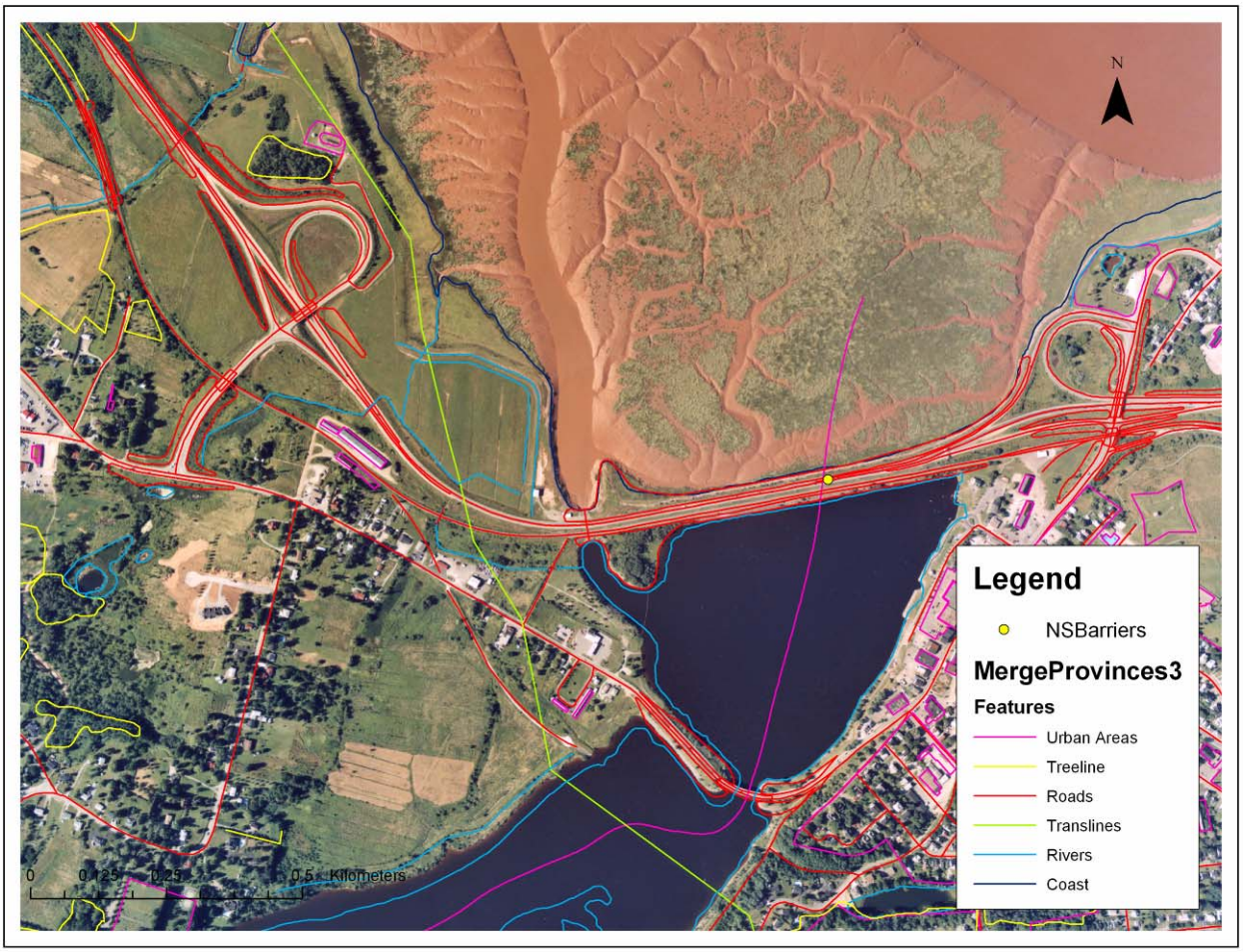

Figure 8: Planimetric vector data used to rectify air photos by collecting Ground Control Points and accurately aligning specified features

In Nova Scotia area, approximately 128 - 1:10,000 additional color aerial photographs (1992 and

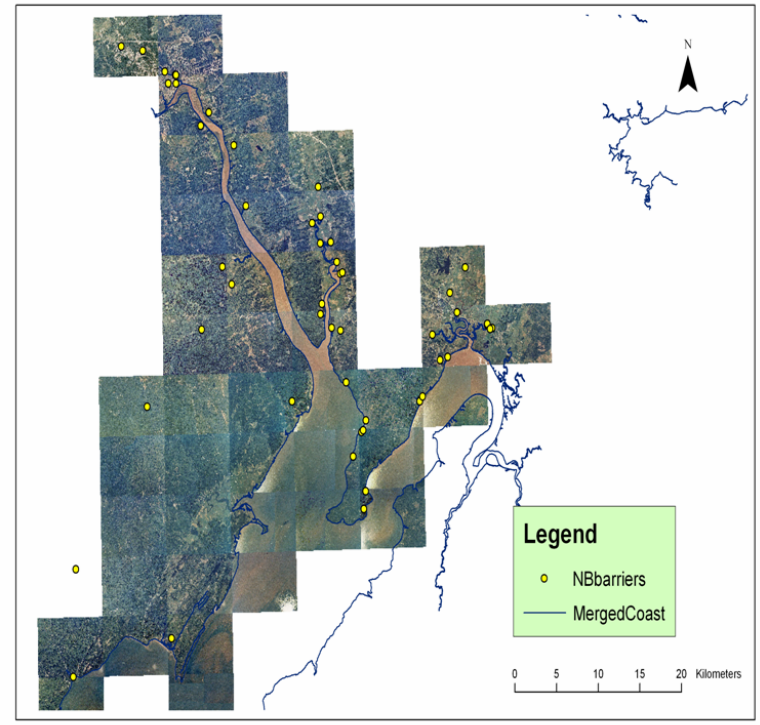

Figure 9: *Initial (prior to refinement) mosaic created using NB digital orthophotographs available on-line at 4 m resolution.*

2002/2003) were scanned at an appropriate resolution (300 dpi) to produce 1 m ground resolution. These photographs were either purchased for this project or are the property of one of the collaborators. Most air photos are located in the Southern Bight of the Minas Basin and the 2002- 03 photos were chosen to be used for the tidal barrier project component. The images were scanned, georeferenced, orthorectified and mosaicked to produce a composite mosaic of aerial photography to date. Additional photos are being added as they become available. Figures 8, 9 and 10 illustrate the results of georeferencing, using first order polynomial and orthorectification using a second order polynomial. Although the images were not rectified using DEM data, the resultant error is within the error of the original 1:10,000 map sheet (typically 3-4 m). A rectification was deemed acceptable when the RMS value was less than 3. An RMS is defined as a "Root Mean Square error and is a measure used to assess the accuracy of geometric correction" (Canada Centre for Remote Sensing). It incorporates the distance between the input (source) location of a GCP and the retransformed location for the same GCP. Once properly orthorectified, the images were mosaiked using the *AP_mosaic_nr.aml* AML summarized in Appendix C. In the future, a similar procedure will be conducted with images from earlier years and these images will be used to determine the current and historical spatial extents and changes in intertidal habitat.

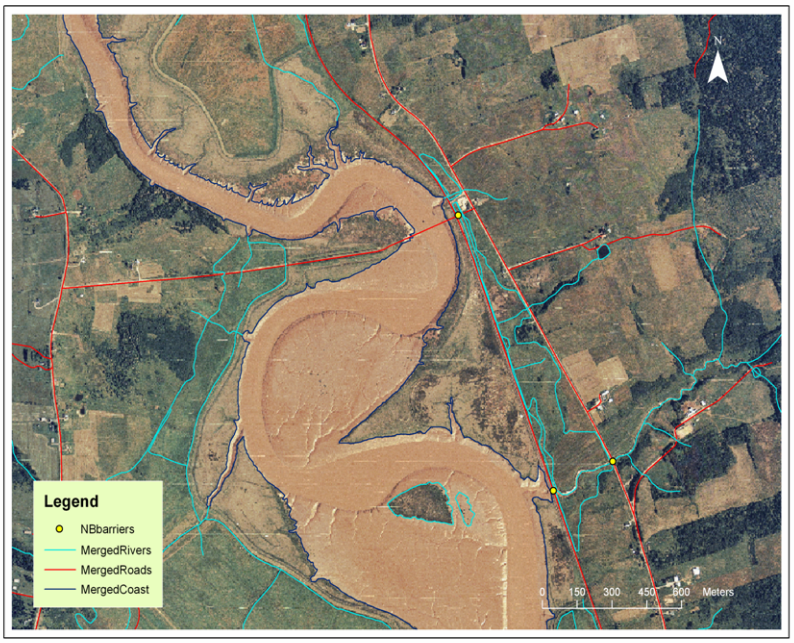

Figure 10: *Magnified 4 m resolution digital orthophoto illustrating planimetric reference layer and tidal barriers.*

3.3.2 Satellite Imagery

A true- color composite image of the Bay of Fundy was created using 30 m resolution Landsat 7 ETM data from 1999 and 2000 to aid in the visualization of the tidal barrier data (Figure 3). Images range from 1999 to 2000. Images were acquired free of charge from the Earth Science Data Interface

(ESDI) at the Global Land Cover Facility at the University of Maryland. Each image was downloaded in GeoTIF format and done so one band at a time. There were six Landsat scenes with three bands each and Bands 1,2,3 were used to make a true- color image. These images were initially converted from TIFF format to PIX format in Geomatica Focus and the three bands were combined using a layer stack procedure to create a multispectral image using using PCI's Xpace program. Once one of the bands was selected, (using Xpace) the *PCIMOD* command was run to create two more image channels. The images were transferred to the one parent image using the Image Transfer command in Xpace to produce a true- color multispectral image. This process was repeated for all six scenes and converted back to TIFF format for creation of the final mosaic. Once all the scenes were combined, an AML script (*AP_mosaic_nr.aml)* (Appendix C) was run to mosaic the scenes together. Once the mosaic was completed, the image was further refined using Adobe Photoshop to correct overlapping flaws (Figure 3).

