Risk Proofing Nova Scotia Agriculture:
NOVA SCOTIA DYKE VULNERABILITY ASSESSMENT

Final report prepared by:

Danika van Proosdij, Chris Ross and Graeme Matheson

Department of Geography and Environmental Studies
Maritime Provinces Spatial Analysis Research Centre (MP_SpARC)
Saint Mary's University

March 31, 2018

Risk Proofing Nova Scotia Agriculture: A Risk Assessment System Pilot (AgriRisk)
Nova Scotia Federation of Agriculture would like to recognize the collaborative relationships that exist among Agriculture and Agri-Food Canada and the Nova Scotia Departments of Agriculture and Environment.

Executive Summary

The Nova Scotia Department of Agriculture (NSDA), Land Protection Section is responsible for maintaining 241 km of dykes along the Province's coasts and waterways, protecting 16,139 Ha of agricultural marshland behind them. Regulated under the Agricultural Marshland Conservation Act 2000, c. 22, s. 1., dykes were constructed to levels to protect agricultural land with critical elevations dictated by the high water line established in the 1950s and 60s. While many of these dykes were topped in the early 2000s and critical elevations increased, numerous reports over the last decade have identified that dykes within the Bay of Fundy are vulnerable to overtopping under current and future sea level rise and storm scenarios (Tibbetts and van Proosdij, 2013; van Proosdij and Page, 2012; Webster et al., 2012). This flooding will directly and adversely affect the productivity of the agricultural land as well as the infrastructure, homes and businesses that have, over time, come to depend on these dykes for protection from coastal waters. Indirectly, this has an impact on many critical elements of the target value supply chain and economy.

This study used all available historical satellite and aerial imagery alongside the most up to date contemporary data of dyke elevations and infrastructure to calculate historical rates of lateral change in foreshore marsh and vulnerability to overtopping. Bayesian network (BN) analysis was used to further examine the probability of dyke overtopping given predicted tidal signals. The BN model results indicate that at a whole of region scale the Annapolis Digby dyke tracts have the highest probability of overtopping across all scenarios, with probabilities of overtopping of between 3.5 to 8.9%. Annapolis Digby dyke tracts were between nine and 26 times more likely to overtop than Cumberland Dyke tracts, three to four times more likely to overtop than Colchester dyke tracts and twice as likely to overtop as Hants Kings dyke tracts. Hants Kings dyke tracts were the second most likely to overtop with probabilities of 0.02 to 0.05 across the scenarios and Cumberland dyke tracts were the least likely to overtop. The probabilities of overtopping increased dramatically under the 2100 sea level rise (2100_SLR) related scenarios: Cumberland was almost six times more likely to have dyke tracts overtop in the 2100_SLR scenarios than the 2050_SLR; Colchester, Annapolis Digby and Hants Kings tracts were all about twice as likely to overtop under the 2100_SLR scenarios than the 2050_SLR scenarios. Sea level rise appears to have a pronounced impact on the probability of dyke tracts overtopping relative to the impacts of storm surge.

Approximately 70% of dyke tracts analyzed within this project were classified as high or very high vulnerability to coastal erosion and overtopping by 2050 based on an initial GIS analysis. Sixteen of these tracts are at risk of losing all of their foreshore marsh by this date assuming mean end point erosion rates remain the same. The data generated within this study will provide managers and decision makers with empirical evidence of where not only dykes are vulnerable to overtopping but also what the probability is of this occurring and a measure of the time within which these decisions need to be made. This report constitutes the most complex and fine scale analysis of foreshore salt marsh erosion rates and overtopping probability of dykes in the entire Province to date. A comprehensive geodatabase (DDST) has been compiled to attach variables which influence the vulnerability of every 25m segment of dyke in the province (nearly 10,000 segments). These variables include: weighted fetch, foreshore width, foreshore platform elevation, length of armouring, foreshore change rates, dyke crest elevation, dyke

orientation, aboiteau presence/absence, maximum exposure, and maximum and wave height. These data provide the foundation for more complex and tailored analyses to be performed after this project.

End point change rates of foreshore saltmarsh provide a solid, high-level indication of marshes that require action to respond to erosion. As mentioned, there are sixteen tracts in the province that are predicted to lose their entire foreshore marsh within the next 30 years. This is important because a robust saltmarsh can mitigate the vulnerability of dykes to overtopping and breaching due to their capacity to dissipate wave energy/attenuate wave heights. The tracts that have the highest "urgency to act" based on EPR and contemporary overtopping probability are NS052_01 Saint Mary's Bay, NS112_01 Sunnyside and NS113_05 Rines Creek. Although the above provides a precursory view of dyke tracts impacted by salt marsh erosion, it is pertinent to acknowledge that the values used for EPR are based on the entire historical range of end point change rate values and may not necessarily reflect contemporary or future values. Even more in-depth statistical analysis of end point change rates are possible with the data generated, warranting a more complete study of the cause and effect of the morphological evolution (i.e. EPR rate and area change) of salt marshes in the Bay of Fundy. Bayesian network modelling provided an additional insight not previously available regarding the probability of potential of overtopping of the existing dyke infrastructure that is of value for testing different scenarios. It is however limited to regional scale analyses due to lack of long term tide level records required for probability determination.

All of the datasets generated within this project can help inform decision making and prioritization of which dykes to maintain in place or those where strategic managed re-alignment should be considered. However, more data is required in order to properly assess dyke vulnerability to breaching including geotechnical data pertaining to dyke material, site classification, and wave modelling and should be prioritized for the near future. These datasets, coupled with an understanding of intertidal morphodynamics, are providing the evidence and tools needed to develop a strategic and proactive plan for addressing the vulnerability of dykelands in the Province.

Acknowledgements

This work would not have been possible without the vision and support of Kevin Bekkers and his team at Land Protection for the development of a more comprehensive analysis of dyke vulnerability in the Province and need to make decisions based on strong science. The team at MP_SpARC and IN_CoaST are thanked for their efforts in the lab and in the field. In particular, Reyhan Aykol, Larissa Sweeney, Raj Tor and Logan Horrocks' careful and endless hours of digitization are appreciated and have allowed us to have the first truly comprehensive coastal erosion rate calculations and up to date quantification of foreshore marsh habitat. Greg Baker, research instrument technician at MP_SpARC, is thanked for his problem solving and technical advice. Thank you to Tim Lyman for introducing our team to Bayesian networks and for guiding/assisting us in generating a working dyke overtopping model with the limited tide data we had available. The work would not have been possible without the geomatics infrastructure and survey equipment available through MP_SpARC, funded by the Canadian Foundation for Innovation.

Table of Contents

1 INTRODUCTION and BACKGROUND

1.1 Rationale

The Nova Scotia Department of Agriculture (NSDA), Land Protection Section is responsible for maintaining 241 km of dykes along the Province's coasts and waterways, protecting 16,139 Ha of agricultural marshland behind them. Regulated under the Agricultural Marshland Conservation Act 2000, c. 22, s. 1., dykes were constructed to levels to protect agricultural land with critical elevations dictated by the high water line established in the 1950s and 60s. While many of these dykes were topped in the early 2000s and critical elevations increased, numerous reports over the last decade have identified that dykes within the Bay of Fundy are vulnerable to overtopping under current and future sea level rise and storm scenarios (Tibbetts and van Proosdij, 2013; van Proosdij and Page, 2012; Webster et al., 2012). This flooding will directly and adversely affect the productivity of the agricultural land as well as the infrastructure, homes and businesses that have, over time, come to depend on these dykes for protection from coastal waters. Indirectly, this has an impact on many critical elements of the target value supply chain and economy. For example, it is estimated that overtopping of dykes at the Tantramar marshlands and flooding of the Trans-Canada highway and CN rail would result in a loss of 50 million dollars of trade per day (Spooner, 2009; Webster et al., 2012). With current resources, the NSDA cannot raise all of the dykes to climate change standards and needs to prioritize which dykes to top and maintain. This requires a solid appreciation of not only where dykes are vulnerable to overtopping or breaching (failure) but also what the probability is of this occurring, what is being protected and a measure of the 'urgency to act'.

1.2 Scope

Under Activity 2.12 of the AgriRisk Project, Saint Mary's University was tasked with developing probability estimates of breach and overtopping of dykes within the Province of Nova Scotia. This included three main activities:

- Determination of current and future dyke sensitivity based on historical and contemporary rates of erosion per dyke tract and a geodatabase of variables that influence dyke sensitivity where available;
- Modelling exposure conditions and creating an exposure index;
- Modelling probability of overtopping and/or breach. This involved close collaboration with Tim Lynman.

Much of this work depended on the availability of data from other sources which did not become available in time for the project, notably dyke material, condition assessment and wave modelling. In addition, the lack of long term tide gauge data in the Upper Bay limited modelling opportunities. As a result, only the probability of overtopping (using predicted tides) under different climate change and storm scenarios were able to be addressed.

1.3 Previous Work

The majority of previous work in the region have been based solely on GIS analyses of predicted water levels exceeding dyke crest elevations with two exceptions. Hydrodynamic models were used to predict overtopping at Windsor (Fedak and van Proosdij, 2012) and Truro (CBCL Ltd., 2017). The comprehensive Truro Flood Risk Study also modelled freshwater contributions to flooding which is the dominant hazard within the Salmon River Estuary (CBCL Ltd., 2017). These models more accurately reflect flooding hazard since they account for the duration of time that water would pass over the dykes given a tidal state. However, Fedak and van Proosdij (2012) demonstrated that for more extreme scenarios, flood extents modelled using GIS (bathtub models accounting for connectivity) or from hydrodynamic modelling were similar and therefore suitable for worst case scenario hazard identification. The probability of overtopping is a function of the duration of time that water levels exceed dyke crest elevation. This is controlled by tidal period and range, surge height and coincidence with high tidal state and future sea levels (Tibbetts and van Proosdij, 2013). Wave energy and run-up are influenced by fetch (exposure), water depth (bathymetry and tidal cycle), dyke slope, and width and platform elevation of salt marsh in the foreshore. Depending on the construction material of the dyke and presence or absence of rock armouring, wave energy reaching the toe of the dyke that has not been dissipated by marsh vegetation can cause scour, weakening the integrity of the dyke. When the assailing forces (e.g. wave energy, floodwater flow velocities) exceed the structural integrity of the dyke, the dyke may be breached through a number of failure mechanisms (van Proosdij and Page, 2012). While the conditions that determine whether or not a dyke will fail are known based on engineering standards, the spatial distribution of dykes currently vulnerable to overtopping or breach has not been mapped at a scale that is effective for emergency management and maintenance.

1.4 Analysis Regions

The analysis was divided into five regions based on the distribution of Nova Scotia dykelands (Figure 1): Advocate, Cumberland, Colchester, Hants and Kings, Annapolis and Digby and broken down into three different levels of geographic analysis. It should be noted that some analyses were not possible at Advocate due to a much smaller dataset.

NSDA identifies their dykes by assigning both marsh identification numbers and tract numbers. There are a total of 82 marsh bodies and 175 dyke tracts in the province. This project analyzed 165 of these tracts. A single marsh may contain several tracts, a continuous section of dyke that ties into upland at either end. The use of tracts as geographical units were chosen since one marshland, or dyke, may have tracts that are impacted differently by assailing and resisting forces (e.g. exposure, eroding versus prograding marsh). This can result in two separate tracts on a single marshbody having significant variation in their vulnerability to overtopping or breaching. For this analysis, dyke tracts were broken down into 25 m segments for two reasons: (1) in order to extract significant parameters at a fine enough local scale and (2) to allow development of statistical outputs for a consistent unit. The geographic units of analysis are illustrated in Figure 2.

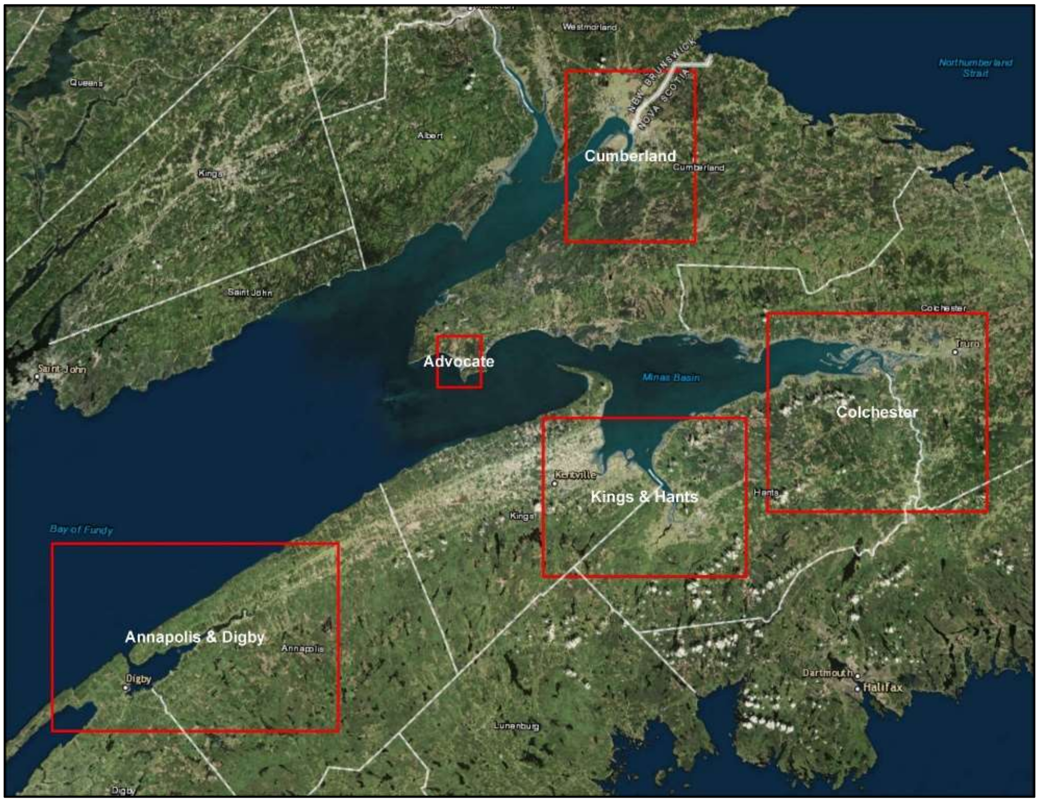


Figure 1: Geographical distribution of analysis regions based on provincial distribution of dykelands.

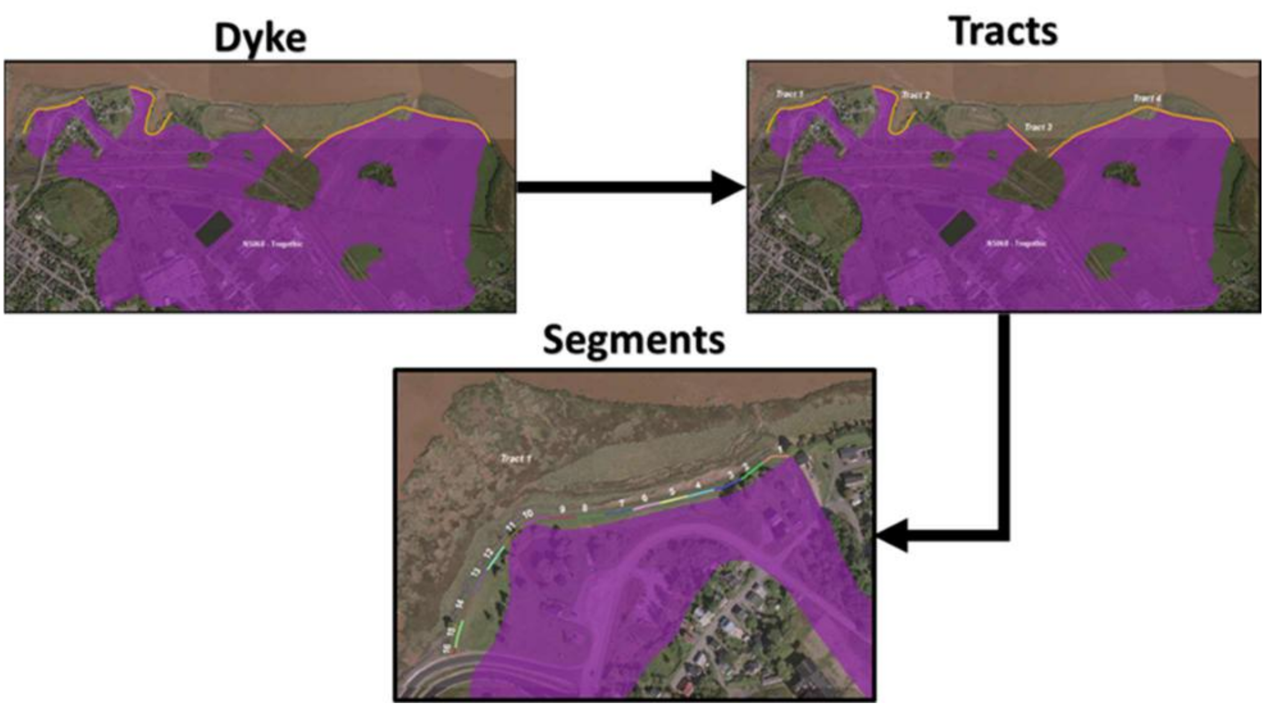


Figure 2: Geographic units of analysis for dykes. Each dyke is made up of tracts (defined by the NSDA) and tracts are broken down into 25 m segments for analysis.