3.4 Integration of Tidal Barrier Audit into GIS

Barrier coordinates were supplied by the Conservation Council of New Brunswick (CCNB) for the New Brunswick coast and by the Ecology Action Centre (EAC) for the Nova Scotia coast as latitude and longitude. These data were provided in .xls format based on GPS coordinates collected (where possible) in the field. In total there were 216 coordinates supplied by the EAC and 91 from the CCNB. These data were converted to decimal degrees and saved as .csv to be added to ArcMap as x/y data. These data were verified in three different stages: 1) checking for outliers or extreme values at provincial scale; 2) close up verification of position with aerial photographs and planimetric data and 3) confirmation of appropriate barrier ID code and attribute information in the GIS with published tidal barrier reports compiled by the CCNB and EAC. Both the NS and NB passed the stage one verification. However only the NS data passed Stage Two and Stage Three verification initially. Considerable difficulties were experienced with the NB data ranging from incomplete coordinates, data entry errors and positional errors however by the end of the project all barriers were incorporated into the GIS and matched the reports available. The development of individual fact sheets however for NB however was not possible due to financial and time constraints.

Figure 11: *Web site banner for Tidal Barrier Project on-line access.*

The web application was developed with consultation and support from Environment Canada's media lab using Macromedia Dreamweaver and may be run directly off of a CD if desired by selecting the *index.htm* file contained within the BOFwebsite folder. Web page contents are included in Appendix D. A template was created with a cascading style sheet and menu buttons using Macromedia Fireworks. The Landsat mosaic was used as the base map and 'hotspots' with hyperlinks were created throughout the map in order to zoom to different scenes and resolutions. At the lowest level, each tidal barrier can be selected individually and links directly to a corresponding PDF fact sheet file for download. Alternatively, facts sheets may also be downloaded as a group by County if desired. Links to other relevant sites are included within the site and individuals are directed to these areas for more detailed information regarding more specific aspects of the Tidal

Barrier Audits and salt marsh restoration in Atlantic Canada rather than duplicate existing information. This web site will be hosted and managed by BoFEP and will be updatable in the future as needed. It is anticipated that the data will be updated as they become available, at a minimum every two years.

RESULTS

4.1 GIS Layers

The following table summarizes the status, availability and current geographical coverage of layers within the GIS database at the present time.

Type	Layer	NS	NB	Comments
Base Data	Planimetric	■	■	
	Property data	■		
	Watersheds	■	■	
	DEM	■	■	
	Landsat	■	■	
	Aerial photographs		■	Rectification of available photographs on-going.
Tidal Barrie	Barrier coordinates	■	■	
	Verification	■	■	
	Fact Sheets			Not all will have aerial photos
	On-line			Basic attribute info, NS fact sheets

Table 1: *Current availability of data within GIS database. Shaded boxes (black vs grey) indicate data currently transformed and integrated into ArcGIS. Refer to Appendix B for status of availability of fact sheets for NS.*

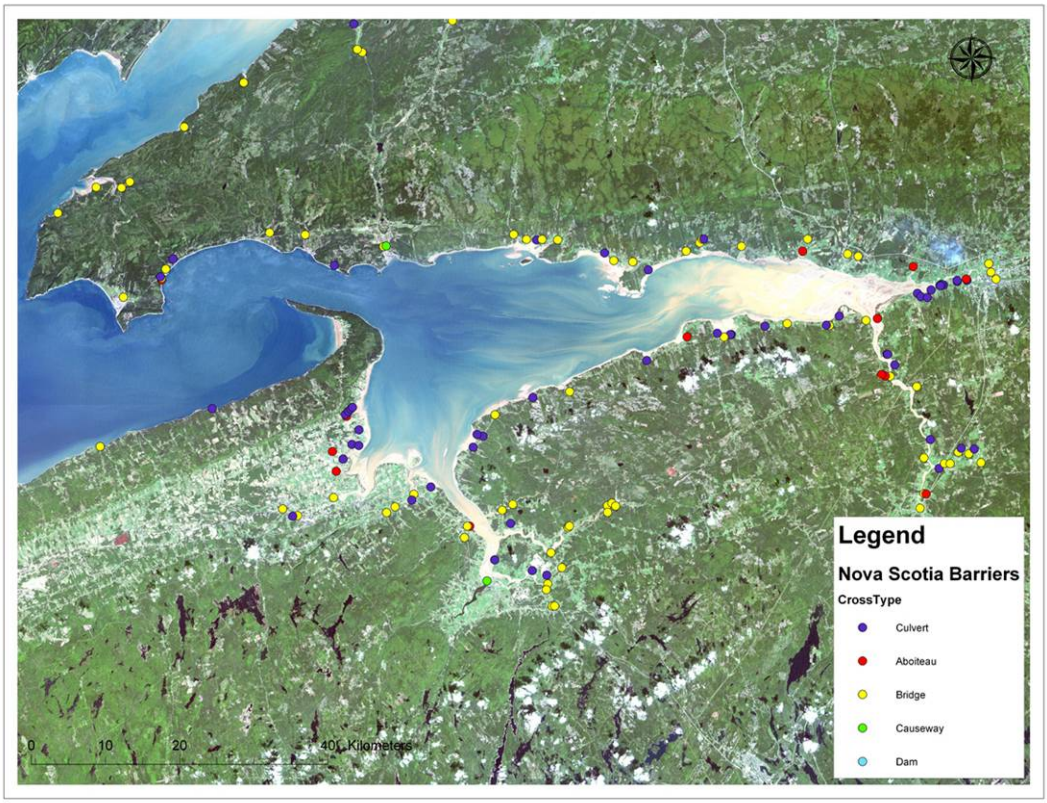

Figure 12: *Example of map produced using a simple 'crossing type' query for tidal barriers in the Southern Bight overlaid on Landsat 7 base image. Data could just as easily be displayed over planimetric base map layer.*

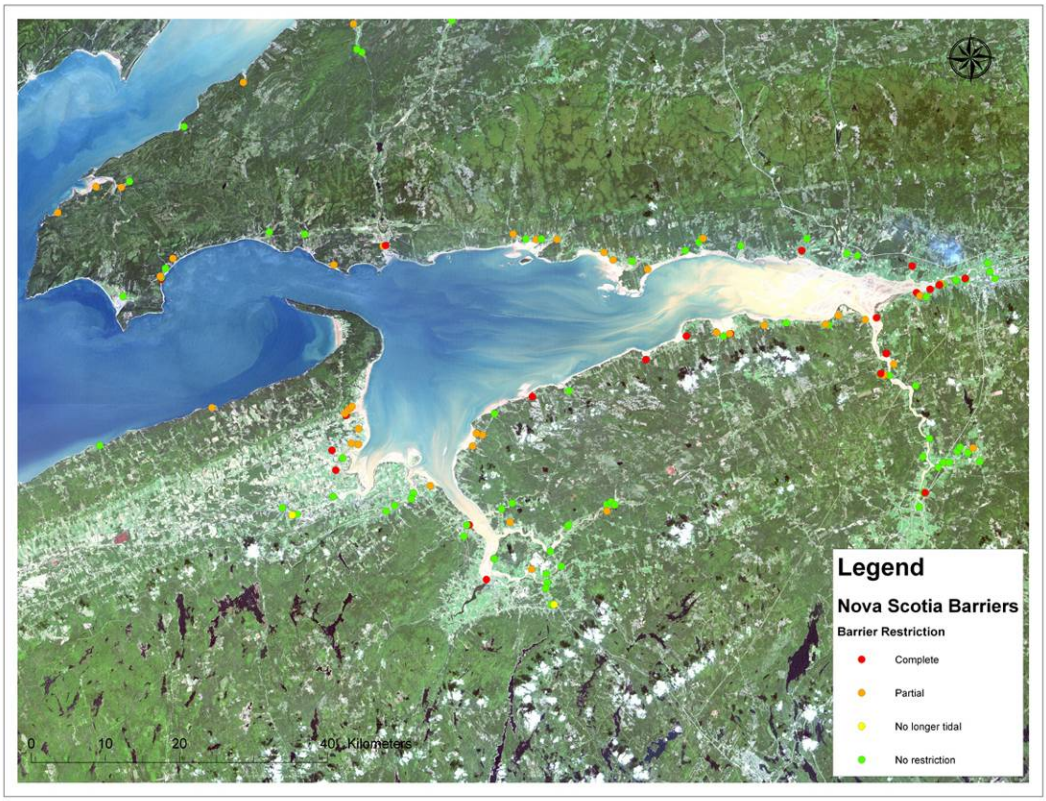

Figure 13: *Example of map produced using a simple 'degree of restriction' query for tidal barriers.*

The database will reside in MP_SpARC at Saint Mary's University and additional data will be added as they become available. All GIS data will also be provided (on an external hard drive) to Environment Canada. Access to individual researchers will be arranged through Saint Mary's University pursuant to the researcher securing licensing approval from data providers. These data can be used to perform simple queries such as 'crossing type' (Figure 12) or 'degree of restriction' (Figure 13) or more complex analyses of change in habitat over time (Figure 14).

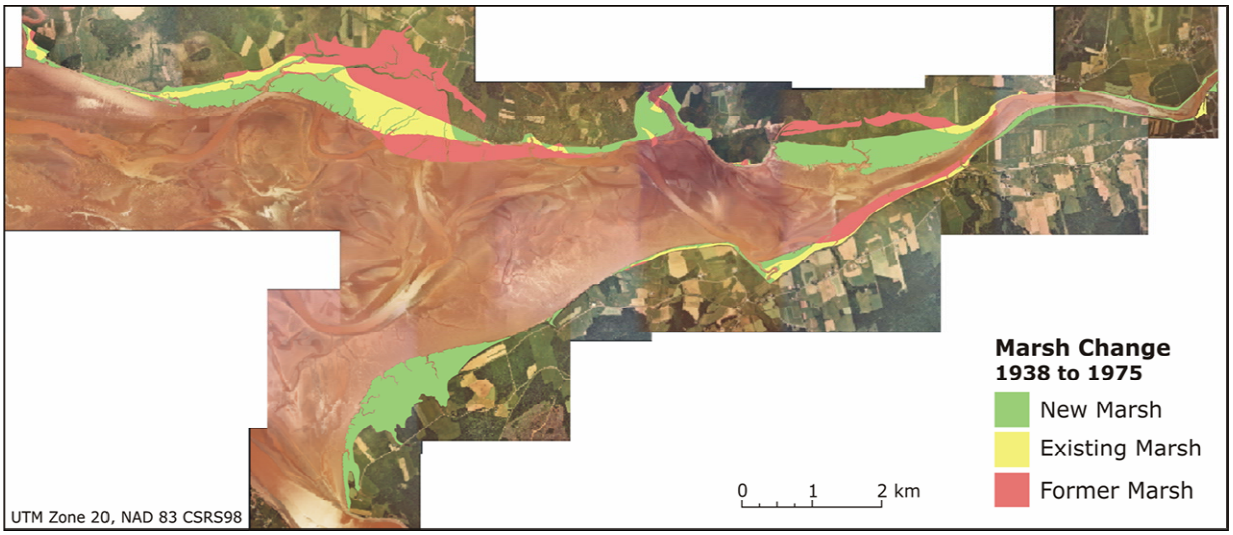

Figure 14: *Example in Cobequid Bay, NS of type of historical spatial analysis (quantification of change in marsh area) that can be conduced using this GIS database. Figure from Baker and van Proosdij, 2004.*

4.2 Tidal Barrier Fact Sheets

The EAC and the CCNB conducted have been systematically developing an inventory of tidal barriers in the Bay of Fundy since 2000. This was a massive undertaking and in total, there have been 216 barriers surveyed in NS and 91 in NB. Although each organization completed (or are nearing completion) an annual report for the barriers surveyed that year, and after 2001 began using a somewhat standard methodology based on input from SMARTS, the storage and organization of those data differed between organizations. Integration of the audits into a GIS system was really more of a hindsight idea which meant that some of the data were not necessarily organized or verified appropriately for use in a geospatial way. This limits the complete integration of all attribute data into the GIS at this time. It should be noted that some of the barrier data are available on-line through the CCNB web site's *Return the Tides – adopt a barrier campaign* however with no spatial reference. With the help of the EAC, tidal barrier fact sheets were developed for all 215 barriers in NS. These fact sheets contain general information regarding the geographical location of the barrier, crossing status and condition, type as well as restriction indicators. Observations downstream and upstream are also provided as well as comments regarding repair or restoration potential. A series of examples of fact sheets are provided in Appendix E. In addition, photographs are included with appropriate captions and as well as maps showing the location of the barrier, surrounding properties with PIDs and an aerial photograph where available. Fact sheets without aerial photographs will be updated as the photographs are secured.

After consultation with Environment Canada's media lab, it was decided that the on-line distribution of the tidal barrier data will be a static system where the general public will be able to download PDFs of maps associated with each barrier. The initial interface will be interactive and the user will be able to navigate (zoom) through a series of static layers to select a barrier of interest off of their screen (Figures 15-17). This will then connect them to a PDF file containing the tidal barrier fact sheet (Appendix E) and associated maps (Figures 18 and 19).

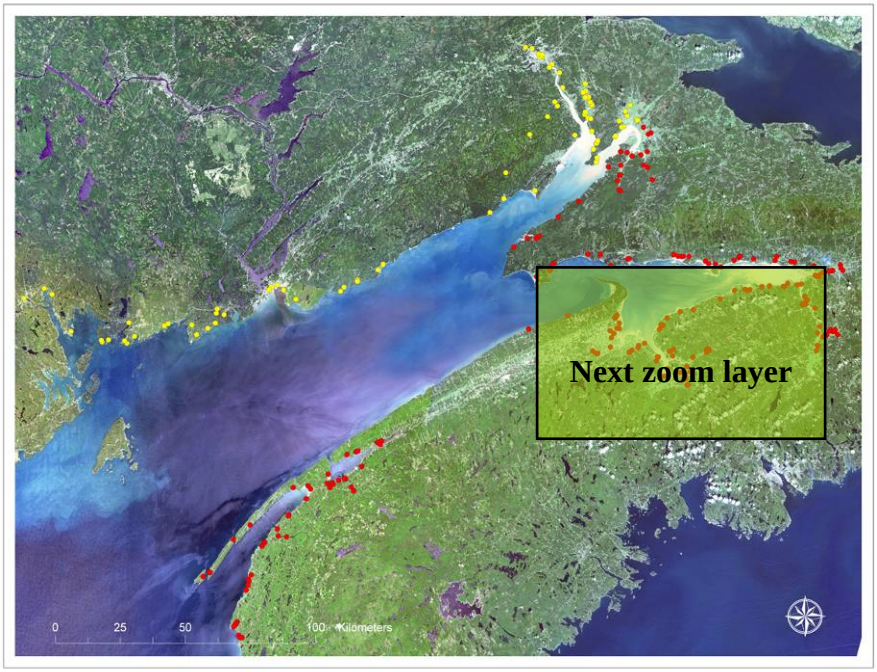

Figure 15: *Full zoom level for on-line distribution of tidal barrier data. User would 'click' on area of choice to get to next zoom layer (indicated by shaded box) illustrated in Figure 15.*

Figure 16: *Second zoom level for on-line distribution of tidal barrier data. User would 'click' on area of choice to get to next zoom layer (indicated by shaded box) illustrated in Figure 16.*

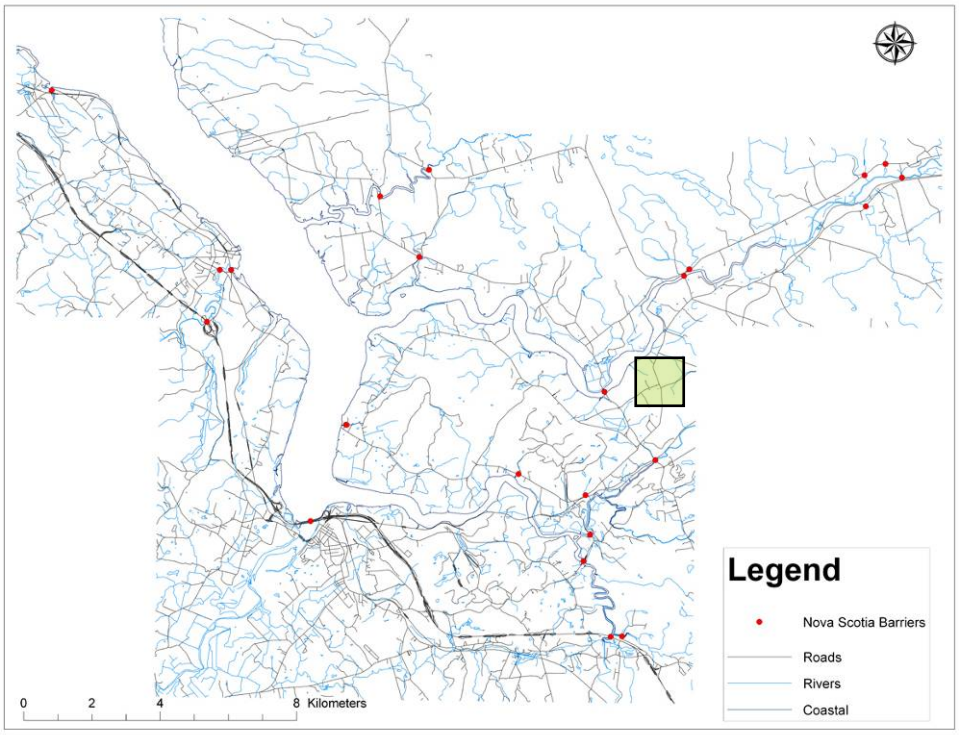

Figure 17: *Third zoom level for on-line distribution of tidal barrier data. View has now switched to planimetric base layer due to coarse resolution of the satellite image at this scale. User would 'click' on barrier of choice to get to final zoom layer (indicated by shaded box) illustrated in Figure 17.*

Figure 18: *Final zoom level for on-line distribution of tidal barrier data. Tidal barrier in question is labeled on the aerial photograph (1 m resolution). Photographs were rectified as much as possible and the position of the barrier is within the margin of error (generally 3-4m) of the errors inherent in the 1:10,000 map sheets. Fact sheet available at this level.*

4.3 Preliminary Historical Imagery Assessment

Initially, one of the objectives of this project was to determine the historical spatial extents of intertidal habitat in the Minas Basin. It was rapidly realized that this was a gross underestimation of the time that it takes to procure and orthorectify the aerial photography as well as cost involved. Based on rough calculations, there are 250 km of coastline in the Minas Basin from Cape Split to Diligent River. This calculation does not duplicate coast where river banks are close enough to be covered in one photo. Based on a scale of 1:10,000 aerial, non-stereographic coverage, it would take approximately 400 photos *each year* to accurately assess this. Therefore, this component of the project simply

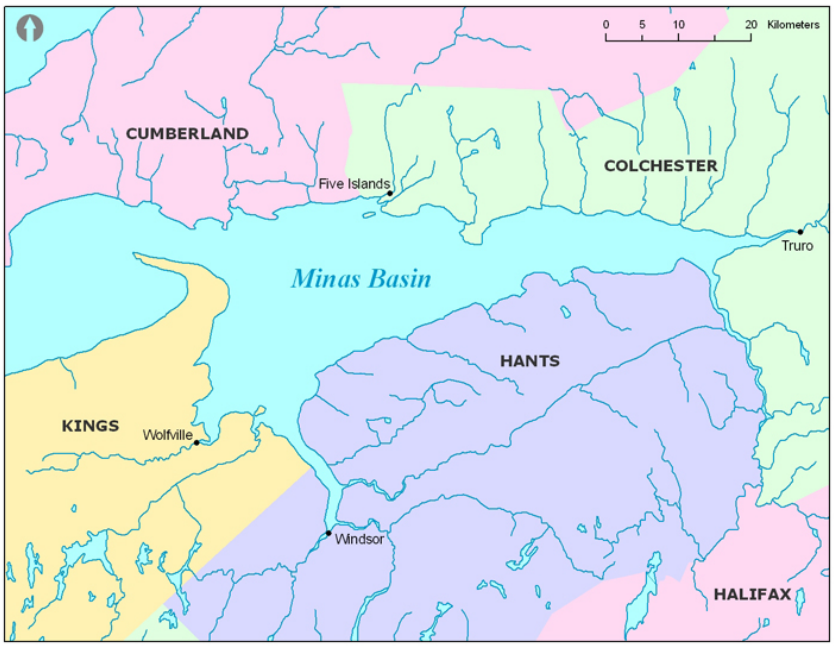

Figure 19: *County boundaries surrounding the Minas Basin, NS.*

assessed the availability of aerial photographs and their suitability for change analysis (e.g. collected at low tide). This information can then be used to choose a more detailed study area for in depth analysis such as adjacent to the Windsor Causeway (e.g. van Proosdij and Townsend, 2004). Although some satellite imagery of the area is available and this avenue will be pursued further, it does not have adequate historical coverage and 30 m resolution really is not accurate enough to pick up smaller scale changes in habitat.