2 BASE DATASETS and METHODS

2.1 Base Datasets

The dyke vulnerability model was dependent on the creation of several important base datasets and subsequent creation of derived datasets. Most base datasets were established at MP_SpARC within the DDST (*Dykeland Decision Support Tool*), a geomatics based database management system and decision support tool developed with the NS Department of Agriculture over the last ten years. Other data sets were obtained through a joint effort from various sources. All of the data used in this analysis were referenced to NAD83 CSRS UTM Zone 20N horizontal coordinate system and the Canadian Vertical Datum of 1928 (CGVD28).

2.1.1 Foreshore Boundaries

Foreshore boundaries previously digitized by SMU were organized by year and placed within a geodatabase. To allow for an extended analysis, additional years without boundaries were identified from historical aerial photographs. Photographs were obtained from GeoNOVA and were filtered based on those excluding foreshore of interest. Photographs taken at high tide were also filtered out. Aerial photographs were then rectified within the ArcGIS environment using the available Nova Scotia Topographic Database along with imagery available to SMU. Foreshore boundaries were then digitized from each imagery source. Attributes including marsh number and image year were given to each feature necessary for analysis. Positional error was then assigned to each digitized boundary to quantify the precision. The equation used was obtained from Tibbetts and van Proosdij (2013) and is provided below:

$$Esp = \sqrt{Er^2 + Ed^2 + Eo^2}$$

Esp: Shoreline Position Error
Er: Rectification Error
Ed: Digitization Error
Eo: Shoreline Proxy Offset

2.1.2 Dyke Centerline Elevations

Dyke centerline elevations were surveyed using a Leica Geosystems GS14 dual-frequency GNSS receiver with GPS and GloNASS reception at sites identified as high priority by the NSDA Land Protection Section (Table 1). This instrument was used in conjunction with a Leica SmartNet Network RTK corrections service over the Telus cellular telephone network. Surveyed points were collected at 25-meter intervals and each assigned an appropriate attribute code. When surveying the dyke centerlines, any point that had a 3D accuracy greater than or equal to 5 cm was accepted. Surveyed data were collected over a period of three months surveying dykes identified as highest priority first. Due to time constraints, all dyke tracts were not able to be surveyed. For those that were not surveyed during the project, the most recent survey data was used. This data was provided by the NSDA.

Table 1: Dyke centerlines surveyed by SMU MP_SpARC research unit based on priority sites established by NSDA in 2017.

Dyke Tract ID	NSDA Number	Tract Number	Marsh Name	Region	Date Last Surveyed	Year
NS039_01	NS039	1	Round	Colchester	08/11/17	2017
NS064_02	NS064	2	Glenhome	Colchester	08/11/17	2017
NS064_03	NS064	3	Glenhome	Colchester	08/11/17	2017
NS064_04	NS064	4	Glenhome	Colchester	08/11/17	2017
NS097_01	NS097	1	Highland Village	Colchester	07/11/17	2017
NS057_02	NS057	2	New Minas	Western	19/10/17	2017
NS057_03	NS057	3	New Minas	Western	19/10/17	2017
NS057_04	NS057	4	New Minas	Western	19/10/17	2017
NS057_05	NS057	5	New Minas	Western	19/10/17	2017
NS082_01	NS082	1	Kentville	Western	19/10/17	2017
NS082_02	NS082	2	Kentville	Western	19/10/17	2017
NS015_01	NS015	1	Isgonish	Colchester	01/08/17	2017
NS086_04	NS086	4	Central Onslow	Colchester	01/08/17	2017
NS086_03	NS086	3	Central Onslow	Colchester	28/07/17	2017
NS068_03	NS068	3	Tregothic	Hants	13/07/17	2017
NS068_04	NS068	4	Tregothic	Hants	13/07/17	2017
NS011_01	NS011	1	Truro Dykeland Park	Colchester	12/07/17	2017
NS014_01	NS014	1	Elderkin	Hants	05/07/17	2017
NS014_02	NS014	2	Elderkin	Hants	05/07/17	2017
NS068_01	NS068	1	Tregothic	Hants	05/07/17	2017
NS068_02	NS068	2	Tregothic	Hants	05/07/17	2017
NS005_02	NS005	2	Dugau-Ryerson	Western	25/04/17	2017
NS008_01	NS008	1	Grand Pré	Western	25/04/17	2017

2.1.3 Armouring

Armouring or rocking data was collected by one of two methods, digitization of aerial imagery or field data collected with handheld GPS. Features collected were given the year of source along with the foreshore classification (backshore, lower foreshore, middle foreshore and upper foreshore). The most contemporary data was utilized for the analysis.

2.1.4 Aboiteaux

Aboiteaux are one-way gated culverts that allow for one way discharge of freshwater with a flap closing on the rising tide to prevent saline waters from entering the marshlands. These locations were surveyed using an RTK GPS. Locations were referenced to the top of dyke. For aboiteaux that were not able to be surveyed, the most recent survey data was used. This data was provided by NSDA.

2.1.5 Digital Elevation Models

Digital elevation models (DEMs) were necessary for the creation of several key outputs including platform elevation, flood layers, etc. DEMs were compiled from a variety of sources. Table 2 provides a list of each DEM with the source, year of data collection, resolution and any additional processing completed.

Table 2: Digital Elevation Models used for Analysis

Dataset Name	Source	Year of Data	Resolution	Additional Processing
Enhanced Digital Elevation Model, Nova Scotia, Canada	Service Nova Scotia and Municipal Relations, Registry and Information Management Services, Nova Scotia Geomatics Centre	1999-2000	20 m	Resampled to 1 m
Kings Lidar DEM	Applied Geomatics Research Group (AGRG)	2003	1 m	
Annapolis Lidar DEM	Applied Geomatics Research Group (AGRG)	2004	2 m	Resampled to 1 m
Hants Lidar DEM	Applied Geomatics Research Group (AGRG) & Saint Mary's University (SMU)	2007	1 m	
Cumberland Lidar DEM	Applied Geomatics Research Group (AGRG)	2009	1 m	
Advocate Lidar DEM	GeoNOVA	2013	1 m	
Avon Hydro System Lidar DEM	GeoNOVA	2011	1 m	
Colchester Lidar DEM	GeoNOVA	2013	1 m	
Urbania Lidar DEM	GeoNOVA	2014	1 m	
Indian Brook Lidar DEM	GeoNOVA	2013	1 m	
Digby Lidar DEM	Applied Geomatics Research Group (AGRG)	2006	1 m	
Lequille Hydro System Lidar DEM	GeoNOVA	2011	1 m	

2.2 Transect Development

As mentioned previously, the base geographic unit of analysis was the dyke tract divided into 25 m segments. Representative variables would be then assigned to each segment based on transects generated perpendicular to the existing dyke orientation. These transects were developed using the Digital Shoreline Analysis System (DSAS) V4.4, a software extension to ESRI ArcGIS. DSAS casts transects, a straight line along which measurements are taken, perpendicular to a reference baseline at a specified spacing. For this analysis, the reference baselines were each dyke tract. Transects were then cast at 25 m spacing at a length determined by features in front of the dyke. Transects were created using a smooth baseline cast with a smoothing distance of 50 m. This was selected to correct the transect cast due to the sharp segment changes of the dyke caused by the 25 m surveying spacing. The smoothed baseline cast setting in DSAS is illustrated in Figure 3. Transects were

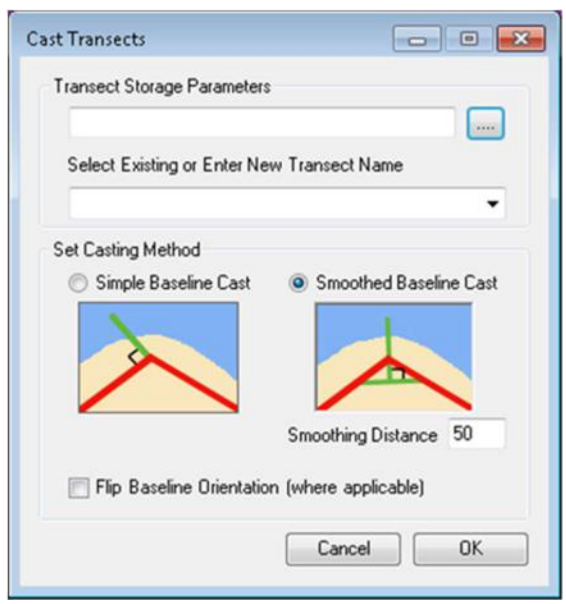


Figure 3: Smoothed baseline cast in DSAS.

cast for each dyke tract then filtered and corrected manually to ensure that each was representative of features in front of the dyke.

2.2.1 Transect Clipping Boundaries

The transect clipping boundaries were polygons developed to ensure that transects were clipped to an appropriate extent during analysis. Several varying boundaries were developed for each dyke segment to allow the correct clipping type for each analysis parameter. The transect clipping boundaries prevented transects from intersecting each other at large lengths along with preventing intersection with features not relevant to that dyke.

3 GIS Model Development and Derived Parameters

In order to process a multitude of parameters for each region, a GIS model was developed using a set of scripts developed in Python V2.7. Script tools were then created within the ArcGIS 10.5 environment to enable user input for select analysis. The model was broken into 6 components, four of which run through ArcGIS Scripts tools, one within ArcMap using DSAS ("*Digital Shoreline Analysis System*") (Thieler et al., 2017) and one within the R statistical package using AMBUR ('*Analyzing Moving Boundaries Using R")*(Jackson et al., 2012). The GIS model allowed the derivation of several parameters. Each of the following sections provide details on both the development and derivation of each key parameter. A master table was created summarizing the results in Appendix C.

3.1 Weighted Fetch

Weighted fetch is an important factor to consider when investigating dyke vulnerability. Weighted fetch is similar to fetch, the unobstructed distance that wind can travel over water in a constant direction, but also considers direction by incorporating wind direction input data. This proves beneficial over regular fetch as wind directional considerations are taken. Fetch domains were selected based on the distribution of marshes and location to major water bodies/systems. A total of three domains were created namely Colchester, Cumberland, and Annapolis and Digby. The Hants and Kings domain used was the same extent as the Colchester domain. In creating the Land/Water rasters, the polygon water boundaries were converted to a raster using the Polygon to Raster (conversion) geoprocessing tool using a cell size of 20 m. While the limitations of this relatively coarse resolution are acknowledged, it was chosen since it matched the provincial DEM available and limited processing time available. Other settings were based on the requirements of the USGS Fetch Model. Initial water boundaries were obtained from the Nova Scotia Topographic Database (NSTDB) and were combined with present day foreshore to extend the model domains up to each dyke.

3.1.1 Climate Station Selection and Wind Data Collection

A Climate station was selected for each region to utilize wind data for input into the fetch model. Data was obtained from Environment Canada. Sites were selected based on geographic location and data availability. Details are provided in Table 3.

Table 3: Climate station information used for input wind data for fetch model from Environment Canada.

a) Annapolis and Digby

Station Name: GREENWOOD A	Station ID: 6354	Climate ID: 8202000
Latitude: 44.98°	Longitude: -64.92°	Elevation (m): 28.0
Daily Data Availability: Total years = 75	First Year: 1942	Last Year: 2017
Years where Wind Data was Used		
1955, 1956, 1957, 1958, 1959, 1960, 1961, 1962, 1963, 1964, 1965, 1966, 1967, 1968, 1969, 1970, 1971, 1972, 1973, 1974, 1975, 1976, 1977, 1978, 1979, 1980, 1981, 1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017		

b) Colchester

Station Name: DEBERT	Station ID: 42243	Climate ID: 8201390
Latitude: 45.42°	Longitude: -63.47°	Elevation (m): 37.5
Daily Data Availability: Total years = 14	First Year: 2003	Last Year: 2017
Years where Wind Data was Used		
2003, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017		

c) Cumberland

Station Name: NAPAN AUTO	Station ID: 42083	Climate ID: 8203702
Latitude: 45.76	Longitude: -64.24°	Elevation (m): 19.8
Daily Data Availability: Total years 14	First Year: 2003	Last Year: 2017
Years where Wind Data was Used		
2003, 2004, 2005, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017		

d) Hants and Kings

Station Name: KENTVILLE DCA SS	Station ID: 27141	Climate ID: 8202810
Latitude: 45.07°	Longitude: -64.48°	Elevation (m): 48.7
Daily Data Availability: Total years 21	First Year: 1996	Last Year: 2017
Years where Wind Data was Used		
2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017		

3.1.2 Wind Data Statistics

In order to run the Weighted Fetch model, a proper wind statistic input file had to be generated for each region. In doing so, wind direction data was classified into the proper compass direction using the classification below.

Wind Direction Classification (Degrees)

N: <=22.5 OR >337.5
NE: >22.5 AND <=67.5
E: >67.5 AND <=112.5
SE: >112.5 AND <=157.5
S: >157.5 AND <=202.5
SW: >202.5 AND <=247.5
W: >247.5 AND <=292.5
NW: >292.5 AND <=337.5

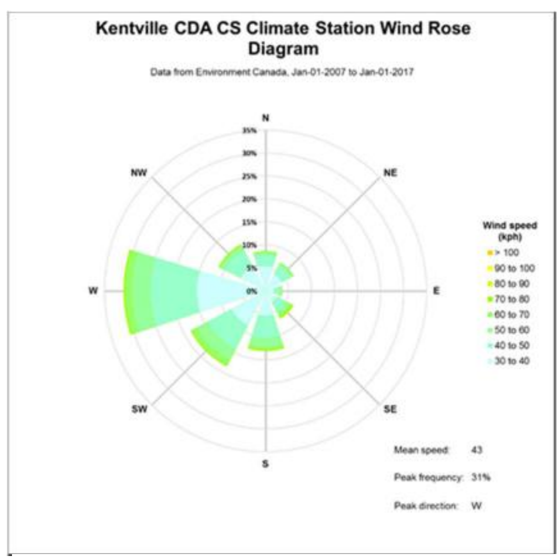


Figure 4: Example of climate station wind rose diagram from Kentville

Wind direction percentage values were also determined using the frequency values generated along with the classification (Figure 4).

3.1.3 Weighted Fetch Raster Generation and Post-Processing

Weighted Fetch rasters were generated using scripts that were originally developed by David Finlayson using the Python scripting language (Finlayson, 2005). The model was modified to more efficiently meet the needs of USACE planning personnel and used the SPM calculation method.

After the Weighted Fetch rasters were generated, unbounded fetch values were removed (negative values) using the SetNull geoprocessing tool. Each raster was first converted to a 32-bit floating point raster using the Float geoprocessing tool. The output raster was then resampled to 1m using the Resample geoprocessing tool and the BILINEAR resampling technique. This was completed in order to determine statistics for small areas of foreshore where cell statistics would be difficult to generate with a 20m cell size.