Table 2 summarizes the years for which photographs are available from NS Land Information Services and the National Aerial Photo archives (pre 1960s primarily). Photographs along each flight line were examined individually and ranked according to their level of tidal height. Unfortunately many of the photographs that have been taken over the years are at high tide which is not usable for assessment of the intertidal zone. Figure 19 illustrates the county boundaries for reference purposes. Another complicating factor is that adjacent counties are not necessarily flown in the same year however most do seem to be flown within 2-3 years of each other. Please refer to Appendix F for a detailed listing of photographs and their assessment.

County	Years photographs available for historical analysis
Cumberland	1967, 1975, 1985, 1995
Colchester	1964, 1967, 1974, 1975, 1994, 2003* (Cobequid Bay only)
Kings	1964, 1966, 1977, 1981, 1992, 2002/03
Hants	1964, 1966, 1977, 1981, 1992, 2002/03

Table 2: *Availability of historical photographs for counties surrounding the Minas Basin. Not all of these will be suitable to use in investigating changes in salt marsh and mudflat habitat since they were flown at mid or high tide. Photos are also available for 1931 to 1945 and 1953 to 1955 in select areas.*

RECOMMENDATIONS and FUTURE DIRECTIONS

This report represents simply one stage in on-going research on the impacts of tidal barriers on ecosystem health in the Bay of Fundy. The integration of the tidal barrier audit and development of a geospatial database has grown into an enormous undertaking, not only in terms of the volume of data but in the transformation, acquisition and organization of these data as well. As with many GIS projects, a considerable amount of time was spent formatting and transforming the data into a format suitable for integration into the GIS. In addition, important pieces of data were not available until the later half of this project, therefore limited the overall scope somewhat. Overall however, the on-going development of this geospatial database is definitely needed, particularly as there is increasing interest and opportunities for restoration through HADS compensation projects. The fact sheets can also provide a base for educating the local public of the impacts of barriers in their local area. This project should definitely be extended to include all of NB and will be a definite help to managers, conservationists and researchers, providing quick access to site specific information.

One of the unique aspects of this project is that it demonstrates successful cooperation across government, academic and community sectors and brings different strengths to the table. It permits the inclusion of local, community based knowledge as well as academic and government expertise and institutional support. However, this integration was not without its challenges. These ranged from challenges in data transformation and management to the integration of point survey data (e.g. tidal barrier audits) originally indented as paper products. One of the principle lessons learned from this exercise was the need to personally train community member conducting ground level surveys

in the proper use of GPS, consistency of reporting and assessment methods and vital need for unique point identifiers within the database, even if the survey spans a number of years. Time should be taken in the initial stage of any project to decide on and refine an effective, proactive database management structure. The success of this was evident by the ease at which some of the later audits breezed through Stages One to Three verification after support and training by academic researchers and the Salt Marsh and Restricted Tidal Systems (SMaRTS) working group of BoFEP after 2002. Future audits or the expansion of existing surveys should follow the database structure and appropriate coordinate system outlined within this project to permit continuity.

It is acknowledged that there are digital layers which are currently not included within the database at this time which would be useful in the future. This project represents a pilot exercise and has purposely been designed as a dynamic system, permitting new data to be added in the future. Presentations and consultations with colleagues (e.g. Environment Canada, SMARTS, Minas Basin Working Group, DFO) have indicated a number of potential additional data layers such as bathymetry, marsh area (dyked and undyked), sedimentation patterns and restoration potential. In addition detailed DEMs should be developed around barriers that have been identified in the audit as having high restoration potential. This will allow for accurate determination of habitat which will potentially be restored.

Viewing and exploring data at varying scales can open up new avenues of inquiry and potentially identify patterns not immediately visible at the local scale. For example, it can reveal spatial patterns of sedimentation and erosion or sequence of barriers needed to be modified or removed along a river course to permit fish passage. Furthermore, the restoration of salt marsh habitat can be used as a means of mitigating some of the impacts of climate change in the long term. However, the long term ecosystem and geomorphic impacts of restoring or enhancing tidal flow in a macrotidal environment such as the Bay of Fundy is not clear nor is it possible to predict if the 'system' will return to a pre-existing 'state'. Models and restoration practices developed and adopted by jurisdictions in other areas cannot be simply extrapolated to marshes facing 14 m tides, high suspended sediment concentrations, dynamic intertidal conditions and ice. This project can help provide the foundation to begin to address these issues and plan for the future. However, it is only by having a solid understanding of present conditions can one explore the questions of 'why', 'how much' and what will happen in the future.

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APPENDIX A

Summary of Geospatial Data Sources and Contact Information

Planimetric Data for Nova Scotia
Acquired from Service Nova Scotia and Municipal Relations.
URL: http://www.gov.ns.ca/snsmr/land/products/geographic_access.asp
Contact Person: Unknown
Free data available on-line.

Planimetric Data for New Brunswick
Acquired from Digital Topographic Data Base 1998
URL: https://www.planet.snb.ca/PLANET/docs/topo/dtdb98/index.html
Contact Person: Peter Webster, (Saint Mary's University Library)
Free data used under academic license.

Property Data for Nova Scotia
Acquired from Service Nova Scotia and Municipal Relations.
URL: http://www.gov.ns.ca/snsmr/land/products/geographic_access.asp
Contact Person: Unknown
Free data used under academic license.

Nova Scotia Watersheds
Acquired from Environment Canada
URL: unknown
Contact Person: Charlie Williams (Provincial Department of the Environment)
Free data

New Brunswick Watersheds
Acquired from Environment Canada
Contact Person: Faye Cowie (NB Aquatic Data Warehouse)
Email: ardw@nbnet.nb.ca

Maritimes DEM
Acquired from Environment Canada
Contact Person: Matt Mahoney
Email: Matthew.Mahoney@EC.GC.CA
Free data

Air Photos for Nova Scotia
Acquired from Environment Canada and archives.
Contact Person: Matt Mahoney
Email: Matthew.Mahoney@EC.GC.CA
Some images purchased with funds from Environment Canada.

Air Photos for New Brunswick
Acquired from Service New Brunswick
Contact Person: Unknown
URL: https://www.web11.snb.ca/snb7001/e/2000/2900e_1b.asp

Free data with academic license.

Landsat Mosaic
Data acquired from the Earth Science Data Interface (ESDI) at the Global Land Cover Facility
Contact Person: Unknown
URL: http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp
Free data to public

Barrier Coordinates for Nova Scotia
Acquired from Ecology Action Centre, modified by Saint Mary's University
Contact Person: Tony Bowron or Danika van Proosdij
Email: tbowron@dal.ca email: dvanproo@smu.ca

Barrier Coordinates for New Brunswick
Acquired from Conservation Council New Brunswick, modified by Saint Mary's University
Contact Person: Janice Harvey or Danika van Proosdij
Email: ccnbharvey@nb.aibn.com email: dvanproo@smu.ca

Data Fact Sheets for Nova Scotia
Acquired from Ecology Action Centre
Contact Person: Tony Bowron
Email: tbowron@dal.ca

APPENDIX B

Codes from Original Property Management Unit Data Classified in Tidal Barrier GIS

This document references the **MergedNSproperty** shapefile along with the **PIDNAME.xls** file.

Classification:

Municipal = All numerical values
Provincial = All "F" values.
Federal = All "G" values
Private Business = P
Private Individual = A, B, D, E, H, N, O, Q, R, S, T
Local Common = L
Society\Club = J
Roads\Unknown = K
Church = C

APPENDIX C

AML and VBA Scripts Developed

The following AML and VBA scripts were created by Greg Baker, the geomatics and geoscience technician at the Maritime Provinces Spatial Analysis Research Center (MP_SpARC) at Saint Mary's University. All scripts were developed for use in ArcGIS. Further details and codes are available by contacting Greg Baker directly at (902) 420-5274 or via e-mail at:

Mosaic Creation and Rectification AML Script

Rectifies groups of scanned (TIFF format) aerial photos (~48,) and creates a geo-referenced mosaic. The resultant mosaic must be less than 2 GB. Contact Greg Baker for more details.