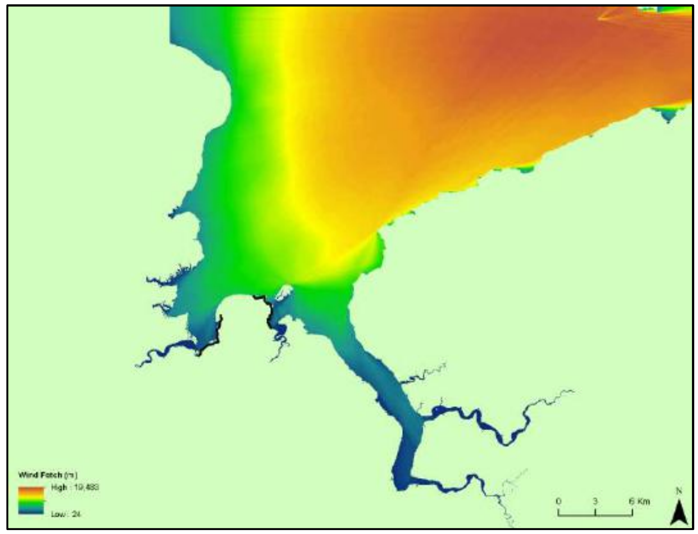


Figure 5: Modelled fetch raster for weighted fetch domain.

3.1.4 Model Weighted Fetch Determination

Once the final processed weighted fetch rasters were completed, they were set as inputs into the GIS model (). Dyke segment weighted fetch values were determined by clipping the weighted fetch raster to the bounding area, defined by two adjacent transects, and the contemporary foreshore marsh boundary. Both mean and standard deviation values were obtained for each segment.

3.2 Foreshore Width

The foreshore width represents the total distance of foreshore in front of each dyke segment. In determining this value, the most contemporary foreshore marsh boundaries were used to clip the transects. This created a set of transects representing the width of foreshore in front of the dyke (**Error! Reference source not found.**). The current foreshore width plays a critical role in the degree of protection from erosion and wave energy dissipation. It is used in the analysis as a base parameter: 'urgency to act', essentially the time available

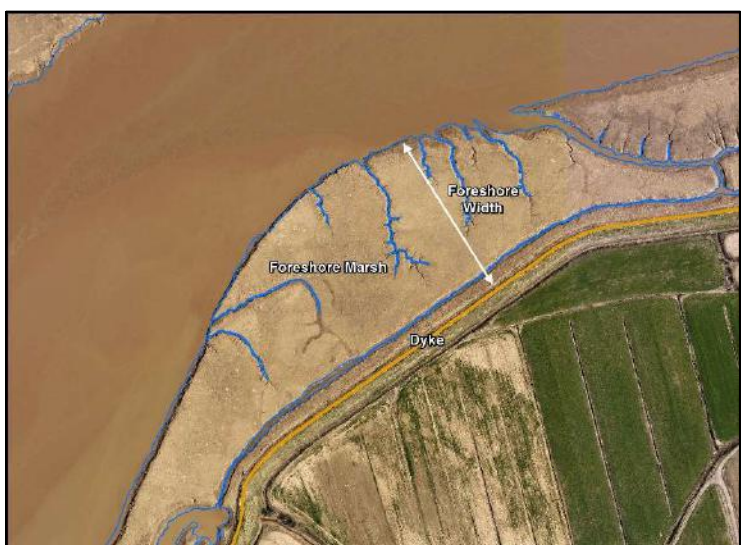


Figure 6: Determination of foreshore width based on contemporary foreshore and cast transects.

before the foreshore is complete gone, based on the rate identified by the end point change rate (EPR) calculated in AMBUR.

3.3 Foreshore Platform Elevation

Foreshore platform elevation is the mean elevation of the marsh platform in front of a dyke segment (Figure 7). To determine this value for each segment, digital elevation models were clipped to the extent of two adjacent bounding transects. Cell statistics were then determined for the clipped foreshore DEM. Both mean platform elevation and standard deviation were derived to be able to predict the depth of water over the foreshore along with how variable that foreshore marsh is. The standard deviation can be used to indicate if the marsh is a 'young' ramped marsh or mature, cliffed high marsh, which have different effects on wave energy dissipation. The accuracy of this data is limited to areas where LIDAR is available and date of survey.

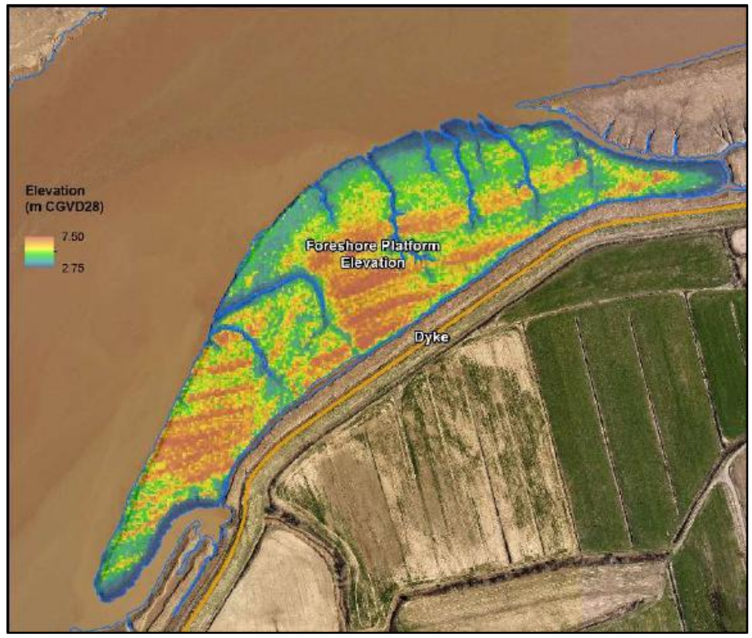


Figure 7: Determination of foreshore platform elevation between transects. Derived from most accurate DEM model available outlined in Table 1.

3.4 Length of Armouring

Armouring, or rocking, is placed in front of the dyke to protect it from wave action. This rocking is sometimes placed at the toe of the dyke or further outwards onto the lower foreshore (Figure 8). In determining the total length of armouring for each dyke segment, the polyline armouring feature class was clipped by two consecutive bounding transects. The clipped polyline length(s) were then summated to provide the total length of armouring. Since the majority of the toe of dykes are armoured, this analysis focused on armouring of the foreshore marsh as these areas would have the most direct impact on coastal processes and resultant response of the foreshore marsh. Their data are limited by the lack of consistent data records and availability of aerial photography.

Figure 8: Location and extent of contemporary armouring of dyke. Although the location of the armouring is symbolized on the dyke segment, it represents armouring of the foreshore marsh.

3.5 Foreshore Change Rate

Foreshore change rates were determined by calculating the linear change between each foreshore boundary year. This was completed using Analysis of Moving Boundaries in R (AMBUR) with the dyke centerline as the baseline and the dyke transects as the feature where measurements were referenced along (Figure 9). Values were observed to determine if any errors existed (e.g. channel shifting, foreshore edge affects, extent limitations). In areas where errors did exist, the data were filtered accordingly. Foreshore change rates less than -20 $m \cdot yr^{-1}$ and above 20 $m \cdot yr^{-1}$ were removed due to the errors discussed above. Mean foreshore change rate and standard deviation were determined for each segment by averaging bounding transect values. They were classified for analysis and display based on the categories outlined in Table 4. 'Urgency to act' or time until foreshore marsh is eroded is calculated as foreshore width/EPR. In this analysis we are assuming that the rate of change is a linear function between available years and data are restricted to available air photos at low tides.

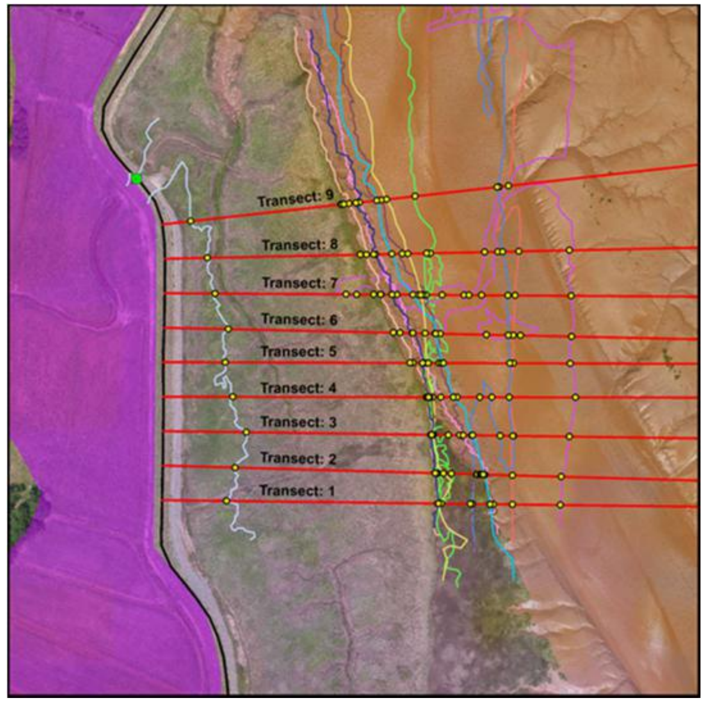


Figure 9: Example of transects and intersection of salt marsh polygons used for end point change rate in AMBER at Elderkin marsh.

Table 4: Classification of ranges of end point change rates (erosion and progradation) of the foreshore marsh.

Range (m/yr)	Change Rate Classification
>-5	Rapid Erosion
-5 to -2.5	Moderate Erosion
-2.5 to -0.25	Slow Erosion
-0.25 to 0.25	No Detectable Change
0.25 to 2.5	Slow Expansion
2.5 to 5	Moderate Expansion
>5	Rapid Expansion

3.6 Dyke Crest Elevation

Dyke crest elevation for each segment was determined by utilizing surveyed crest elevations (described in Section 2.1.2). A 3D line feature was first created using the point elevations. Points were then created along the line at 25-meter spacing. Segment elevations were then linearly interpolated depending on where the 25 meter points were located along the line. Dyke crest elevation is a critical parameter in the Bayesian overtopping model.

3.7 Dyke Orientation

Dyke orientation represents the azimuth or direction at which the dyke is oriented towards. This is an important parameter as it can be related to the local channel orientation to observe erosion/accretion patterns. Each dyke segment orientation was determined using the X and Y coordinates of each of its end point. Dyke normal orientation represents the perpendicular orientation at which the dyke is facing. This value was determined by using the average azimuth between the 2 adjacent transects for each segment.

3.8 Aboiteau Presence/Absence

The presence or absence of an aboiteau is important to consider when looking at factors contributing to dyke vulnerability. A near analysis was completed with aboiteau locations and dyke segments as inputs. The segment that is the closest to each aboiteau feature was assigned a value of "Yes" having an aboiteau present.

3.9 Maximum Exposure

The maximum exposure considered in this analysis was determined by comparing the dyke normal orientation to the peak wind direction from the weighted fetch statistics. The peak wind directions were represented by 45 degree ranges (e.g. 0 – 45 degrees). If the dyke normal orientation value was within the range of the peak wind direction then the segment was assigned a value of Yes, meaning it aligned with the maximum exposure direction.

3.9.1 Maximum Wave Height

The maximum wave height was defined as the difference between the Higher High Water Large Tide (HHWLT) value and the foreshore platform elevation. This value was determined by using the regional HHWLT value and foreshore platform elevation described in section 3.3.

3.10 Flood Layers

Flood layers were created for several scenarios of interest which included the following:

- Contemporary (2010) HHWLT
- HHWLT + SLR (2050/2055)
- HHWLT + SLR (2100)
- HHWLT + SLR (2050/2055) + Storm Surge (50-Year)
- HHWLT + SLR (2050/2055) + Storm Surge (100-Year)
- HHWLT + SLR (2100) + Storm Surge (50-Year)
- HHWLT + SLR (2100) + Storm Surge (100-Year)

It should be noted that these values are highly dependent on the accuracy of the predicted HHWLT station values. Current HHWLT values provided by the CHS in the upper Bay do not reflect observed values in the field, nor vegetative indicators. As such, a decision was made to adhere to published station values and not use the most current tidal surface model. This project and others have identified the serious need for longer term tide level records in intertidal areas of the Upper Bay that are not well resolved in existing hydrodynamic models. A sensitivity analysis was performed on the flood extend of a different of less than 0.5 m vertical and for most areas the results are very similar in flood extent.

Table 5: Reference source for HHWLT values and sea level rise projections for each Region.

Region	Report Reference	Year Published	Author	Comments
Colchester	*Scenarios and Guidance for Adaptation to Climate Change and Sea-Level-Rise - NS and PEI Municipalities*	2011	William Richards and Real Daigle	
Hants & Kings	*Sea-Level Rise and Coastal Flooding Estimates for Hantsport*	2016	R.J. Daigle Enviro	
Advocate			CBCL Limited	Joggins station for SLR & SS values (R & Daigle, 2011)
Annapolis & Digby	*Scenarios and Guidance for Adaptation to Climate Change and Sea-Level-Rise - NS and PEI Municipalities*	2011	William Richards and Real Daigle	Digby Station
Cumberland	*Sea-Level Rise and Flooding Estimates for New Brunswick Coastal Sections 2017*	2017	R.J. Daigle Enviro	Zone 14

Table 6: Regional scenario parameters derived from sources in Table 5.

Region	**HHWLT (m CGVD28)**	**SLR to 2050/2055 (m)**	**SLR to 2100 (m)**	**Storm Surge (1:50 YR)**	**Storm Surge (1:100 YR)**
Colchester	9.30	0.42	1.05	1.10	1.20
Hants & Kings	8.03	0.33	0.90	1.04	1.13
Advocate	6.53	0.42	1.05	1.04	1.13
Annapolis & Digby	4.70	0.42	1.05	0.81	0.87
Cumberland	7.50	0.33	0.88	1.07	1.17

Table 7: Regional sea level rise and storm surge scenario values.

Scenario	**Colchester**	**Hants & Kings**	**Advocate**	**Annapolis & Digby**	**Cumberland**
Contemporary (2010) HHWL	9.30	8.03	6.53	4.70	7.50
HHWLT + SLR (2050/2055)	9.72	8.36	6.95	5.12	7.83
HHWLT + SLR (2100)	10.35	8.93	7.58	5.75	8.38
HHWLT + SLR (2050/2055) + Storm Surge (50-Year)	10.82	9.40	7.99	5.93	8.90
HHWLT + SLR (2050/2055) + Storm Surge (100-Year)	10.92	9.49	8.08	5.99	9.00
HHWLT + SLR (2100) + Storm Surge (50-Year)	11.45	9.97	8.62	6.56	9.45
HHWLT + SLR (2100) + Storm Surge (100-Year)	11.55	10.06	8.71	6.62	9.55

3.11 Vulnerability Classification

Dykes that are the most vulnerable are those that are at risk of overtopping due to storm surge and have high rates of erosion. A very simple vulnerability classification was performed in ArcGIS 10.5.1 based on the parameters identified in Table 8.

Table 8: Parameter scales used to calculate vulnerability using foreshore end point change rate and overtopping.