VB script for concatenating using field calculator

```
Dim Primary as String
Dim Secondary as String
Dim Combined as String

Primary = [PRIMARY]
Secondary = [SECONDARY]

Combined = Primary & " - " & Secondary
```

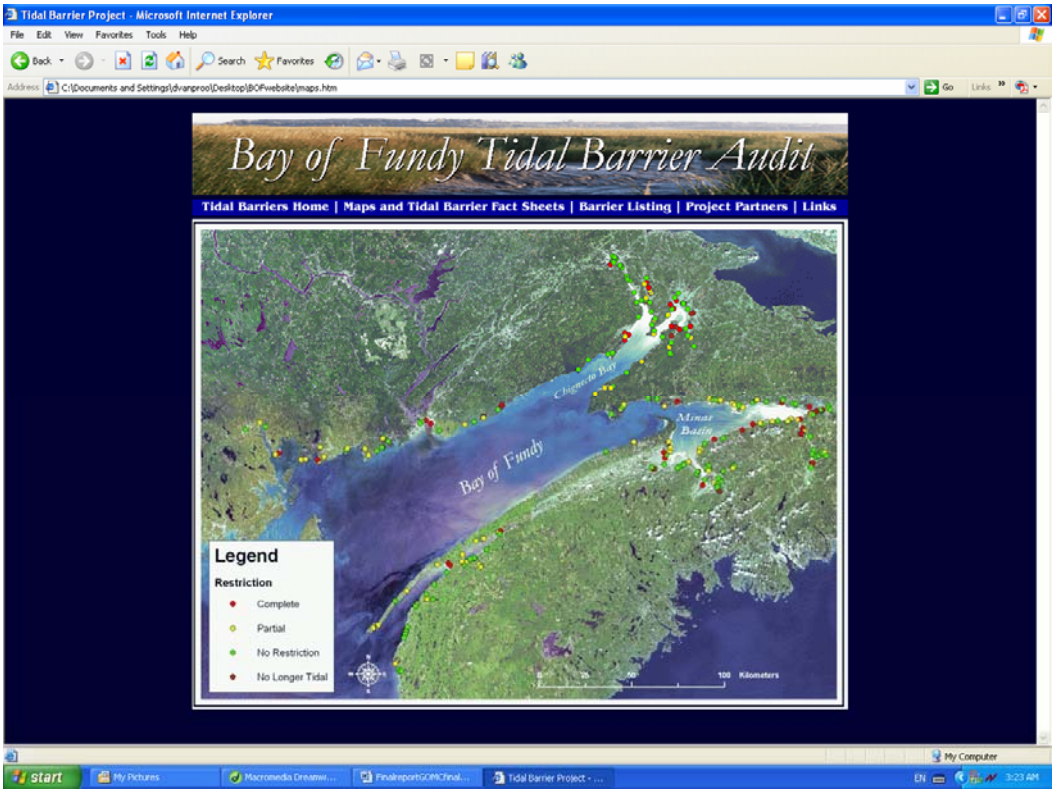
VB script for concatenating using field calculator

```
Dim Primary as String
Dim Secondary as String
Dim Tertiary as String
Dim Combined as String

Primary = [PRIMARY]
Secondary = [SECONDARY]
Tertiary = [TERTIARY]

Combined = Primary & "," & Secondary & "," & Tertiary
```

APPENDIX D
Web Interface

"Tidal Barriers Home"

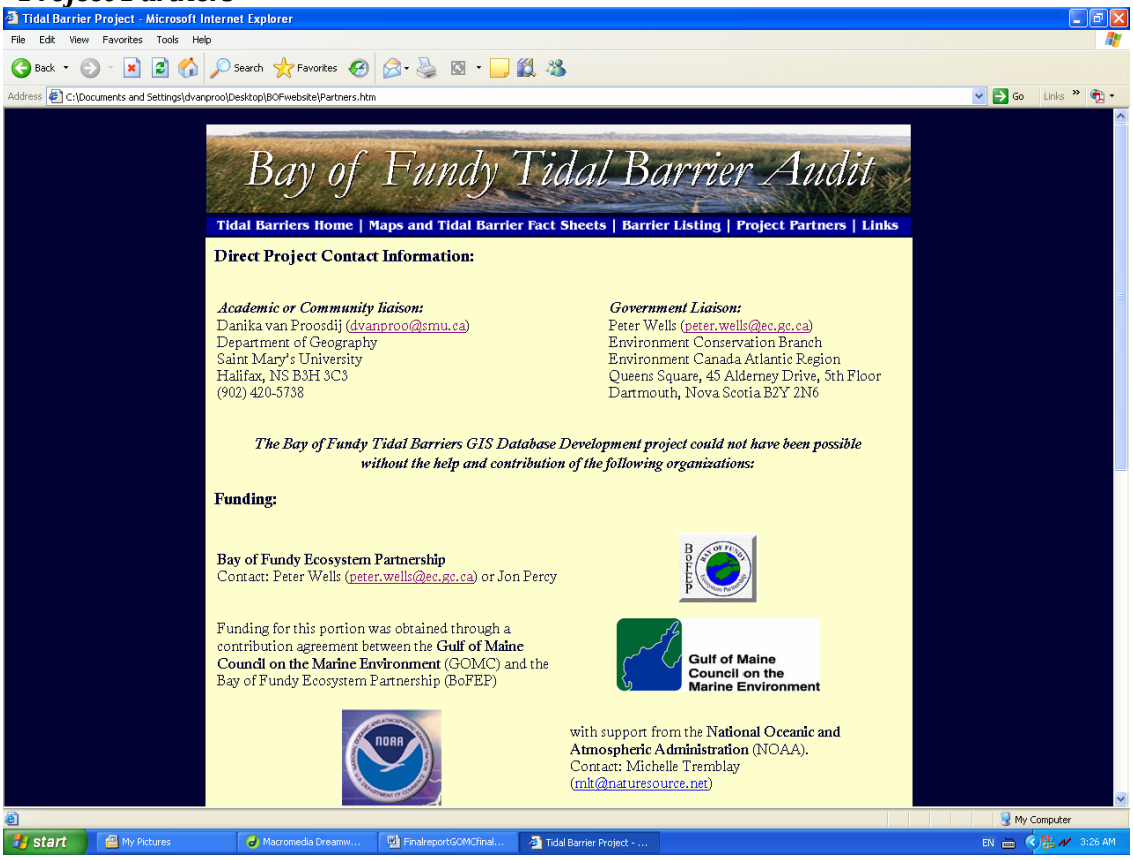
"Maps and Tidal Barrier Fact Sheets"



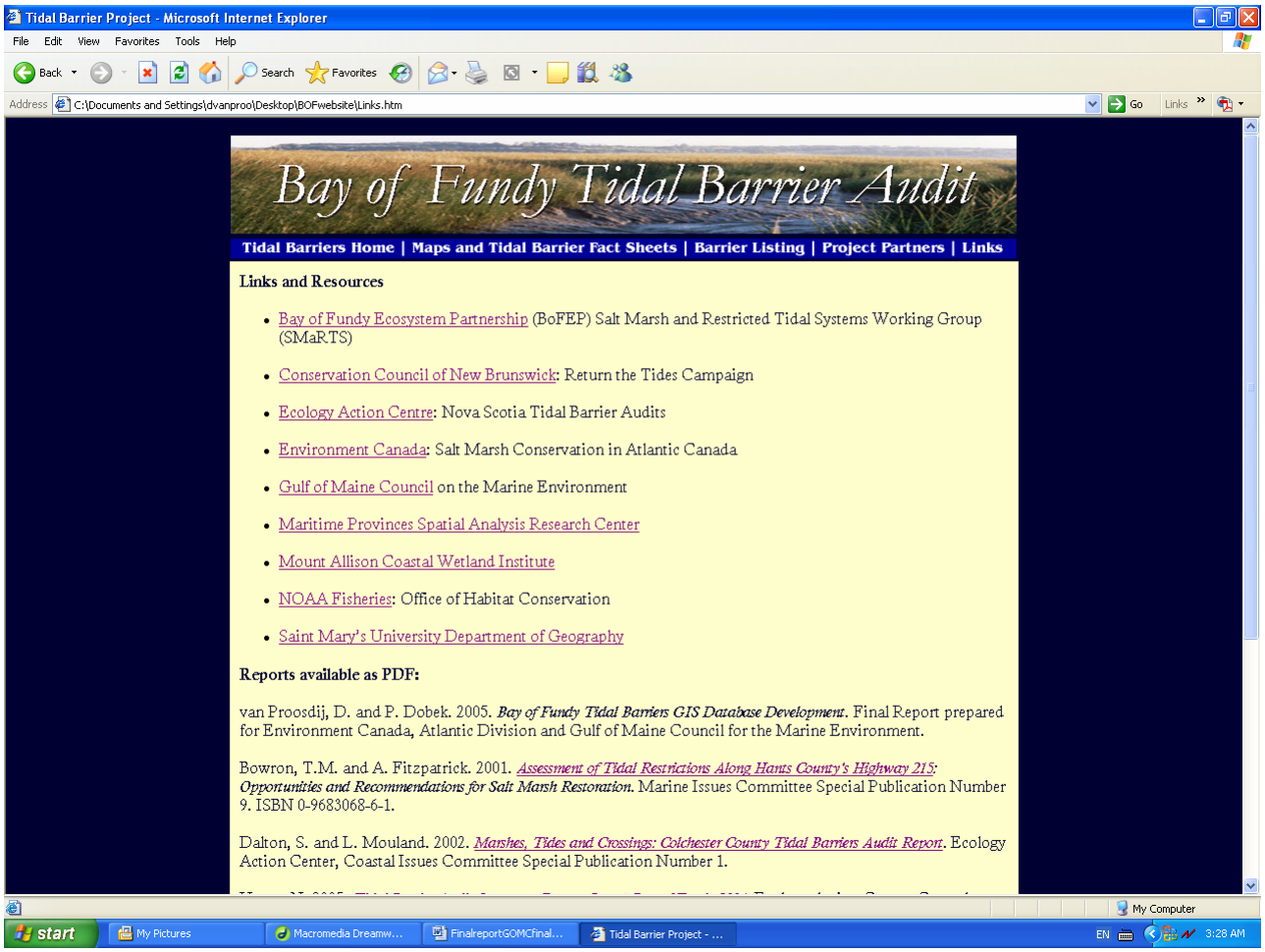
"Barrier Listing"

ID	LOCATION	CROSSTYPE	LATITUDE	LONGITUDE	RESTRICTION
CCCB1B	Missaguash River	two bridges	45,85613900000	-64,26316700000	no restriction
CCCB2B	LaPlanche River	hwy-bridge	45,83747200000	-64,22550000000	no longer tidal
CCCB3B	LaPlanche River	two bridges	45,83288900000	-64,23850000000	no longer tidal
CCCB4A	Nappan River	aboiteau	45,77252800000	-64,24322200000	complete
CCCB5B	St. Georges Brook	bridge	45,71741700000	-64,23877800000	partial
CCCB6C	St. Georges Brook	two culverts	45,71741700000	-64,23877800000	partial
CCCB7B	Little Forks River	bridge	45,67586100000	-64,21630600000	no restriction
CCCB8B	Maccan River	bridge	45,72480600000	-64,26038900000	no restriction
CCCB9B	Maccan River tributary	bridge	45,76111100000	-64,27475000000	no restriction
CCCB10C	Maccan Loop	culvert	45,75630600000	-64,31841700000	complete
CCCB11B	River Hebert	bridge	45,63569400000	-64,37183300000	no restriction
CCCB12B	Mill Creek	bridge	45,63925000000	-64,38038900000	no restriction
CCCB13C	Christie Brook	two culverts	45,66988900000	-64,38705600000	partial
CCCB14B	Latta Brook	bridge	45,68919400000	-64,37777800000	no restriction
CCCB15B	River Hebert	bridge	45,69038900000	-64,37352800000	no restriction
CCCB16C	John Curry Brook	culvert	45,72369400000	-64,37191700000	no longer tidal
CCCB17	Minudie/ Barronsfield	culvert	45,76813900000	-64,34222200000	no longer tidal
CCCB18A	Mill Creek	aboiteau	45,77088900000	-64,37427800000	complete
CCCB19B	Little River	bridge	45,71769400000	-64,43411100000	no restriction