Foreshore end point change rate (m/yr)	**Overtopping:** YES	**Overtopping:** NO
Erosion (< -0.25 m/yr)	Very High	High
No detectable change	High	Medium
Prograding (>0.25 m/yr)	High	Very Low

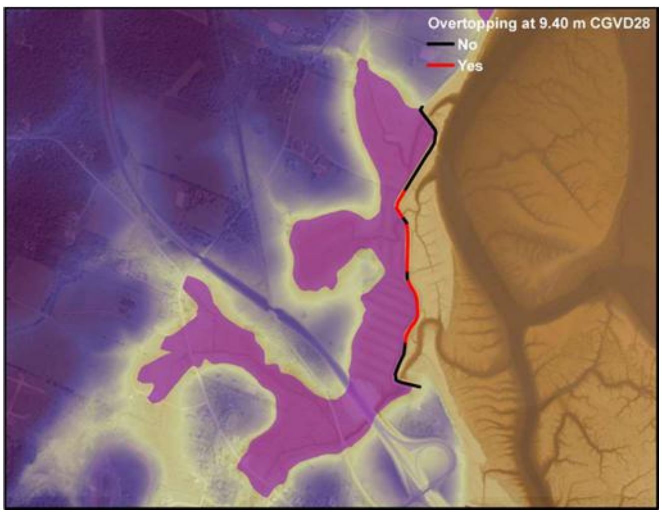
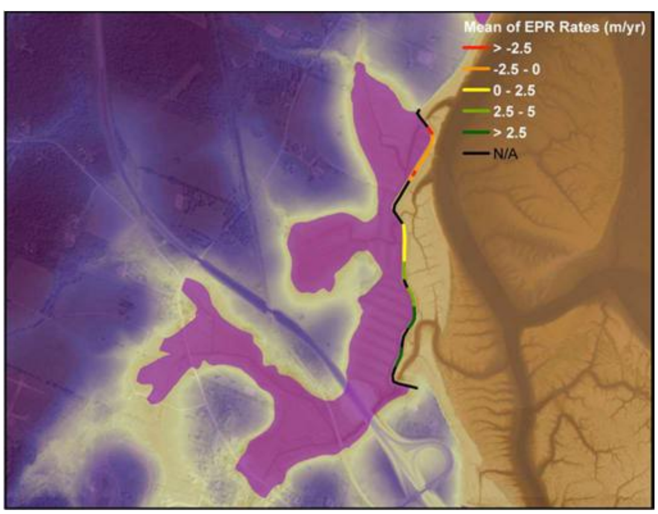


Figure 10: Example of binary (Yes/No) overtopping and mean end point change rates (m/yr) at Elderkin marsh.



A significant limitation of this classification is that it focused on the extreme event and does not consider repetitive erosive action and is highly dependent on accurate tide level recordings. In addition, this analysis does not incorporate the probability of a dyke segment overtopping. That is dealt with in the

Bayesian modelling exercise. It should be noted as well that in this section, vulnerability is treated synonymously with hazard. With all of the base and derived parameters now established within a geodatabase, there are many more permutations of analyses that can be performed that are beyond the scope of this project.

3.12 Bayesian Model Development

A Bayesian model was created in Netica to determine the probability of overtopping for each dyke tract. This model was developed with the assistance of Tim Lynam. A diagram of the model is found in Appendix A. While this model did provide significant additional benefits from the traditional GIS based overtopping model, it was limited by the availability of an extensive tidal level record in the Upper Bay and assumes a normal distribution of the input data and output analysis.

3.12.1 Input Parameter Identification

The following were selected as inputs into the Bayesian model:

- ***Regions*** – Each select area of interest
- ***Storm Surge Return Periods*** – Values of storm surge for various return periods
- ***Sea Level Rise Values*** – Values of sea level rise for 2050 & 2100
- ***Predicted Tides*** – Values of predicted tide elevations
- ***Dyke Crest Elevations*** – Values of dyke crest elevation
- ***Dyke Tracts*** – Each dyke tract ID

3.12.2 Model Nodes

The following are the nodes within the Bayesian model:

- ***Region*** – *Input option*
- ***Storm Surge Return Period*** – *User selects from list of predefined values*
- ***Sea Level Rise Year*** – *Input option*
- ***RCP Scenario*** – *Input option*
- ***Tides*** – *User selects from predefined list of values*
- ***Dyke Tract ID*** – *User selects from predefined list of values*
- ***Dyke Crest Elevation*** – *User selects from predefined list of values*
- ***Storm Surge Residual*** – *User selects from predefined list of values*
- ***Sea Level Rise Height*** – *User selects from predefined list of values*
- ***Water Level Elevation*** – Defined by the addition of storm surge, tide elevation, and sea level rise height
- ***Water Level Over Dyke*** – Defined by the difference of water level elevation and minimum dyke crest elevation
- ***Dyke Overtopping*** – Defined as Yes/No where Yes occurs when Water Level Over Dyke is greater than 0

3.12.3 Model Relationships and Model Learning

Many of the relationships developed in the Bayesian Network (BN) were based on simple numerical equations. For example, the water elevation node used the following equation to parameterise its conditional probability table (CPT):

WaterLevelElevation (StormSurge, TideElevation_mCGVD28, height) =
(StormSurge + TideElevation_mCGVD28 + height)
Where:
StormSurge was the residual storm surge height in metres;
TideElevation_mCGVD28 was the tidal elevation in metres; and
Height was the estimates sea level rise

Some CPT's (e.g. sea level rise or height) were learnt using Netica's built-in Expectation maximisation (EM) algorithm. Data on the relationships between the RCP scenario, year and height were used to train the sea level rise node.

An important numerical relationship used in the model was the water level over the dyke. This was estimated as the height of the water less the minimum dyke crest elevation in any tract of a region. The assumption here is that the risks of overtopping are greatest at the lowest elevation dyke tract.

3.12.4 Sensitivity Analysis

Using Netica's built in function, a sensitivity analysis was undertaken with the "Dyke Overtopping" node as the focus and with each region selected separately. The results are available in Appendix B. The dominant sources of uncertainty in model estimation of the probability of dyke overtopping were water level elevation (e.g. the sum of tides, storm surge and sea level rise), tides and dyke crest elevation.

3.12.5 Assumptions & Limitations

One of the challenges of working with many Bayesian Network software tools for applications such as dyke overtopping, is the need to discretize continuous variables. New tools are emerging that can work with continuous (predominantly Gaussian) data but Netica is not one of these. As a consequence, care needs to be taken in selecting discretization levels for all variables. The assumption of dyke overtopping being most likely at the tract with the minimum elevation in a region may require further exploration and testing.

3.13 Quality Assurance & Quality Control

All data were generated using standardized protocols within MP_SpARC and verified by at least one other senior member of the team before it was integrated into the geodatabase. This included manual inspection of the generated feature class against aerial imagery and consultation with those individuals knowledgeable of conditions at the site. This was particularly relevant for the end point change rates calculated, as the orientation of the transects have a large influence on the results. The orientation of these transects were therefore manipulated manually as needed to reflect the likely direction of dominant coastal processes. All results were examined to ensure that they made sense from a coastal processes perspective.

4 Interpretation and Application of Results

4.1 GIS Model Results

The majority of this project dealt with the generation of base and derived datasets for analysis of dyke vulnerability. Anticipated variables such as wave energy, dyke material and condition were not available from other sources and the lack of long term tide data limited some of the analyses that could be performed. However, this study provides the first standardized measures of changes in the foreshore marsh which can be used to inform management decisions as well as detailed characterization of all of the dyke tracts in the Province at 25 m intervals.

On the whole, the mean rate of change in salt marsh foreshore is 0.03 $m \cdot yr^{-1}$ ±3.87 $m \cdot yr^{-1}$. So although the rate of change is essentially neutral, the standard deviation indicates considerable variability. The Annapolis and Digby regions have the highest mean rates of erosion, losing just under 1m of foreshore per year (Table 9). Marshes in Colchester are also eroding on average of 21 cm per year. The fastest mean rate of progradation or lateral growth in foreshore marsh is occurring in Cumberland County, expanding by 32 cm per year (Table 9). The standard deviation however suggests that this trend is spatially and temporally variable.

Table 9: Mean foreshore change rate per region. Statistics are calculated after filtering outliers (>20m/yr, <-20 m/yr). Negative values indicate erosion, positive values are progradation or lateral marsh expansion.

Region	Mean Foreshore Change Rate (m/yr)	Mean Foreshore Change Rate Standard Deviation (m/yr)
Annapolis & Digby	-0.93	1.65
Colchester	-0.21	3.06
Cumberland	0.32	5.21
Hants & Kings	0.15	3.83

Assuming a linear rate of erosion based on historical trends, there are 16 tracts that will have no foreshore remaining by 2050 (Table 10). Three of these (NS038_02, NS052_01 and NS065_99) have less than 10 years remaining until the foreshore marsh is completely gone (Table 10). Based on current SLR projections, 52% of the dyke at St. Mary's Bay will be overtopping on the highest tides in the next 30 years (Appendix E). Noel Shore will have 78% of its dyke overtopped by 2050 (Appendix E) and has 20 years until it no longer has a foreshore. Although both Rines Creek (NS112) and Southside (NS113) have lower rates of erosion, they are also the most exposed (Table 10) and at present, it appears that 88-89% of the dyke overtop on the highest spring tides (Appendix E). They are therefore classified as having a very high vulnerability, alongside St. Mary's Bay (Table 10).

On average, based on the GIS analysis, the dykes in the Annapolis and Digby areas are among the most vulnerable in the Province, with St. Mary's Bay (NS52) classified as Very High due to low crest elevation and high rate of foreshore erosion (Appendix C). Based on the current EPR, the foreshore will be gone in under 5 years (**Error! Not a valid bookmark self-reference.**). The remaining marshes are classified as High vulnerability primarily due to lower dyke elevations relative to the tides (Table 11, Appendix E). In addition, the foreshore marshes in that region are at a lower platform elevation, and therefore, do not serve as great a protection against storm surge or overtopping. This is a result of the relatively lower suspended sediment concentrations in the lower Bay. In Colchester County, three of the marshlands are rated as High Vulnerability: NS112 and NS113 as mentioned previously, and NS097 (Highland Village) (Appendix C). All of these sites are modelled as currently overtopping at high spring tides. These sites are in more sheltered locations therefore are less likely to be as vulnerable to storm surge. A number of sites are classified as having very low vulnerability due to limited overtopping by 2050 and lateral growth of the foreshore marsh. In Cumberland County, none of the dykes are modelled to overtop in 2050 but some marshes do experience erosion, and therefore, are rated at a High Vulnerability (Appendix C). As mentioned previously, further analyses can be performed to tease out and differentiate, vulnerability rank according to different criteria such as exposure, platform elevation, etc. In Hants and Kings counties, NS092 Avonport and NS101 Pereau have the highest vulnerability ranking (Appendix C) and Avonport in particular also has a high mean rate of erosion of -3.3 ±15.5 $m \cdot yr^{-1}$ (Appendix C). However given a current foreshore width of 146 m, there is approximately 40 years before it erodes to the dyke (Appendix C).

Table 10: Marshlands that will have no foreshore remaining by 2050 based assuming a constant erosion rate based on the mean EPR calculated from historical imagery.

Marsh Name	Tract ID	Foreshore width (m) mean	End Point Rate (m/yr) mean	min	max	Time until no foreshore (yrs)	Dyke crest elevation (m CGVD28) mean	min	vulnerability Class	Max Exposure (%)
Bishop Beckwith	NS065_99	15.6	-2.8	-2.8	-2.8	5.6	8.8	8.7	High	25.0
St. Marys Bay	NS052_01	14.5	-2.5	-14.6	1.8	5.8	5.1	4.4	Very High	3.6
St. Croix	NS038_02	43.6	-4.3	-13.1	4.7	10.1	8.8	8.7	High	100.0
Burntcoat	NS111_01	26.5	-1.8	-2.2	-1.6	14.3	10.3	10.3	High	100.0
Barronsfield	NS045_01	21.2	-1.2	-14.0	6.8	17.2	8.5	8.3	High	3.5
Noel Shore	NS024_01	64.3	-3.3	-13.8	12.1	19.7	9.5	9.0	High	40.7
River Hebert	NS046_00	22.5	-1.1	-1.4	-0.9	20.0	8.6	8.3	High	69.2
Bishop Beckwith	NS065_02	19.0	-0.9	-2.1	0.0	20.0	8.8	8.4	High	60.9
St. Croix	NS038_07	18.3	-0.9	-1.6	0.0	21.1	8.9	8.7	High	70.0
New Minas	NS057_01	43.4	-2.0	-4.5	0.7	21.7	8.5	8.2	High	8.3
Masstown	NS023_01	95.3	-3.6	-11.3	4.3	26.2	9.8	9.4	High	8.0
St. Croix	NS038_09	16.8	-0.6	-1.1	0.0	27.6	8.8	8.6	High	69.2
St. Croix	NS038_05	20.1	-0.7	-3.4	1.4	27.7	8.8	8.5	High	8.1
Rines Creek	NS112_01	26.5	-0.9	-10.6	1.1	30.8	9.2	9.1	Very High	100.0
Southside	NS113_05	16.3	-0.5	-1.6	-0.2	31.7	9.0	8.4	Very High	100.0
Fort Ellis	NS106_01	27.4	-0.9	-2.1	0.3	31.7	9.8	9.5	High	19.2

Table 11: Condensed summary of results of GIS modelling per Region.

	Region							
	Annapolis & Digby		Colchester		Cumberland		Hants & Kings	
Variable	***Mean***	***Std. Dev***	***Mean***	***Std. Dev***	***Mean***	***Std. Dev***	***Mean***	***Std. Dev***
Dyke Orientation (Degrees)	127	92	157	96	165	103	179	112
Dyke Normal Orientation (Degrees)	199	85	184	89	189	92	163	97

Dyke Crest Elevation (m CGVD28)	5.58	0.20	9.71	0.49	8.55	0.41	8.76	0.28
Foreshore Width (m)	46.5	40.9	70.9	96.7	46.2	50.0	90.4	130.3
Total Armouring Length (m)	6.5	11.4	3.6	9.9	2.0	7.2	1.6	7.4
Mean Platform Elevation (m CGVD28)	3.26	0.48	8.28	0.60	6.63	0.97	6.39	0.83
Platform Elevation Std. Dev (m CGVD28)	0.40	0.21	0.47	0.29	0.29	0.22	0.69	0.32
Mean Weighted Fetch (m)	1089	482	2365	3769	522	729	1062	1648
Weighted Fetch Std. Dev (m)	66	75	221	596	23	43	64	120
Mean Foreshore Change Rate (m/yr.)	-0.6	0.7	-0.5	4.0	-0.4	4.9	0.4	3.0
Foreshore Change Rate Std. Dev (m)	1.0	1.2	3.9	9.6	6.1	14.0	4.2	6.1

Although mean end point change rates developed from historical values are useful for identifying vulnerable marshes or dyke tracts, an important caveat to this is that they may not reflect contemporary or future rates of change. For example, a marsh could have a historic end point change rate indicating it is an eroding marsh; however, anthropogenic changes on the marsh (e.g. implementation of rocking or kicker) or changes in natural drivers can alter the contemporary or future state of the marsh to progradational. As such, it is important to critically assess each marsh/dyke tract based on the entire range of data generated during the EPR calculation. Included in this data is the end point change rate of each transect between any two given foreshore boundary dates. The case studies below provide an example of three marshes with different historical and contemporary trends of end point change (dyke segments in the figures are a mean of the adjacent transect EPR values). These case studies highlight the value in further examining end point change rates within the Bay of Fundy. Even more in-depth statistical analysis of end point change rates are possible with the data generated, warranting a more complete study of the cause and effect of the morphological evolution (i.e. EPR rate and area change) of salt marshes in the Bay of Fundy.

4.1.1 Example Application and Analysis: NS023 Masstown west

Although the dyke on NS023 Masstown is over 7.5 km long, there are three distinct salt marshes on its foreshore side. The salt marsh in front of the western portion of NS023 Masstown (i.e. first 4km from the western edge) has experienced near continuous erosion since 1938. Mean end point change rates of individual transects during this time, range from -11m·yr^{-1} to -1 m·yr^{-1}, with an overall mean rate of 7 m·yr^{-1}. This erosion has coincided with major losses of salt marsh area. The most significant loss of salt marsh occurred between 1938 and 1975 following a major dyke building project in 1953, where approximately 138ha of salt marsh were lost due to reclamation. Since then, there has been a steady decline of salt marsh area reaching a low in 2013 of 67ha (complete data are not available for more recent dates) and a net loss of over 210ha since 1938 (133ha since 1975) (Table 12). Contemporary mean end point change rates suggest that erosion may be slowing down, but still constitute a moderate erosion rate at -3 m·yr^{-1} and -4 m·yr^{-1} between 2015-2016 and 2016-2017, respectively. Beyond the initial loss of salt marsh to reclamation, the legacy effect of the 1953 dyke in Masstown is that it has acted as a barrier for the eroding salt marsh to retreat beyond (i.e. coastal squeeze). With foreshore widths ranging from <50m – 200m in this area, complete foreshore loss could be expected in front of some portions of the dyke within 10 – 15 years if historical rates continue and ~25 years at contemporary rates. The western portion of NS023 Masstown can therefore be classified as an eroding marsh that has always been eroding (Figure 11).