"Project Partners"



"Links"


Tidal Barrier Project - Microsoft Internet Explorer
File Edit View Favorites Tools Help
Back Search Favorites
Address C:\Documents and Settings\dvanproo\Desktop\BOFwebsite\Links.htm
Go Links
Bay of Fundy Tidal Barrier Audit
Tidal Barriers Home | Maps and Tidal Barrier Fact Sheets | Barrier Listing | Project Partners | Links
Links and Resources
Bay of Fundy Ecosystem Partnership (BoFEP) Salt Marsh and Restricted Tidal Systems Working Group (SMaRTS)
Conservation Council of New Brunswick: Return the Tides Campaign
Ecology Action Centre: Nova Scotia Tidal Barrier Audits
Environment Canada: Salt Marsh Conservation in Atlantic Canada
Gulf of Maine Council on the Marine Environment
Maritime Provinces Spatial Analysis Research Center
Mount Allison Coastal Wetland Institute
NOAA Fisheries: Office of Habitat Conservation
Saint Mary's University Department of Geography
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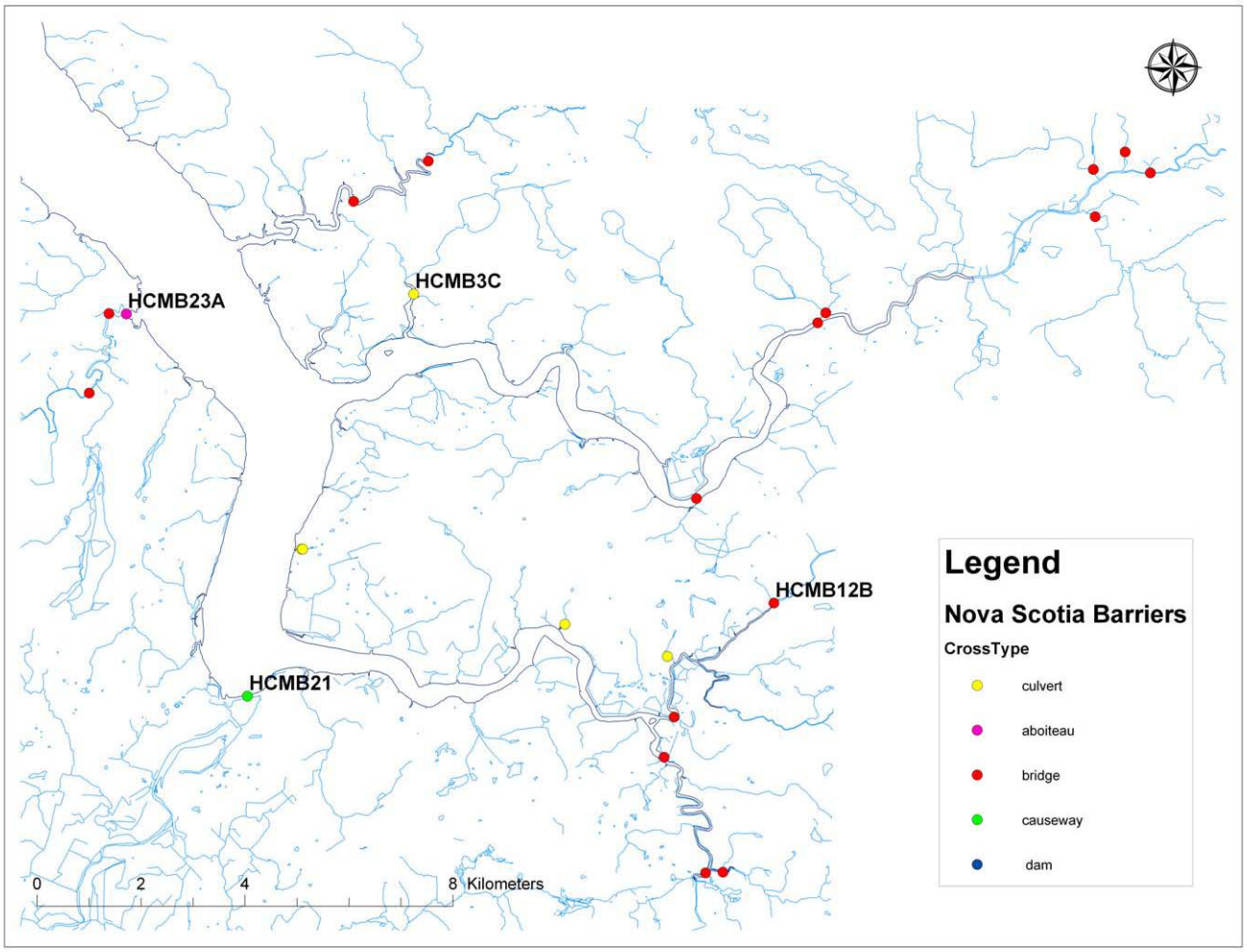
My Computer
start
My Pictures
Macromedia Dreamw...
FinalreportGOMCfinal...
Tidal Barrier Project - ...
EN
3:28 AM

APPENDIX E

Examples of Tidal Barrier Fact Sheets for the Southern Bight of Nova Scotia

Fact sheets are provided as examples for the sites indicated in the map below in the Southern Bight of the Minas Basin near the Avon River.



Please refer to the PDF files accompanying this report.

APPENDIX F
(refer to accompanying PDF files for additional documentation)
Note: Mid tide and below will have a visible intertidal zone (full marsh and mudflat)

1931 to 1945

21H/08				**Tide Level**				
Best Cov	Flight Line	Photo Range	Date	Low	Between	Mid	Between	High
2-14	A-8718	1 to 15	1945		X			
17,19 / 21,22	A-8718	16 to 22	1945		X			
24,26 / 29,31	A-8718	23 to32	1945		X			
34,36 / 42,44	A-8718	33 to 45	1945		X			
2,3,4,6	A-6532	1 to 6	1939				X	
1-33	A-6531	1 to34	1939				X	
39-45	A-5925	39 to 45	1938	X				
21H/01				Low	Between	Mid	Between	High
69,71 / 78,80	A-8718	69 to 80	1945	x				
64,66	A-8718	56 to 68	1945	X				
24,26	A-8650	23 to 41	1945	X				
18,20	A-8650	16-20	1945	X				
79,81,82	A-8719	79 to 82	1945				X	
71-77	A-8719	71 to 77	1945				X	
64-70	A-8719	59 to70	1945			X		
37-41	A-8719	59 to 70	1945			X		
25-35	A-8719	24 to 36	1945		X			
96-98	A-8719	87 to 98	1945		X			
44256	A-10178	1 to 21	1946			X		
38534	A-3619	1 to 8	1931	X				
22-30	A-3624	22 to 30	1931	X				
92-102	A-3624	92 to 102	1931	X				
na	A-8719	98 to 102	1945					X
45-61	A-8645	42 to 66	1945		X			
na	A-8646	46 to 60	1945					X
na	A-8647	85 to 70	1945					X
5,6	A-8647	1 to 9	1945			X		
39-47	A-8648	39 to 50	1945			X		
na	A-8725	1 to 24	1945					X
na	A-8726	75 to 93	1945					X
na	A-8727	4 to 22	1945					X

11E/05				Low	Between	Mid	Between	High
31-35	A-5922	30 to 35	1938	X				
35-41	A-5922	41 to 65	1938	X				
40-50	A-5913	40 to 50	1938		X			
58-68	A-5923	58 to 67	1938	X				
50,51	A-6524	50 to 51	1939	X				
28-38	A-5925	28 to 38	1938	X				
39-71	A-5925	39 to 85	1938	X				
85-99	A-5926	84 o 99	1938			X		
na	A-5927	1 to 30	1938					X
na	A-5927	56 to 75	1938					X
11E/06				Low	Between	Mid	Between	High
na	A-5912	23 to 33	1938					X
98	A-5913	98	1938			X		
19,20	A-6655	18 to 20	1939			X		
58-66	A-5923	58 to 66	1938	X				
43040	A-5924	11 to 17	1938	X				
1,4 / 64,66,68	A-5926	to 4 & 64 to 6	1938	X				
45-47	A-5654	45 to 47	1939		X			
2,4	A-5922	1 to 4	1938	X				
na	A-5913	10 to 15	1938					X
41,43,45	A-6526	41 to 45	1939	X				
85,87 / 97-99	A-5924	82 to 99	1938	X				

1953 To 1955

				Tide Level				
Best Cov	**Flight Line**	**Photo Range**	**Date**	**Low**	**Between**	**Mid**	**Between**	**High**
73, 74, 75	A-14285	73 to 80	1954		X			
63,65	A-14192	62 to 70	1954	X				
142-143	A-14010	140 to 143	1954		X			
142-144	A-14489	145-140	1954		X			
37,39	A-14489	35 to 40	1954		X			
39,41	A-14490	35 to 43	1954	X				
200-206	A-14486	197-203	1954	X				
124-126	A-14486	127-121	1954			X		
84-88	A-14491	82 to 88	1954		X			
173, 174, 175	A-14392	174-176	1954	X				
107-111	A-14282	101 to 112	1954			X		
na	A-14285	27 to 28	1954					X
1,3,5	A-14093	1 to 5	1954		X			
218-220	A-14092	216-224	1954				X	
81- 89 / 101,1	A-14092	81-105	1954				X	
148-168	A-14010	148-169	1954			X		
1,3	A-14088	1 to 5	1954				X	
21-31	A-14286	19-31	1954				X	
51-59	A-14285	58-45	1954			X		
na	A-14285	60-63	1954					X
61-63	A-14285	61 to 63	1954			X		
64-74	A-14285	64 to 74	1954			X		
35-53 / 56,58	A-14192	35 to 44	1954			X		
63,65	A-14192	45 to 62	1954			X		
100-128	A-14010	101 to 130	1954			X		
170, 171	A-14010	175 to 170	1954			X		
148, 150	A-14087	150 to 135	1954			X		