Table 12: Salt marsh area in Masstown West per available aerial imagery and assessment if eroding or prograding. Note area values are estimates only since the full marsh polygon extends beyond the frame of analysis for this exercise.

Year	*Salt marsh Area (ha)	Eroding/Prograding
1938	~300ha	Eroding
1975	~200ha	Eroding
1994	~150ha	Eroding
2003	~97ha	Eroding
2013	~67ha	Eroding

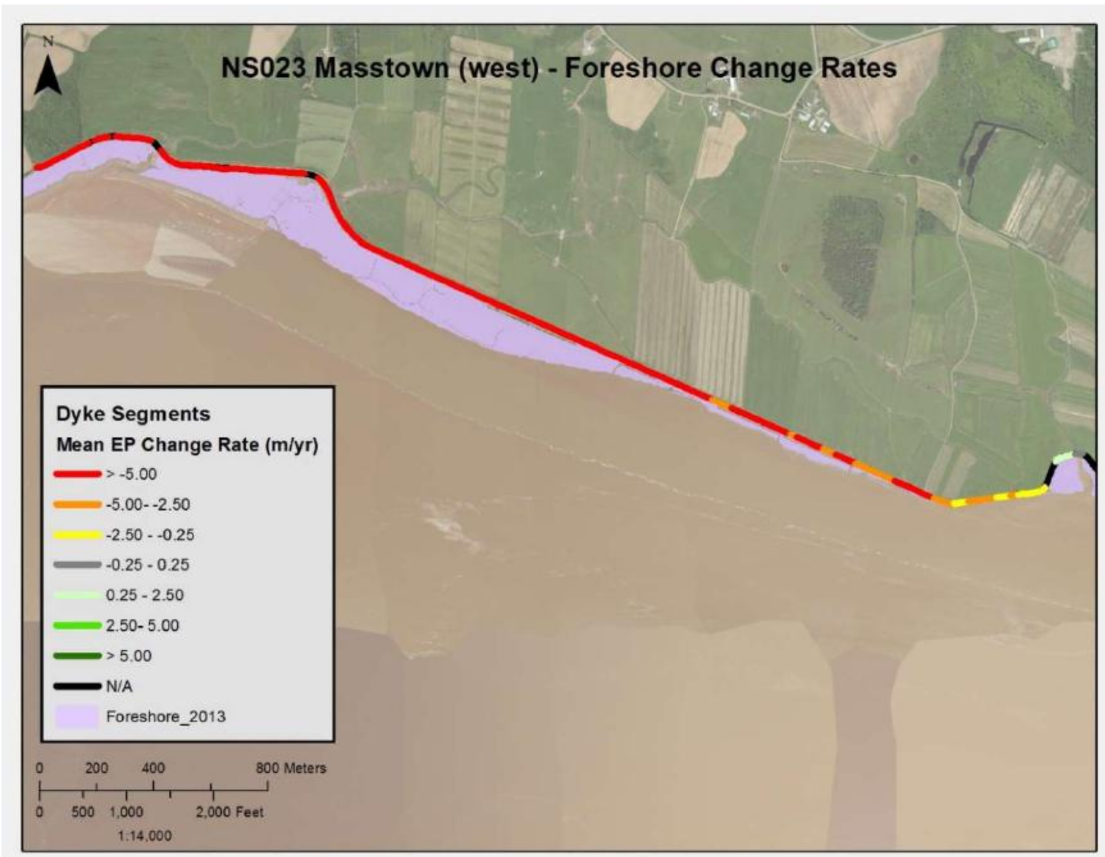


Figure 11: Mean end point (EP) change rates in foreshore marsh per dyke segments at NS023 Masstown. Negative values indicate erosion, positive values indicate lateral growth or progradation.

4.1.2 Example Application and Analysis: NS012 Victoria Diamond Jubilee (VDJ)

NS012 Victoria Diamond Jubilee (VDJ) is one of the few marshes in the Cobequid area to have experienced reclamation since the 1950's following the realignment of the dyke, in 1996. That is because NS012 VDJ has experienced continuous progradation (i.e. positive mean end point change rate) along the majority of the foreshore since 1938. The mean end point change rate along the entire tract has been approximately 1 $m \cdot yr^{-1}$ since 1975, with a single transect maximum EPR of 6 $m \cdot yr^{-1}$, and a minimum of -2 $m \cdot yr^{-1}$; however, the negative values in mean end point change rate correspond to changes in the position of a large aboiteau channel, or are a result of moving the dyke forward in 1996 (shortening the foreshore width). This highlights the importance of closer examination of end point change rate values.

Contemporary change rates suggest that the foreshore position of the salt marsh in front of NS012 VDJ may have reached a dynamic equilibrium with minimal changes occurring east of the aboiteau channel since 2003, and west of the channel since 2013. Mean end point erosion rates along the entire tract, between 2015 and 2016, were 1 $m \cdot yr^{-1}$ and -1 $m \cdot yr^{-1}$, respectively. Positive end point change rates (i.e. progradation) have resulted in an increase in salt marsh area between 1938 and 2013, while losses were primarily associated with reclamation (Table 13). The pattern of progradation may be a result of natural drivers, and the localized reduction of tidal prism precipitated by dyke construction. NS012 is an example of a marsh were reclamation is most appropriate. It has constantly increased in area, with a prograding foreshore pioneering an expanding mudflat. Salt marsh area loss is primarily associated with reclamation; however, the overall area of salt marsh regained over half of what it lost in 1996 (-45ha). A caveat to the previous is that static contemporary end point change rates suggest reclamation may no longer be appropriate on NS012 VDJ. Therefore NS012 VDJ can be classified as a marsh that is currently in equilibrium that has always been prograding (Figure 12).

Table 13: Salt marsh area per available aerial imagery and assessment if eroding or prograding at VDJ. Note area values are estimates only since the full marsh polygon extends beyond the frame of analysis for this exercise.

Year	*Salt marsh Area (ha)	Eroding/Prograding
1938	~38ha	Prograding
1975	~97ha	Prograding
1994	~124ha	Prograding
2003	~92ha (-45ha in 1996 to reclamation)	Prograding
2013	~101ha	Mostly Prograding/No Change

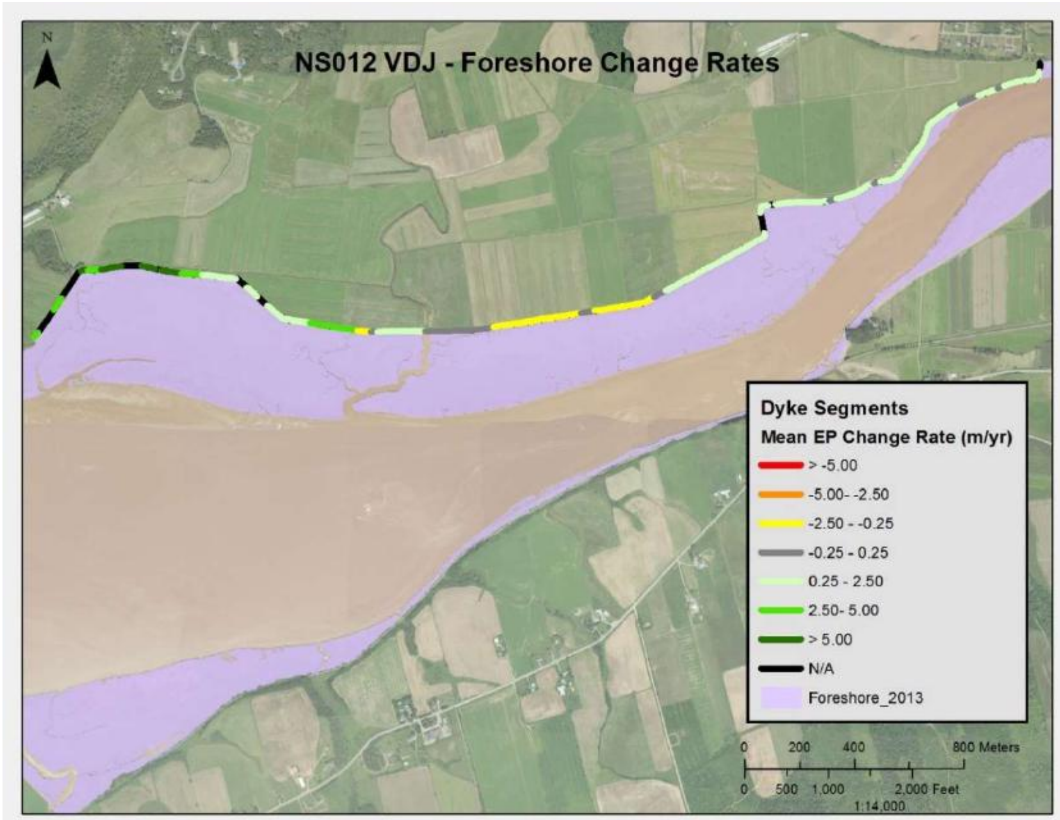


Figure 12: Mean end point (EP) change rates in foreshore marsh per dyke segments at NS012 Victoria Diamond Jubilee (VDJ). Negative values indicate erosion, positive values indicate lateral growth or progradation. Negative values are associated with channel migration and dyke realignment, not foreshore erosion.

4.1.3 Example Application and Analysis: NS081 Lower Truro

NS081 Lower Truro can be segmented into two sections in the context of foreshore change. The western section has primarily experienced continuous progradation and salt marsh area increases following the construction of a kicker around the 1950's. The eastern section has shown to switch between erosional and progradational phases. The latter is consistent with marshes that are in the mixed-to-fluvial dominated portion of the estuary. In the western portion downstream of the kicker, the average mean end point rate has been approximately <1 $m \cdot yr^{-1}$, since 1938. The maximum end point change rate along a single transect was 3 $m \cdot yr^{-1}$, and the minimum -1 $m \cdot yr^{-1}$. In the eastern portion upstream of the kicker, end point change rates are close to 0 $m \cdot yr^{-1}$. However, these end point erosion rates do not translate to a constant maintenance of salt marsh area. Following reclamation in 1954, NS081 Lower Truro experienced a loss of >20ha between 1938 and 1964 (Table 14). After reclamation there have been periods of salt marsh area increase, decrease, and periods of relatively no change. Contemporary end point change rates are only available for the western portion of the salt marsh. Between 2015 and 2016 the mean end point change rate for this portion was -2 $m \cdot yr^{-1}$, while the mean end point change rate between 2016 and 2017 was 2 $m \cdot yr^{-1}$, indicating that the foreshore has reached a dynamic equilibrium. Finally, despite almost no change in the foreshore salt marsh position between 2013 and 2015, the area of the salt marsh decreased due to the construction of multiple borrow pits in the western section. NS081 can be classified as a marsh that has always been switching between erosional and progradational phases, and may have reached a dynamic equilibrium in foreshore position (Figure 13).

Table 14: Saltmarsh area per available aerial imagery and assessment if eroding or prograding at NS081 Lower Truro. Note area values are estimates only since the full marsh polygon extends beyond the frame of analysis for this exercise.

Year	*Salt marsh Area (ha)	Eroding/Prograding
1938	~33ha	
1964	~9ha (-20ha in 1954 to reclamation)	Eroding
1975	~15ha	Prograding
1994	~16	No Change
2003	~17	No Change
2011	~17	No Change
2013	~21	Prograding
2015	~18	No Change

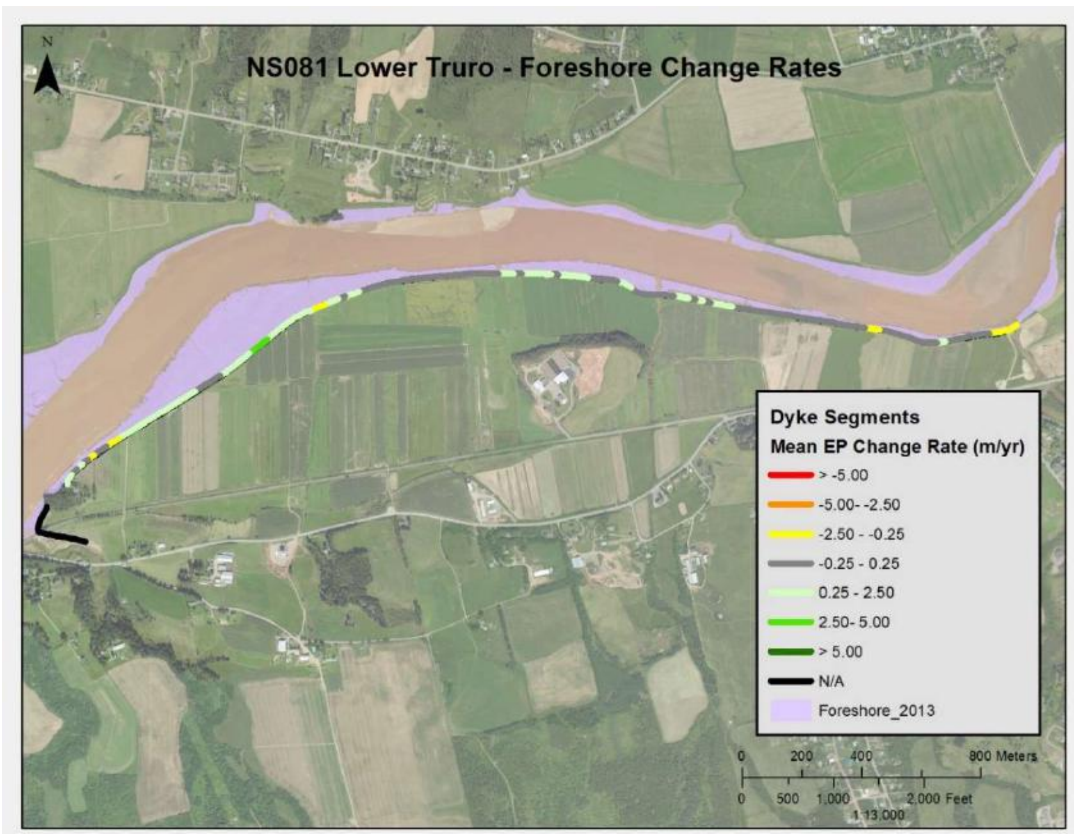


Figure 13: Mean end point (EP) change rates in foreshore marsh per dyke segments at NS081 Lower Truro. Negative values indicate erosion, positive values indicate lateral growth or progradation.

The above case studies illustrate that although mean end point change rates based on the entire range of historical value have merit in identifying "at risk" marshes/dyke tracts, a complete understanding of morphological change in salt marshes and their drivers requires a more comprehensive analysis. In the scientific literature, these types of analyses are called intertidal morphodynamic analysis or morphological evolution analysis and endeavour to quantify change (e.g. erosion rates or salt marsh area) and determine causation for said change (e.g. anthropogenic changes in the estuary or SLR) via various statistical approaches.

4.2 Bayesian Network Modelling

The BN model results indicate that at a whole of region scale the Annapolis Digby dyke tracts have the highest probability of overtopping across all scenarios, with probabilities of overtopping of between 0.035 to 0.089 (3.5 to 8.9%). Annapolis Digby dyke tracts were between nine and 26 times more likely to overtop than Cumberland Dyke tracts, three to four times more likely to overtop than Colchester dyke tracts and twice as likely to overtop as Hants Kings dyke tracts. Hants Kings dyke tracts were the second most likely to overtop with probabilities of 0.02 to 0.05 across the scenarios and Cumberland dyke tracts were the least likely to overtop (Table 15).