				Low	**Between**	**Mid**	**Between**	**High**
195, 196	A-14010	193 to 198	1954				X	
187-195	A-14287	177 to 209	1954				X	
60-98	A-14010	60 to 99	1954				X	
19-37	A-14192	19 to 37	1954				X	
158-168	A-14087	158 to 169	1954				X	
170-178	A-14087	170 to 178	1954				X	
47,48 / 51,52	A-14282	47 to 52	1954			X		
53,55 / 57,58	A-14282	53 to 59	1954			X		
1-7 / 11,13	A-14661	4 to 14	1954				X	
15,17 /24-30	A-14661	15 to 26	1954				X	
1-7	A-14668	1 to 7	1954	X				
1,3,5 / 12,14 /	A-14630	1 to 24	1954			X		
39,41 / 53,55,5	A-14668	39 to 58	1954			X		
79 , 81, 83	A-14668	66 to 83	1954			X		
49, 51	A-14661	48 to 52	1954			X		
13-21	A-14668	13 to 25	1954			X		
53,55	A-14661	53 to 56	1954			X		
77-91	A-14661	67 to 95	1954			X		
150-170	A-14661	145 to 170	1954		X			
184-196 / 201	A-14661	179 to 210	1954			X		
na	A-14803	1 to 9	1954					X
na	A-14738	22 to 35	1954					X
82-90	A-14713	82 to 93	1954		X			
69-77	A-14662	65 to 78	1954		X			
85-93	A-14662	84 to 94	1955	X				
47,49,51	A-14714	46 to 52	1955		X			
10,12	A-14663	5 to 15	1955		X			
44,45	A-14745	44 to 66	1955		X			

1964 to 1967

				Tide Level				
Best Cov	**Flight Line**	**Photo Range**	**Date**	**Low**	**Between**	**Mid**	**Between**	**High**
9-43	A-19982	9 to 43	1967	X				
HT	A-20234	1 to 10	1967					X
68, 69	A-19545	68 to 69	1967				X	
1, 5	A-19575	1 to 5	1967				X	
14, 16	A-19985	14 to 20	1967			X		
67, 70- 78	A-19575	67 to 80	1967			X		
40, 41, 42	A-19514	40 to 42	1967			X		
42, 43	A-19985	40 to 45	1967				X	
101, 109	A-19985	100 to 110	1967				X	
171, 179	A-19985	190 to 170	1967				X	
181	A-19986	180 to 220	1967			X		
63- 70	A-19513	55 to 70	1967				X	
HT	A-19512	130 to 140	1967					X
204- 212	A-19514	196 to 212	1967		X			
43, 45	A-19514	43 to 45	1967			X		
36, 38- 82	A-19995	16 to 90	1967			X		
172- 184	A-20770	172 to 205	1967			X		
1- 22	A-20769	1 to 30	1967		X			
72- 80, 84/ 86	A-20769	60 to 80	1967		X			
55/ 57	A-20771	55 to 65	1967					
81	A-20769	80 to 81	1967					
64- 68	A-20769	163 to 169	1967			X		
47- 50, 53, 55	A-19995	145 to 159	1967				X	
217, 219	A-19995	210 to 221	1967				X	

				Tide Level				
Best Cov	**Flight Line**	**Photo Range**	**Date**	**Low**	**Between**	**Mid**	**Between**	**High**
1, 19	A-18353	1 to 19	1964				X	
27, 31	A-18503	27 to 31	1964	X				
1- 11/ 21, 23, 25	A-18350	1 to 25	1964				X	
75, 101/ 112- 114	A-18356	70 to 120	1964	X				
192- 194	A-18356	180 to 195 & 170 to 165	1964	X				
49- 53	A-18439	49 to 60 & 80 to 82	1964	X				
8, 10	A-18358	5 to 10	1964	X				
44- 48	A-18439	35-42 / 5-10	1964	X				
205- 210	A-18352	207 to 210 & 245 to 250	1964	X				
73- 77	A-18352	115 to 220	1964	X				
204, 205	A-18352	204 to 206 & 160 to 165	1964	X				
217	A-18357	214 to 217 & 252 to 254	1964	X				
29, 31	A-18352	24 to 33	1964	X				
212	A-18357	200 to 213	1964	X				
80- 86, 87	A-18357	78 to 90	1964	X				
61- 65	A-18357	60 to 68	1964	X				

1973 to 1978

Cobequid				Tide Level					
Best Cov	**Flight Line**	**Photo Range**	**Date**	**Low**	**Between**	**Mid**	**Between**	**High**
44- 58	A-30671	44 to 58	1973	X				
76- 101, 102	A-30671	75 to 102	1973	X				
134- 148	A-30671	130 to 155	1973	X				
1, 2, 4	A-30671	1 to 10	1973	X				
211- 217	A-30672	205 to 217	1973	X				
143, 145	A-30672	143 to 150	1973	X				
222/ 224	A-30671	215 to 224	1973	X				
119, 121	A-30893	118 to 125	1973	X				
175, 176, 178	A-30676	175 to 178	1973	X				
80- 98	A-30676	80 to 100	1973	X				
6- 12	A-30676	1 to 15	1973	X				
155- 163	A-30674	155 to 165	1973	X				
157- 161	A-30670	150-160	1973	X				
134, 136	A-30670	130-140	1973		X			
60, 62	A-30670	55 to 65	1973			X		
59- 61	A-30671	59 to 62	1973	X				
188, 190	A-30672	188 to 190	1973	X				
176, 178	A-30671	175 to 178	1973	X				
103, 105	A-30671	103 to 107	1973	X				
41, 43	A-30671	40 to 43	1973	X				
185, 187	A-30672	184 to 187	1973	X				
179, 181	A-30671	179 to 182	1973	X				
213, 215	A-30676	212 to 215	1973	X				

Avon								
Best Cov	**Flight Line**	**Photo Range**	**Date**	**Low**	**Between**	**Mid**	**Between**	**High**
11- 35	77315	11 to 35	1977	X				
156-165	77316	156 to 165	1977	X				
145 to 155	77316	145 to 155	1977	X				
132-144	77316	132 to 144	1977	X				
116-131	77316	116 to 131	1977	X				
95-115	77316	95 to 115	1977	X				
69- 75 / 85-94	77316	69 to 75 & 85 to 94	1977	X				
37- 50 / 65* 68	77316	37 to 50 & 65 to 68	1977	X				
1, 2, 30, 32, 34	77316	1 to 5 & 20 to 36	1977	X				
1, 3, 5/ 29, 31	78350	1 to 5 & 25 to 32	1977				x	
145-149 / 155-161	77301	145 to 161	1977	X				
59- 73	77301	59 to 75	1977	X				
43- 57	77301	40 to 58	1977	X				
46- 62	77300	46 to 65	1977	X				
1, 3/ 6, 7/ 11, 19	77300	1 to 20	1977		X			
	77319	82 to 115	1977					X
	77319	45 to 81	1977					X
24, 26	77317	24 to 30	1977		x			

Cap Split	**Flight Line**	**Photo Range**	**Date**	**Low**	**Between**	**Mid**	**Between**	**High**
2 to 8	75063	1 to 18	1975	X				
91 to 121, 122	75044	94 to 122	1975	X				
77, 84	75044	75 to 93	1975	X				
110, 113, 126, 137	75046	107 to 137	1975	X				
159 to 164, 194, 198, 299	75041	155 to 199	1975			x		
19, 21, 23	75040	1 to 6 & 19 to 25	1975			X		
	Flight Line	**Photo Range**	**Date**	**Low**	**Between**	**Mid**	**Between**	**High**
178- 198	75038	193 to 198	1975		X			
Check	75038	186 to 192	1975					
Check	75038	186 to 135	1975					
Check	75038	178 to 104	1975					
Check	75040	129 to 135	1975					
Check	75044	137 to 173	1975					
18 to 27/ 31, 35	75044	6 to 42	1975		X			
Truro	**Flight Line**	**Photo Range**	**Date**	**Low**	**Between**	**Mid**	**Between**	**High**
46-48	75040	104 to 128	1975	X				
160	75040	135 to 151	1975	X				
104- 122	75040	152 to 168	1975	X				
189- 189 / 193-196	75040	169 to 196	1975	X				
1- 3	75042	1 to 6	1975	X				
23- 25	75042	22 to 27	1975	X				

1981 to 1987

Cobequid				Tide Level				
Best Cov	Flight Line	Photo Range	Date	**Low**	**Between**	**Mid**	**Between**	**High**
25-29	81314	25 to 30	1981		x			
1-5/71-75	81312	1 to 6 & 71 to 75	1981	x				
78-80/153-155	81312	77 to 82 & 153 to 155	1981	x				
159-161	81312	159 to 161	1981	x				
0	81312	103 to 105	1981					x
2-6,10/45-47	81313	1 to 5, 10 & 45 to 47	1981	x				
44-46/97-99	81313	49 to 35 & 97 to 99	1981	x				
102-110/157-159	81313	102 to110 & 157 to 160	1981	x				
31-69	81314	31 to 59	1981		x			
87-88	81314	60 to 89	1981		x			
90-94/122-123	81314	90 to 95 & 120 to 123	1981		x			
124-132/165-167	81314	124 to 135 & 165 to 167	1981		x			
1-7	81314	1 to 7 & 210 to 213	1981		x			
1,2,3	81317	1 to 3	1981		x			
2-4/68-70	81318	1 to 5 & 68 to 70	1981		x			
109-111/176-180	81318	109 to 111 & 176 to 180	1981		x			
196-200	81318	195 to 200	1981		x			
0	81326	15 to 19	1981					x
0	81328	145 to 148 & 155 to 157	1981					x
165-179	81332	165 to 180	1981	x				
97-109	81332	97 to 109	1981		x			
16-26	81332	16 to 28	1981	x				
1-3	81335	1 to 3	1981			x		
0	81336	77 to 85	1981					x
0	81336	4 to 22	1981					x
0	81337	85 to 90	1981					x
0	81337	1 to 10	1981					x

Truro					Tide Level			
Best Cov	Flight Line	Photo Range	Date	**Low**	**Between**	**Mid**	**Between**	**High**
0	85306	30 to 105	1985					x
26-36	85308	26 to 36	1985			x		
18-24	85308	18 to 25	1985			x		
1-9	85308	1 to 9	1985			x		
11-17	85308	10 to 17	1985			x		
190-212	85311	187 to 210	1985			x		
62-70	85311	62 to 72	1985			x		
1-7	85311	1 to 7 & 210 to 213	1985			x		
123-125	85311	123 to 127	1985			x		
56-58	85312	56 to 58	1985		x			
77-79	85313	77 to 79	1985	x				
36-40	85313	36 to 40	1985	x				
1-5	85313	1 to 5	1985	x				
1-54	85315	1 to 60	1985			x		
92-97 / 105-111	85316	92 to 110	1985	x				
2-4	85316	2 to 4	1985		x			
2-4	85317	1 to 5	1985	x				
0	85319	1 to 5	1985					x
2-4	85321	1 to 5	1985	x				
2-4	85325	2 to 4	1985	x				
128-130	85330	128 to 132	1985	x				
199-200	85330	198 to 200	1985	x				
2-4	85331	1 to 5	1985				x	

Avon					Tide Level			
Best Cov	Flight Line	Photo Range	Date	**Low**	**Between**	**Mid**	**Between**	**High**
n/a	87301	43 to 46	1987			x		
32-46	87301	32 to 42	1987			x		
76-82	87301	76 to 83	1987			x		
67-70/73-75	87301	67 to 70 & 73 to 75	1987			x		
56-58/63-65	87301	56 to 58 & 63 to 65	1987			x		
84-86/92-94	87301	84 to 86 & 92 to 94	1987			x		
0	87301	17 to 21 & 29 to 31	1987					x
0	87301	14 to 16	1987					x
151-153	87304	150 top 153	1987				x	
128-132	87304	127 to 132	1987				x	
104-106	87304	102 to 106	1987				x	
74-76	87304	74 to 76	1987				x	

1991 to 1995

Avon River

				Tide Level				
Best Cov	**Flight Line**	**Photo Range**	**Date**	**Low**	**Between**	**Mid**	**Between**	**High**
154-158/163-165	92316	154 to 158 & 163 to 165	1992	x				
141-145	92316	141 to 145 & 151 to 153	1992	x				
115-117	92316	115 to 118	1992	x				
90-92	92316	88 to 92	1992	x				
93-95	92305	193 to 195	1992				x	
55	92318	50 to 68	1992				x	
45-47/52-54 & 58	92302	43 to 58	1992	x				
170-178/183-185/189-199	92303	170 to 185 & 190 to 195	1992			x		
95-101/108-110/117,124	92317	95 to 112 & 118 to 124	1992				x	
49-63	92316	48 to 58	1992	x				
96, 108	92343	96 to 108	1992	x				
19, 26, 30	92344	18 to 23 & 26 to 30	1992	x				
61-63/67,98	92301	62 to 64 & 66 to 68	1992	x				
0	92391	82 to 84	1992					x
26-32/77-81	92391	25 to 84	1992				x	
2-6/10-12	92391	1 to 11	1992			x		
1-5	92385	1 to 6	1992			x		
1-5	92319	1 to 5	1992				x	
141-143	92318	141 to 143	1992				x	
19-23	92317	19 to 23	1992			x		

Cobequid

				Tide Level				
Best Cov	**Flight Line**	**Photo Range**	**Date**	**Low**	**Between**	**Mid**	**Between**	**High**
123-129	94012	123 to 130	1994	x				
2-6	94001	1 to 6	1994	x				
112-122	94012	111 to 122	1994	x				
10-14/24-48	94009	10 to 14 & 24 to 46	1994		x			
53-57	94002	52 to 58	1994		x			
7-9	94001	7 to 9	1994	x				
198-202	92314	197 to 202	1994	x				
1-9/ 13 / 17-23	92334	1 to 25	1994	x				
137-141/145-147	92333	136 to 141 & 145 to 147	1994	x				
94-102	92333	93 to 94	1994	x				
46-56	92333	46 to 52 & 54 to 56	1994	x				

Truro

				Tide Level				
Best Cov	**Flight Line**	**Photo Range**	**Date**	**Low**	**Between**	**Mid**	**Between**	**High**
59-75	94002	60-70 / 74-76	1994		x			
73	94001	67 to 73	1994	x				
124-128	94001	124 to 128	1994	x				
1-3	94002	1 to 3	1994	x				
68-70	94011	98 to 70	1994	x				
197-199	94011	196 to 198	1994	x				
1-3	94011	1 to 3	1994	x				
132-134	94011	132 to 134	1994	x				
204	92314	203 to 204	1992	x				
35-66	92334	63 to 66	1992	x				
31-33	92334	31 to 34	1992	x				
166-168	92333	166 to 168	1992	x				
131-135	92333	132 to 134	1992	x				
90-92	92333	89 to 92	1992	x				

Cape Split

						Tide Level		
Best Cov	**Flight Line**	**Photo Range**	**Date**	**Low**	**Between**	**Mid**	**Between**	**High**
97-74	94008	67 to 74	1991					x
0	94001	247 to 255	1993					x
1-9	94008	1 to 9	1991					x
2-6	94007	1 to 2	1991			x		
190-194/201-206	94014	195 to 201	1991	x				
22-24	94013	22 to 24	1991	x				
1-3	94009	1 to 3	1991	x				
44-48	94009	44 to 48	1991	x				
0	94014	189 to 193	1991					x
1-9	95020	1 to 9	1995		x			
11-37	95020	10 to 37	1995		x			
0	95007	58 to 64 & 70 to 86	1995					x
0	95008	179 to 181 & 190 to 199	1995					x
114-129	94017	114 to 123	1994	x				
1-9	94009	1 to 9	1994			x		

2000's

Avon River

				Tide Level				
Best Cov	**Flight Line**	**Photo Range**	**Date**	**Low**	**Between**	**Mid**	**Between**	**High**
119, 121	02307	119 to 121	2002	X				
148	02307	145 to 148	2002	X				
179, 181	02307	179 to 181	2002	X				
71, 72	02307	70 to 72	2002	X				
90, 92/ 98, 99	02307	90 to 92 & 98 to 100	2002	X				
2, 4	02308	1 to 4	2002	X				
13, 15	02308	111 to 115	2002	X				
153, 159- 161	02308	153 to 165	2002	X				
37, 38	02308	36 to 38	2002			x		
81- 87	02308	81 to 87	2002	X				
76, 80	02308	83 to 80	2002	X				
1, 7/ 11, 16,	02309	1 to 7 & 111 to 118	2002	X				
121- 125 / 138, 142/ 131, 133	02322	115 to 125 & 129 to 142	2002		X			
147- 149/ 173	02322	142 to 153 & 160 to 175	2002			X		
110, 112, 114	02327	112 to 114	2002				X	
143, 145, 147	02329	142 to 146	2002					x
189, 195,197 ,202, 203	02329	189 to 203	2002		X			
14 / 23, 25	03301	15 to 17	2003			X		
18,20	03302	14 to 22	2003			X		
	03308	162 to 164 & 169 to 173	2003					X
	03308	3 to 12	2003					X
	03308	91 to 107	2003					X
14-22	03317	14 to 22	2003	X				
89- 99	03321	90 to 96	2003	X				
1, 3/ 14, 16	04308	1 to 3	2004			X		
83, 84/ 29, 31, 33/ 40, 42	04308	83 to 84	2004			x		
	04317	10 to 16	2004					X
	04317	150 to 154	2004					X
	04317	86 to 94	2004					X
	04318	1 to 4	2004					X
94- 100	04322	93 to 100	2004		X			
2, 3	04325	17 to 19	2004			X		
1, 3, 5	04328	1 to 5	2004			X		
1, 3, 5	04331	1 to 5	2004					X
42705	04331	12 to 16	2004					X

Truro				Tide Level				
Best Cov	Flight Line	Photo Range	Date	**Low**	**Between**	**Mid**	**Between**	**High**
61- 78	04316	67 to 80	2004	X				
10- 26	04312	8 to 26	2004			X		
199- 197	04312	193 to 196	2004			X		
93- 101	04320	91 to 100	2004		X			
22- 24	04320	21 to 24	2004				X	
183, 185, 187	04320	184 to 187	2004		X			
31, 33	04321	31 to 33	2004		X			
103, 105	04321	103 to 105	2004	X				
51, 55	04322	51 to 55	2004	X				
102, 104	04323	102 to 104	2004	X				
Cobequid						Tide Level		
Best Cov	Flight Line	Photo Range	Date	**Low**	**Between**	**Mid**	**Between**	**High**
1- 7	04314	1 to 7	2004	X				
9- 15	04314	8 to 16	2004	X		X		
147- 151	04311	146 to 151	2004				X	
	04312	135 to 187	2004					X
81, 83, 85	04306	81 to 85 & 97 to 116	2004	X				
	04312	1 to 8	2004					X
	04316	61 to 67	2004					
88, 90	04320	87 to 91	2004				X	
1- 21	04320	1 to 21	2004				X	
156- 180	04320	156 to 180	2004	X				
1- 11	04321	1 to 4 & 8 to 12	2004			X		
26- 34	04304	25 to 34	2004		X			
46- 56	04324	46 to 55	2004	X				
56- 60	04325	55 to 60	2004	X				

Cape split				Tide Level				
Best Cov	Flight Line	Photo Range	Date	**Low**	**Between**	**Mid**	**Between**	**High**
	04317	1 to 9	2004					X