The probabilities of overtopping increased dramatically under the 2100 sea level rise (2100_SLR) related scenarios: Cumberland was almost six times more likely to have dyke tracts overtop in the 2100_SLR scenarios than the 2050_SLR; Colchester, Annapolis Digby and Hants Kings tracts were all about twice as likely to overtop under the 2100_SLR scenarios than the 2050_SLR scenarios. Sea level rise appears to have a pronounced impact on the probability of dyke tracts overtopping relative to the impacts of storm surge. These results are conditional on the data and model used and reflect the conditional probabilities of the worst-case scenarios given all possible combinations of tide, sea level rise and storm surge.

Table 15: Probabilities of dyke tracts overtopping for each region and for each of four scenarios.

	Scenario:	**1:50_SS**	**1:100_SS**	**1:50_SS**	**1:100_SS**
Region #	**Region Name**	**2050_SLR**	**2050_SLR**	**2100_SLR**	**2100_SLR**
R1	Annapolis/Digby	0.035	0.038	0.083	0.089
R2	Hants/Kings	0.022	0.023	0.042	0.047
R3	Colchester	0.011	0.012	0.022	0.025
R4	Cumberland	0.001	0.002	0.007	0.009
Ratios of likelihoods	R1/R2	1.6	1.6	2.0	1.9
	R1/R3	3.3	3.2	3.7	3.5
	R1/R4	25.5	24.6	11.3	9.4
	R2/R3	2.0	2.0	1.9	1.9
	R2/R4	15.8	15.1	5.7	5.0
	R3/R4	7.8	7.7	3.0	2.7

ANNAPOLIS and DIGBY		
Scenario	**Probability of Overtopping Occurring (%)**	**Probability of Overtopping Not Occurring (%)**
HHWLT + SLR (2050/2055) + Storm Surge (50-Year)	3.49	96.51
HHWLT + SLR (2050/2055) + Storm Surge (100-Year)	3.81	96.20
HHWLT + SLR (2100) + Storm Surge (50-Year)	8.34	91.66
HHWLT + SLR (2100) + Storm Surge (100-Year)	8.87	91.13
COLCHESTER		
Scenario	**Probability of Overtopping Occurring (%)**	**Probability of Overtopping Not Occurring (%)**
HHWLT + SLR (2050/2055) + Storm Surge (50-Year)	1.07	98.93
HHWLT + SLR (2050/2055) + Storm Surge (100-Year)	1.19	98.81
HHWLT + SLR (2100) + Storm Surge (50-Year)	2.23	97.77

HHWLT + SLR (2100) + Storm Surge (100-Year)	2.51	97.49
HANTS and KINGS		
Scenario	**Probability of Overtopping Occurring (%)**	**Probability of Overtopping Not Occurring (%)**
HHWLT + SLR (2050/2055) + Storm Surge (50-Year)	2.16	97.84
HHWLT + SLR (2050/2055) + Storm Surge (100-Year)	2.33	97.67
HHWLT + SLR (2100) + Storm Surge (50-Year)	4.21	95.79
HHWLT + SLR (2100) + Storm Surge (100-Year)	4.69	95.31
CUMBERLAND		
Scenario	**Probability of Overtopping Occurring (%)**	**Probability of Overtopping Not Occurring (%)**
HHWLT + SLR (2050/2055) + Storm Surge (50-Year)	0.14	99.86
HHWLT + SLR (2050/2055) + Storm Surge (100-Year)	0.15	99.85
HHWLT + SLR (2100) + Storm Surge (50-Year)	0.74	99.26
HHWLT + SLR (2100) + Storm Surge (100-Year)	0.94	99.06

5 Conclusions:

Approximately 70% of dyke tracts analyzed within this project were classified as high or very high vulnerability to coastal erosion and overtopping by 2050. The data generated within this study will provide managers and decision makers with empirical evidence of where not only dykes are vulnerable to overtopping but also what the probability is of this occurring and a measure of the time within which these decisions need to be made. This report constitutes the most complex and fine scale analysis of foreshore salt marsh erosion rates and overtopping probability of dykes in entire Province to date. A comprehensive geodatabase (DDST) has been compiled to attach variables which influence the vulnerability of every 25m segment of dyke in the province (nearly 10,000 segments). These variables include: weighted fetch, foreshore width, foreshore platform elevation, length of armouring, foreshore change rates, dyke crest elevation, dyke orientation, aboiteau presence/absence, maximum exposure, and maximum and wave height.

The dykes in the Annapolis and Digby region are the most susceptible to both contemporary and future overtopping based on their crest elevation, increased duration of the tidal cycle, and the lack of sediment supply for vertical salt marsh accretion compared with the Upper Bay. Following Annapolis and Digby on the list of most vulnerable to overtopping are the Hants and Kings, Colchester, and Cumberland regions, respectively.

End point change rates of foreshore saltmarsh provide a solid, high-level indication of marshes that require action to respond to erosion. There are 16 tracts in the province that are predicted to lose their entire foreshore marsh within the next 30 years. This is important because a robust saltmarsh can mitigate the vulnerability of dykes to overtopping and breaching due to their capacity to dissipate wave energy/attenuate wave heights. It is highly recommended that at these sites any dyke topping being considered should not use borrow pit material from the foreshore marsh to do so. The tracts that have the highest "urgency to act" based on EPR and contemporary overtopping probability are NS052_01 Saint Mary's Bay, NS112_01 Sunnyside and NS113_05 Rines Creek. Although the above provides a precursory view of dyke tracts impacted by salt marsh erosion, it is pertinent to acknowledge that the values used for EPR are based on the entire historical range of end point change rate values and may not necessarily reflect contemporary or future values. Even more in-depth statistical analysis of end point change rates are possible with the data generated, warranting a more complete study of the cause and effect of the morphological evolution (i.e. EPR rate and area change) of salt marshes in the Bay of Fundy. Bayesian network modelling provided an additional insight not previously available regarding the probability of potential of overtopping of the existing dyke infrastructure that is value for testing different scenarios. It is however limited to regional scale analyses due to lack of long term tide level records required for probability determination.

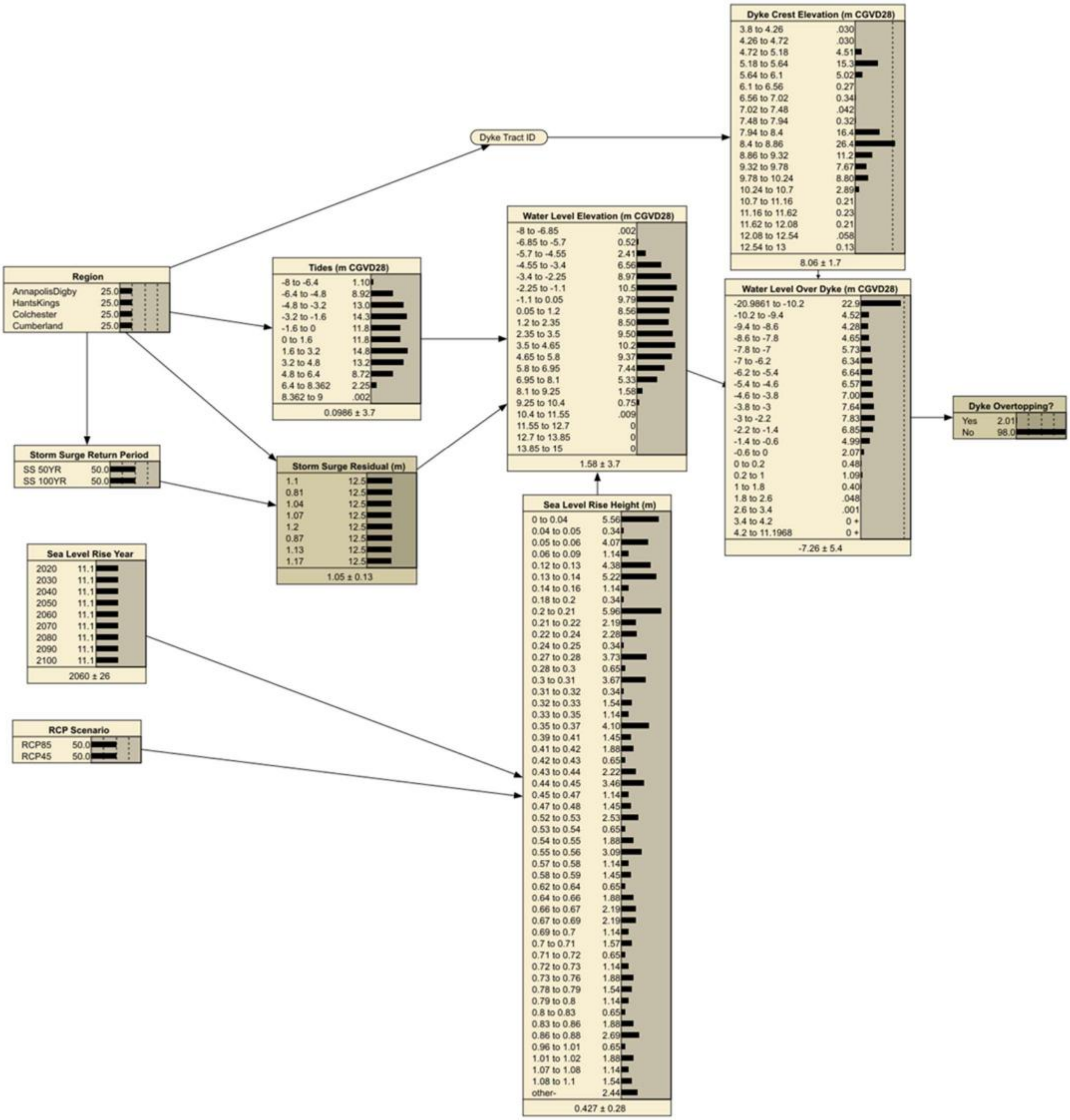
All of the datasets generated within this project can help inform decision making and prioritization of which dykes to maintain in place or those where strategic managed re-alignment should be considered. However, more data is required in order to properly assess dyke vulnerability to breaching including geotechnical data pertaining to dyke material, site classification, and wave modelling and should be prioritized for the near future. These datasets, coupled with an understanding of intertidal morphodynamics, are providing the evidence and tools needed to develop a strategic and proactive plan for addressing the vulnerability of dykelands in the Province.

6 References

- Agricultural Marshlands Conservation Act 2002 (NS) c.22, s.1 (CDN).
- CBCL Ltd. 2017. *Truro Flood Risk Study*. Submitted to the Joint Advisory Committee, County of Colchester, Town of Truro and Millbrook First Nations. 106 pp.
- Fedak, M. and D. van Proosdij. 2012. Hydrodynamic Flood Modelling within Fundy Dykelands: Windsor Case Study. Final report submitted to Atlantic Climate Adaptation Solutions Association (ACASA), Climate Change Directorate, Nova Scotia Department of Environment. 73pp.
- Jackson, C.W.; Alexander, C.R.; and Bush, D.M. 2012. Application of the AMBUR R package for spatio- temporal analysis of shoreline change: Jekyll Island, Georgia, USA. Computers & Geosciences, 41(4):199-207.
- Richards, R. and R. Daigle. 2011. *Scenarios and Guidance for Adaptation to Climate Change and Sea-Level-Rise - NS and PEI Municipalities.*
- Daigle, R.J. 2016. *Sea-Level Rise and Coastal Flooding Estimates for Hantsport*
- Daigle, R.J. 2017. *Sea-Level Rise and Flooding Estimates for New Brunswick Coastal Sections 2017*
- Spooner, T. 2009. The Economics of Climate Change Impacts on Nova Scotia's Highways. Thesis submitted for a Master of Resource & Environmental Management, Dalhousie University, Halifax, NS. Report # MREM 56, December 8, 2009.
- Thieler, E.R., Himmelstoss, E.A., Zichichi, J.L., and Ergul, Ayhan, 2017, Digital Shoreline Analysis System (DSAS) version 4.0—An ArcGIS extension for calculating shoreline change (ver. 4.4, July 2017): U.S. Geological Survey Open-File Report 2008-1278, https://pubs.er.usgs.gov/publication/ofr20081278
- Tibbetts, J. and D. van Proosdij. 2013. Development of a Relative Coastal Vulnerability Index for Climate Change Adaptation in a Macro-tidal Environment. *Journal of Coastal Conservation,* 17:775-797. DOI 10.1007/s11852-013-0277-9
- van Proosdij, D and S. Page. 2012. Best Management Practices for Climate Change Adaptation in Dykelands: Recommendations for Fundy ACAS sites. Final report submitted to ACASA 151 pp.

- Webster, T., Kongwongthai, M., & Crowell, N. (2012). An evaluation of flood risk to infrastructure across the Chignecto isthmus. *Atlantic Climate Adaptation Solutions Association, Nova Scotia Department of Transportation and Infrastructure Renewal, Halifax*.

Appendix A: Bayesian Model Framework



Appendix B: Bayesian Model Sensitivity Analysis

Advocate, 2050

Node	Mutual Information	Percent	Variance of Believes
Dyke Overtopping?	0.20017	100	0.030189
Water Level Over Dyke (m CGVD28)	0.20017	100	0.030189
Water Level Elevation (m CGVD28)	0.13756	68.7	0.015308
Tides (m CGVD28)	0.11548	57.7	0.009818
Dyke Crest Elevation (m CGVD28)	0.00556	2.78	0.00023
Tract ID	0.00209	1.04	9.48E-05
Storm Surge Residual (m)	0.00007	0.033	2.8E-06
Storm Surge Return Period	0.00007	0.033	2.8E-06
Sea Level Rise Height (m)	0.00002	0.0125	0.000001
RCP Scenario	0	0	0
Sea Level Rise Year	0	0	0
Region	0	0	0

Hants & Kings, 2050

Node	Mutual Information	Percent	Variance of Believes
Dyke Overtopping?	0.15293	100	0.021587
Water Level Over Dyke (m CGVD28)	0.15293	100	0.021587
Water Level Elevation (m CGVD28)	0.12521	81.9	0.015356
Tides (m CGVD28)	0.11065	72.4	0.011714
Dyke Crest Elevation (m CGVD28)	0.00163	1.07	4.74E-05
Tract ID	0.00071	0.462	2.05E-05
Storm Surge Residual (m)	0.00003	0.0171	8E-07
Storm Surge Return Period	0.00003	0.0171	8E-07
Sea Level Rise Height (m)	0	0.00276	1E-07
RCP Scenario	0	0	0
Sea Level Rise Year	0	0	0
Region	0	0	0

Colchester, 2050

Node	Mutual Information	Percent	Variance of Believes
Dyke Overtopping?	0.07941	100	0.009697
Water Level Over Dyke (m CGVD28)	0.07941	100	0.009697
Water Level Elevation (m CGVD28)	0.05654	71.2	0.004691
Tides (m CGVD28)	0.0432	54.4	0.001772
Dyke Crest Elevation (m CGVD28)	0.00417	5.26	0.000053
Tract ID	0.00298	3.75	4.17E-05
Storm Surge Residual (m)	0.00004	0.0503	5E-07
Storm Surge Return Period	0.00004	0.0503	5E-07
Sea Level Rise Height (m)	0.00001	0.00645	1E-07
RCP Scenario	0	0	0
Sea Level Rise Year	0	0	0

Region	0	0	0

Cumberland, 2050

Node	Mutual Information	Percent	Variance of Believes
Dyke Overtopping?	0.01555	100	0.001425
Water Level Over Dyke (m CGVD28)	0.01555	100	0.001425
Water Level Elevation (m CGVD28)	0.00564	36.3	3.94E-05
Tides (m CGVD28)	0.00506	32.5	4.91E-05
Dyke Crest Elevation (m CGVD28)	0.00465	29.9	0.000026
Tract ID	0.00451	29	4.34E-05
Storm Surge Residual (m)	0	0.0222	0
Storm Surge Return Period	0	0.0222	0
Sea Level Rise Height (m)	0	0.00192	0
RCP Scenario	0	0	0
Sea Level Rise Year	0	0	0
Region	0	0	0

Appendix C: Vulnerability Statistics per Dyke Tract for SLR 2050

Annapolis and Digby			Foreshore width (m)	End Point Rate (m/yr)			Dyke crest elevation (m CGVD28)			
NSDA No.	Marsh Name	Tract ID	mean	mean	min	max	mean	min	Vulnerability Class	Max Exposure (%)
NS052	St. Marys Bay	NS052_01	14.5	-2.5	-14.6	1.8	5.1	4.4	Very High	3.6
NS004	Queen Anne	NS004_01	44.0	-0.6	-2.2	0.5	5.6	5.2	High	2.6
NS005	Dugau-Ryerson	NS005_01	50.3	-0.9	-2.5	1.7	5.6	5.3	High	5.9
NS005	Dugau-Ryerson	NS005_02	51.9	-0.9	-1.7	-0.1	5.5	5.1	High	91.1
NS013	Dentiballis	NS013_01	49.3	-0.5	-3.1	0.3	5.6	4.9	High	1.6
NS030	Allain River	NS030_01	85.4	-0.1	-0.7	0.6	5.4	5.2	High	50.0
NS030	Allain River	NS030_02	19.3	-0.3	-1.0	0.3	5.7	5.4	High	20.7
Colchester			**Foreshore width (m)**	**End Point Rate (m/yr)**			**Dyke crest elevation (m CGVD28)**			
NSDA No.	**Marsh Name**	**Tract ID**	**mean**	**mean**	**min**	**max**	**mean**	**min**	**vulnerability Class**	**Max Exposure (%)**
NS097	Highland Village	NS097_01	36.9	-0.3	-1.6	1.9	9.5	9.1	Very High	34.5
NS112	Rines Creek	NS112_01	26.5	-0.9	-10.6	1.1	9.2	9.1	Very High	100.0
NS112	Rines Creek	NS112_02	31.9	-0.8	-3.4	0.2	9.4	9.2	Very High	7.7
NS112	Rines Creek	NS112_03	31.5	-0.9	-3.2	2.0	9.2	9.0	Very High	100.0
NS113	Southside	NS113_04	18.6	-0.4	-1.5	0.3	9.0	8.8	Very High	100.0
NS113	Southside	NS113_05	16.3	-0.5	-1.6	-0.2	9.0	8.4	Very High	100.0
NS011	Truro Dykeland Park	NS011_01	24.8	-0.2	-0.8	0.9	10.7	10.3	High	43.8
NS023	Masstown	NS023_01	95.3	-3.6	-11.3	4.3	9.8	9.4	High	8.0
NS024	Noel Shore	NS024_01	64.3	-3.3	-13.8	12.1	9.5	9.0	High	40.7
NS024	Noel Shore	NS024_03	237.5	-0.9	-7.6	9.0	9.7	9.4	High	12.5
NS039	Round	NS039_01	68.0	0.0	-1.9	0.8	9.7	9.4	High	1.3
NS040	Fort Belcher	NS040_05	64.4	0.1	-4.4	5.6	10.1	9.8	High	13.3
NS064	Glenhome	NS064_01	46.6	-1.2	-1.2	-1.1	9.5	9.4	High	100.0
NS064	Glenhome	NS064_02	139.0	0.2	-2.1	1.8	9.8	9.4	High	9.2
NS064	Glenhome	NS064_03	34.1	0.0	-0.6	0.5	9.9	9.8	High	58.3
NS064	Glenhome	NS064_04	40.5	0.2	0.0	0.3	9.9	9.7	High	16.7
NS066	Flemming	NS066_01	132.3	-0.9	-4.1	3.1	9.9	9.6	High	5.9
NS067	Onslow North River	NS067_01	22.6	-0.2	-1.9	1.7	10.1	9.7	High	100.0
NS067	Onslow North River	NS067_02	33.3	0.0	-1.4	6.6	9.8	9.4	High	1.3
NS077	Princeport	NS077_01	43.1	2.6	0.2	5.1	9.5	9.2	High	5.4
NS081	Lower Truro	NS081_01	23.9	-0.7	-1.2	-0.3	9.9	9.7	High	60.0
NS086	Central Onslow	NS086_02	35.3	-0.8	-2.2	1.6	10.2	10.1	High	100.0
NS090	Old Barns	NS090_01	152.8	0.0	-0.5	0.4	10.3	10.2	High	100.0
NS090	Old Barns	NS090_02	87.2	-0.9	-1.1	-0.8	9.8	9.8	High	100.0
NS090	Old Barns	NS090_03	85.7	0.2	-0.6	1.7	10.0	9.9	High	100.0
NS090	Old Barns	NS090_04	313.8	-0.7	-17.2	5.0	10.0	9.6	High	11.8

NS098	Stewiacke	NS098_02	11.0	0.7	-0.4	1.4	8.5	8.4	High	100.0
NS098	Stewiacke	NS098_03	18.5	0.6	-1.2	2.0	9.2	8.9	High	29.6
NS098	Stewiacke	NS098_04	20.3	0.5	-0.1	1.0	8.9	8.7	High	85.2
NS106	Fort Ellis	NS106_01	27.4	-0.9	-2.1	0.3	9.8	9.5	High	19.2
NS106	Fort Ellis	NS106_02	30.7	0.3	-2.9	3.1	9.3	9.1	High	0.7
NS106	Fort Ellis	NS106_03	36.8	0.4	-1.2	4.4	9.4	9.3	High	62.2
NS106	Fort Ellis	NS106_04	20.3	0.0	-1.0	1.5	9.6	9.3	High	100.0
NS106	Fort Ellis	NS106_05	25.9	-0.5	-1.7	0.9	10.7	9.4	High	7.7
NS111	Burntcoat	NS111_01	26.5	-1.8	-2.2	-1.6	10.3	10.3	High	100.0
NS113	Southside	NS113_01	21.7	1.0	-1.1	3.4	9.1	9.0	High	60.7
NS113	Southside	NS113_02	17.2	0.0	-1.6	1.6	9.1	9.0	High	57.7
NS113	Southside	NS113_03	13.4	0.1	-1.3	1.6	9.0	8.9	High	5.6
NS114	Great Village	NS114_01	93.5	0.2	-1.0	1.7	10.2	9.5	High	11.6
NS116	Shubenacadie	NS116_01	33.2	0.1	-0.3	0.6	9.3	9.1	High	100.0
NS117	Tufts	NS117_01	21.6	0.2	-0.3	0.7	9.2	9.0	High	38.9
NS128	Cobequid	NS128_01	30.1	0.1	-4.4	1.4	10.5	9.7	High	0.4
NS012	Victoria Diamond Jubilee	NS012_01	237.6	1.1	-2.2	5.9	10.3	9.9	Very Low	13.4
NS015	Isgonish	NS015_01	39.8	1.4	-0.7	8.9	10.4	9.4	Very Low	17.4
NS015	Isgonish	NS015_02	9.3	0.9	-4.4	6.2	10.3	9.9	Very Low	81.3
NS025	Maitland	NS025_01	74.9	4.7	3.2	6.0	10.1	10.1	Very Low	100.0
NS025	Maitland	NS025_03	103.4	7.9	2.4	19.3	9.8	9.5	Very Low	100.0
NS040	Fort Belcher	NS040_01	114.6	4.2	1.3	10.1	10.3	10.1	Very Low	100.0
NS040	Fort Belcher	NS040_03	46.4	0.3	-1.0	2.4	10.1	9.9	Very Low	12.5
NS047	Selma	NS047_01	341.8	2.6	-1.1	5.1	9.7	9.5	Very Low	45.5
NS081	Lower Truro	NS081_02	48.2	0.3	-1.5	2.7	10.1	9.6	Very Low	100.0
NS086	Central Onslow	NS086_01	44.3	0.8	-0.1	1.8	10.2	10.2	Very Low	100.0
NS086	Central Onslow	NS086_03	31.0	0.4	-0.6	4.6	9.8	9.6	Very Low	1.3
NS086	Central Onslow	NS086_04	26.2	0.5	-0.4	3.2	10.2	9.8	Very Low	6.3

Cumberland			Foreshore width (m)	End Point Rate (m/yr)			Dyke crest elevation (m CGVD28)			
NSDA No.	Marsh Name	Tract ID	mean	mean	min	max	mean	min	vulnerability Class	Max Exposure (%)
NS042	Amherst Point	NS042_02	117.9	-3.2	-19.6	3.2	8.5	8.3	High	4.7
NS044	Converse	NS044_01	42.0	-0.1	-18.9	3.0	8.4	8.0	High	11.7
NS045	Barronsfield	NS045_01	21.2	-1.2	-14.0	6.8	8.5	8.3	High	3.5
NS046	River Hebert	NS046_00	22.5	-1.1	-1.4	-0.9	8.6	8.3	High	69.2
NS046	River Hebert	NS046_03	26.4	-0.3	-0.5	-0.2	8.7	8.5	High	31.6
NS046	River Hebert	NS046_06	18.1	0.1	-0.6	0.6	8.2	8.0	High	92.9
NS046	River Hebert	NS046_07	18.4	0.1	-0.7	1.0	8.3	8.0	High	28.2
NS046	River Hebert	NS046_08	20.3	0.1	-0.4	0.9	8.3	8.0	High	12.5
NS046	River Hebert	NS046_09	19.9	0.0	-0.6	1.2	8.3	8.1	High	100.0
NS046	River Hebert	NS046_10	17.5	0.1	-0.9	1.5	8.5	8.4	High	100.0
NS046	River Hebert	NS046_11	35.2	0.1	-1.6	3.1	9.0	8.2	High	14.7
NS046	River Hebert	NS046_12	19.1	-0.2	-1.1	0.7	8.3	7.6	High	24.5
NS046	River Hebert	NS046_13	51.2	-0.5	-2.6	1.5	8.3	7.9	High	12.0

NS053	John Lusby	NS053_01	394.2	-0.4	-19.9	6.2	8.4	8.0	High	10.8
NS055	Seaman	NS055_01	51.2	-0.4	-1.4	1.0	8.5	8.1	High	7.5
NS063	Maccan	NS063_01	26.9	0.0	-1.9	2.1	8.3	8.0	High	12.0
NS063	Maccan	NS063_03	34.6	0.0	-1.8	2.3	8.4	8.1	High	100.0
NS115	Nappan-Maccan	NS115_01	38.4	-0.2	-7.2	14.4	8.6	8.0	High	0.7
NS119	Upper Maccan	NS119_02	21.6	-0.1	-2.3	0.7	8.6	8.2	High	100.0
NS127	Maccan Village	NS127_01	27.5	-0.6	-1.5	-0.1	8.8	8.5	High	29.0
NS042	Amherst Point	NS042_01	101.5	4.0	-1.0	18.5	8.5	8.2	Very Low	11.2
NS042	Amherst Point	NS042_03	99.4	0.8	-7.5	2.8	8.8	8.5	Very Low	100.0
NS044	Converse	NS044_02	28.4	0.5	-1.4	3.8	8.3	8.0	Very Low	83.3
NS044	Converse	NS044_03	34.2	1.8	-0.7	4.2	8.2	8.0	Very Low	15.4
NS046	River Hebert	NS046_01	42.8	0.4	-2.0	4.4	8.9	8.4	Very Low	13.9
NS046	River Hebert	NS046_02	19.2	0.8	-0.5	2.1	8.2	7.9	Very Low	87.2
NS054	Minudie	NS054_01	247.1	1.5	-10.4	18.9	8.4	7.9	Very Low	17.5
NS055	Seaman	NS055_02	135.8	0.9	0.1	2.6	8.2	7.9	Very Low	20.0
NS063	Maccan	NS063_02	41.6	0.6	-0.5	2.0	8.3	8.1	Very Low	100.0
NS078	Athol	NS078_01	17.7	0.8	0.0	1.8	8.5	8.3	Very Low	100.0
NS078	Athol	NS078_03	19.2	0.6	-0.2	1.3	8.2	8.0	Very Low	100.0
NS087	Chignecto	NS087_01	34.6	0.7	-19.7	7.0	8.6	8.3	Very Low	17.6
NS119	Upper Maccan	NS119_01	25.2	0.3	-0.6	2.1	8.6	8.3	Very Low	100.0

Hants and Kings			Foreshore width (m)	End Point Rate (m/yr)			Dyke crest elevation (m CGVD28)			
NSDA No.	Marsh Name	Tract ID	mean	mean	min	max	mean	min	vulnerability Class	Max Exposure (%)
NS092	Avonport	NS092_02	145.3	-3.3	-13.7	1.8	8.5	8.0	Very High	30.2
NS101	Pereau	NS101_01	243.8	-0.8	-1.0	-0.5	8.3	8.0	Very High	21.1
NS008	Grand Pré	NS008_02	174.5	-0.6	-6.2	2.8	8.8	8.4	High	39.7
NS027	Newport Town	NS027_02	45.5	-0.4	-4.8	0.9	8.9	8.6	High	4.2
NS038	St. Croix	NS038_01	34.0	0.0	-1.5	1.5	8.8	8.6	High	36.8
NS038	St. Croix	NS038_02	43.6	-4.3	-13.1	4.7	8.8	8.7	High	100.0
NS038	St. Croix	NS038_04	39.2	-0.4	-1.9	1.9	8.8	8.4	High	5.3
NS038	St. Croix	NS038_05	20.1	-0.7	-3.4	1.4	8.8	8.5	High	8.1
NS038	St. Croix	NS038_06	18.9	-0.1	-2.6	1.2	8.7	8.6	High	8.5
NS038	St. Croix	NS038_07	18.3	-0.9	-1.6	0.0	8.9	8.7	High	70.0
NS038	St. Croix	NS038_08	24.8	-0.4	-2.3	0.8	8.9	8.8	High	100.0
NS038	St. Croix	NS038_09	16.8	-0.6	-1.1	0.0	8.8	8.6	High	69.2
NS038	St. Croix	NS038_11	21.2	-0.6	-1.7	1.3	8.8	8.7	High	100.0
NS038	St. Croix	NS038_15	41.1	-0.4	-1.4	0.8	8.8	8.4	High	18.2
NS041	Habitant	NS041_01	69.8	0.2	-1.0	1.0	8.8	8.3	High	22.7
NS048	Centre Burlington	NS048_01	197.0	3.3	1.2	6.9	8.4	8.0	High	38.5
NS050	Herbert River	NS050_01	15.9	-0.1	-0.5	0.4	8.6	8.6	High	20.0
NS050	Herbert River	NS050_02	35.0	-0.2	-0.5	0.2	8.7	8.6	High	100.0
NS050	Herbert River	NS050_03	32.3	-0.4	-3.3	1.9	8.9	8.7	High	59.2
NS057	New Minas	NS057_01	43.4	-2.0	-4.5	0.7	8.5	8.2	High	8.3

NS057	New Minas	NS057_02	71.5	-0.5	-3.5	1.3	8.3	8.1	High	31.9
NS057	New Minas	NS057_03	33.1	0.2	-0.6	1.0	8.3	8.0	High	10.0
NS057	New Minas	NS057_04	37.9	0.2	-0.9	1.3	8.5	8.2	High	5.8
NS057	New Minas	NS057_05	31.3	0.2	-3.1	2.8	8.4	8.1	High	100.0
NS065	Bishop Beckwith	NS065_01	100.7	-1.4	-15.2	1.0	8.6	8.1	High	9.4
NS065	Bishop Beckwith	NS065_02	19.0	-0.9	-2.1	0.0	8.8	8.4	High	60.9
NS065	Bishop Beckwith	NS065_99	15.6	-2.8	-2.8	-2.8	8.8	8.7	High	25.0
NS068	Tregothic	NS068_02	9.7	-0.3	-1.4	0.6	9.5	8.6	High	71.4
NS072	Horton	NS072_01	43.2	0.0	-1.3	1.6	8.4	8.0	High	96.3
NS072	Horton	NS072_02	47.6	-0.4	-4.8	0.6	8.4	8.2	High	4.3
NS072	Horton	NS072_03	46.7	0.0	-1.8	0.7	8.7	8.2	High	11.0
NS072	Horton	NS072_04	18.8	0.1	-0.4	1.7	8.5	8.2	High	4.6
NS076	Farnham	NS076_01	45.9	-1.0	-2.8	0.2	8.5	8.2	High	4.4
NS079	Chambers	NS079_01	21.3	0.0	-1.3	2.0	8.7	8.5	High	65.9
NS082	Kentville	NS082_02	40.8	0.2	-0.4	0.8	8.6	8.3	High	37.0
NS085	Mantua Poplar Grove	NS085_03	37.2	-0.2	-2.0	2.2	9.0	8.8	High	47.4
NS085	Mantua Poplar Grove	NS085_04	49.2	-0.1	-2.2	2.1	8.9	8.8	High	100.0
NS085	Mantua Poplar Grove	NS085_06	32.2	-0.2	-0.7	0.5	8.9	8.7	High	100.0
NS091	Belcher Street	NS091_01	34.7	0.1	-7.7	2.6	8.5	8.0	High	1.0
NS091	Belcher Street	NS091_02	34.7	0.1	-1.6	1.8	8.5	8.2	High	89.0
NS091	Belcher Street	NS091_03	28.0	-0.1	-1.3	0.9	8.6	8.4	High	2.6
NS091	Belcher Street	NS091_04	20.8	-0.4	-2.4	0.2	8.5	8.4	High	100.0
NS091	Belcher Street	NS091_05	31.6	0.0	-1.6	2.3	8.8	8.4	High	77.8
NS092	Avonport	NS092_01	80.4	-1.9	-5.1	-0.4	8.3	8.1	High	100.0
NS105	Belmont	NS105_02	52.8	-0.4	-1.1	0.6	8.7	8.6	High	40.9
NS105	Belmont	NS105_03	38.5	-0.1	-2.0	1.8	8.5	8.3	High	12.0
NS008	Grand Pré	NS008_01	129.7	1.6	-4.9	10.1	8.9	8.2	Very Low	8.4
NS014	Elderkin	NS014_01	88.9	3.4	-0.9	18.6	8.6	8.4	Very Low	19.0
NS014	Elderkin	NS014_02	155.8	2.3	-2.9	13.0	9.5	9.4	Very Low	23.6
NS027	Newport Town	NS027_01	116.9	2.1	-0.6	12.3	8.7	8.5	Very Low	1.4
NS038	St. Croix	NS038_03	25.8	0.4	-0.5	1.8	8.8	8.7	Very Low	100.0
NS049	Scotch Village	NS049_01	44.2	0.9	-0.3	2.1	8.8	8.5	Very Low	23.1
NS056	Wellington	NS056_01	143.8	0.5	-0.5	1.7	8.8	8.3	Very Low	6.9
NS056	Wellington	NS056_02	296.2	2.9	-0.8	9.8	9.2	8.1	Very Low	38.1
NS061	Kennetcook	NS061_01	49.1	0.4	-4.4	3.7	8.8	8.3	Very Low	16.5
NS068	Tregothic	NS068_01	312.4	1.5	0.3	4.3	9.1	8.8	Very Low	81.3
NS068	Tregothic	NS068_03	191.2	0.6	0.0	1.2	9.3	9.2	Very Low	100.0
NS068	Tregothic	NS068_04	110.9	0.5	-0.5	1.3	9.2	8.8	Very Low	100.0
NS072	Horton	NS072_07	44.4	0.4	0.1	0.8	8.8	8.6	Very Low	70.8
NS080	Starr's Point	NS080_01	436.1	9.5	-5.4	19.4	8.7	8.5	Very Low	5.1
NS082	Kentville	NS082_01	43.3	0.3	-1.2	2.0	8.4	8.1	Very Low	24.6
NS085	Mantua Poplar Grove	NS085_01	87.8	1.3	0.3	2.6	8.7	8.5	Very Low	100.0
NS085	Mantua Poplar Grove	NS085_02	52.0	0.5	-6.9	11.7	8.9	8.5	Very Low	100.0
NS085	Mantua Poplar Grove	NS085_05	75.0	1.1	-0.4	3.0	8.9	8.7	Very Low	100.0
NS088	Burlington	NS088_01	73.3	1.5	0.5	2.1	8.8	8.5	Very Low	100.0
NS088	Burlington	NS088_02	39.8	1.4	-0.3	2.4	8.7	8.5	Very Low	28.6
NS088	Burlington	NS088_03	69.7	1.1	-0.2	1.7	8.8	8.4	Very Low	100.0
NS093	Greenhill	NS093_01	153.0	3.5	1.6	7.7	8.8	8.6	Very Low	100.0

NS093	Greenhill	NS093_02	69.7	0.7	-0.5	4.2	8.9	8.7	Very Low	100.0
NS100	Wentworth	NS100_01	50.3	0.4	-7.5	3.7	9.0	8.7	Very Low	84.6
NS105	Belmont	NS105_01	42.8	1.0	-0.2	3.8	8.6	8.4	Very Low	17.2

Appendix D: Dyke Overtopping Scenario Results

The results below represent the percentage of dykes in each region overtopped and not overtopped, based on each given scenario. This differs from the probability of overtopping as it only directly compares the difference of the scenario height versus the dyke height. The Bayesian model considers all tidal elevations (low to high) and develops a probability of overtopping.

ADVOCATE		
Scenario	**Percent Overtopped (%)**	**Percent Not Overtopped (%)**
Contemporary (2010) HHWL	25.00	75.00
HHWLT + SLR (2050/2055)	91.67	8.33
HHWLT + SLR (2100)	100.00	0.00
HHWLT + SLR (2050/2055) + Storm Surge (50-Year)	100.00	0.00
HHWLT + SLR (2050/2055) + Storm Surge (100-Year)	100.00	0.00
HHWLT + SLR (2100) + Storm Surge (50-Year)	100.00	0.00
HHWLT + SLR (2100) + Storm Surge (100-Year)	100.00	0.00
ANNAPOLIS and DIGBY		
Scenario	**Percent Overtopped (%)**	**Percent Not Overtopped (%)**
Contemporary (2010) HHWL	0.24	99.76
HHWLT + SLR (2050/2055)	15.05	84.95
HHWLT + SLR (2100)	90.32	9.68
HHWLT + SLR (2050/2055) + Storm Surge (50-Year)	97.85	2.15
HHWLT + SLR (2050/2055) + Storm Surge (100-Year)	99.04	0.96
HHWLT + SLR (2100) + Storm Surge (50-Year)	100.00	0.00
HHWLT + SLR (2100) + Storm Surge (100-Year)	100.00	0.00
COLCHESTER		
Scenario	**Percent Overtopped (%)**	**Percent Not Overtopped (%)**
Contemporary (2010) HHWL	22.05	77.95
HHWLT + SLR (2050/2055)	46.04	53.96
HHWLT + SLR (2100)	91.07	8.93
HHWLT + SLR (2050/2055) + Storm Surge (50-Year)	97.62	2.38
HHWLT + SLR (2050/2055) + Storm Surge (100-Year)	97.77	2.23
HHWLT + SLR (2100) + Storm Surge (50-Year)	98.51	1.49
HHWLT + SLR (2100) + Storm Surge (100-Year)	98.75	1.25
CUMBERLAND		
Scenario	**Percent Overtopped (%)**	**Percent Not Overtopped (%)**
Contemporary (2010) HHWL	0.00	100.00
HHWLT + SLR (2050/2055)	0.30	99.70
HHWLT + SLR (2100)	44.87	55.13
HHWLT + SLR (2050/2055) + Storm Surge (50-Year)	94.33	5.67
HHWLT + SLR (2050/2055) + Storm Surge (100-Year)	96.76	3.24
HHWLT + SLR (2100) + Storm Surge (50-Year)	99.17	0.83
HHWLT + SLR (2100) + Storm Surge (100-Year)	98.23	0.77
HANTS and KINGS		
Scenario	**Percent Overtopped (%)**	**Percent Not Overtopped (%)**
Contemporary (2010) HHWL	0.61	99.39
HHWLT + SLR (2050/2055)	15.56	84.44
HHWLT + SLR (2100)	87.51	12.49
HHWLT + SLR (2050/2055) + Storm Surge (50-Year)	97.89	2.11
HHWLT + SLR (2050/2055) + Storm Surge (100-Year)	98.73	1.27
HHWLT + SLR (2100) + Storm Surge (50-Year)	99.86	0.14
HHWLT + SLR (2100) + Storm Surge (100-Year)	99.92	0.08

Appendix E: Overtopping Based on GIS Analysis per Tract

Annapolis and Digby			Percent dykes overtopped (%)							total length of dyke (km)
NSDA No.	Marsh Name	Tract ID	Current HHWLT	2050 SLR	SLR 2100	2050 1:50 yr storm	2050 1:100 yr storm	2100 1:50 yr storm	2100 1:100 yr storm	
NS052	St. Marys Bay	NS052_01	0.9	52.3	100.0	100.0	100.0	100.0	100.0	2.9
NS004	Queen Anne	NS004_01	0.0	0.0	87.0	98.3	99.1	100.0	100.0	1.7
NS005	Dugau-Ryerson	NS005_01	0.0	0.0	76.5	100.0	100.0	100.0	100.0	1.1
NS005	Dugau-Ryerson	NS005_02	0.0	2.2	73.3	77.8	84.4	100.0	100.0	3.1
NS013	Dentiballis	NS013_01	0.0	1.6	90.2	97.6	99.2	100.0	100.0	0.6
NS030	Allain River	NS030_01	0.0	0.0	100.0	100.0	100.0	100.0	100.0	1.4
NS030	Allain River	NS030_02	0.0	0.0	58.6	84.5	96.6	100.0	100.0	2.8

Colchester			Percent dykes overtopped (%)							total length of dyke (km)
NSDA No.	Marsh Name	Tract ID	Current HHWLT	2050 SLR	SLR 2100	2050 1:50 yr storm	2050 1:100 yr storm	2100 1:50 yr storm	2100 1:100 yr storm	
NS097	Highland Village	NS097_01	30.3	76.5	100.0	100.0	100.0	100.0	100.0	3.0
NS112	Rines Creek	NS112_01	88.9	100.0	100.0	100.0	100.0	100.0	100.0	0.4
NS112	Rines Creek	NS112_02	21.5	100.0	100.0	100.0	100.0	100.0	100.0	1.6
NS112	Rines Creek	NS112_03	89.2	94.6	100.0	100.0	100.0	100.0	100.0	0.9
NS113	Southside	NS113_04	100.0	100.0	100.0	100.0	100.0	100.0	100.0	1.8
NS113	Southside	NS113_05	95.7	100.0	100.0	100.0	100.0	100.0	100.0	0.6
NS011	Truro Dykeland Park	NS011_01	0.0	0.0	6.3	68.8	81.3	100.0	100.0	0.4
NS023	Masstown	NS023_01	0.0	24.6	100.0	100.0	100.0	100.0	100.0	7.5
NS024	Noel Shore	NS024_01	0.0	78.0	100.0	100.0	100.0	100.0	100.0	1.5
NS024	Noel Shore	NS024_03	0.0	50.0	100.0	100.0	100.0	100.0	100.0	0.6
NS039	Round	NS039_01	0.0	62.3	100.0	100.0	100.0	100.0	100.0	1.9
NS040	Fort Belcher	NS040_05	0.0	0.0	96.0	100.0	100.0	100.0	100.0	1.9
NS064	Glenhome	NS064_01	0.0	100.0	100.0	100.0	100.0	100.0	100.0	0.1
NS064	Glenhome	NS064_02	0.0	42.1	100.0	100.0	100.0	100.0	100.0	1.9
NS064	Glenhome	NS064_03	0.0	0.0	100.0	100.0	100.0	100.0	100.0	0.3
NS064	Glenhome	NS064_04	0.0	0.0	100.0	100.0	100.0	100.0	100.0	0.1
NS066	Flemming	NS066_01	0.0	2.9	100.0	100.0	100.0	100.0	100.0	2.5
NS067	Onslow North River	NS067_01	0.0	0.0	80.0	97.2	97.2	97.2	97.9	3.6
NS067	Onslow North River	NS067_02	0.0	32.5	96.1	100.0	100.0	100.0	100.0	1.9
NS077	Princeport	NS077_01	7.1	100.0	100.0	100.0	100.0	100.0	100.0	1.4
NS081	Lower Truro	NS081_01	0.0	10.0	100.0	100.0	100.0	100.0	100.0	0.2
NS086	Central Onslow	NS086_02	0.0	0.0	81.8	100.0	100.0	100.0	100.0	0.3
NS090	Old Barns	NS090_01	0.0	0.0	75.0	100.0	100.0	100.0	100.0	0.4
NS090	Old Barns	NS090_02	0.0	0.0	100.0	100.0	100.0	100.0	100.0	0.1
NS090	Old Barns	NS090_03	0.0	0.0	100.0	100.0	100.0	100.0	100.0	0.4
NS090	Old Barns	NS090_04	0.0	2.9	91.2	100.0	100.0	100.0	100.0	0.8
NS098	Stewiacke	NS098_02	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.5
NS098	Stewiacke	NS098_03	80.3	100.0	100.0	100.0	100.0	100.0	100.0	1.8

NSDA No.	Marsh Name	Tract ID	Current HHWLT	2050 SLR	SLR 2100	2050 1:50 yr storm	2050 1:100 yr storm	2100 1:50 yr storm	2100 1:100 yr storm	total length of dyke (km)
NS098	Stewiacke	NS098_04	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.7
NS106	Fort Ellis	NS106_01	0.0	30.8	100.0	100.0	100.0	100.0	100.0	0.6
NS106	Fort Ellis	NS106_02	67.2	100.0	100.0	100.0	100.0	100.0	100.0	3.4
NS106	Fort Ellis	NS106_03	2.7	100.0	100.0	100.0	100.0	100.0	100.0	0.9
NS106	Fort Ellis	NS106_04	2.7	75.7	100.0	100.0	100.0	100.0	100.0	0.9
NS106	Fort Ellis	NS106_05	0.0	15.4	46.2	53.8	53.8	61.5	76.9	0.3
NS111	Burntcoat	NS111_01	0.0	0.0	75.0	100.0	100.0	100.0	100.0	0.1
NS113	Southside	NS113_01	96.4	100.0	100.0	100.0	100.0	100.0	100.0	0.7
NS113	Southside	NS113_02	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.6
NS113	Southside	NS113_03	94.4	100.0	100.0	100.0	100.0	100.0	100.0	0.4
NS114	Great Village	NS114_01	0.0	7.4	72.6	100.0	100.0	100.0	100.0	2.4
NS116	Shubenacadie	NS116_01	28.8	100.0	100.0	100.0	100.0	100.0	100.0	1.3
NS117	Tufts	NS117_01	77.8	100.0	100.0	100.0	100.0	100.0	100.0	1.3
NS128	Cobequid	NS128_01	0.0	0.9	66.7	81.6	82.1	87.2	88.0	5.8
NS012	Victoria Diamond Jubilee	NS012_01	0.0	0.0	66.3	100.0	100.0	100.0	100.0	4.3
NS015	Isgonish	NS015_01	0.0	4.3	21.7	100.0	100.0	100.0	100.0	0.6
NS015	Isgonish	NS015_02	0.0	0.0	62.5	93.8	100.0	100.0	100.0	0.4
NS025	Maitland	NS025_01	0.0	0.0	100.0	100.0	100.0	100.0	100.0	0.1
NS025	Maitland	NS025_03	0.0	33.3	88.9	100.0	100.0	100.0	100.0	0.4
NS040	Fort Belcher	NS040_01	0.0	0.0	60.0	100.0	100.0	100.0	100.0	0.4
NS040	Fort Belcher	NS040_03	0.0	0.0	96.9	100.0	100.0	100.0	100.0	0.8
NS047	Selma	NS047_01	0.0	68.2	100.0	100.0	100.0	100.0	100.0	0.5
NS081	Lower Truro	NS081_02	0.0	5.8	63.0	99.3	100.0	100.0	100.0	3.4
NS086	Central Onslow	NS086_01	0.0	0.0	100.0	100.0	100.0	100.0	100.0	0.1
NS086	Central Onslow	NS086_03	0.0	56.4	98.7	98.7	98.7	100.0	100.0	1.9
NS086	Central Onslow	NS086_04	0.0	0.0	78.1	93.8	96.9	100.0	100.0	0.8

Cumberland

NSDA No.	Marsh Name	Tract ID	Percent dykes overtopped (%) Current HHWLT	2050 SLR	SLR 2100	2050 1:50 yr storm	2050 1:100 yr storm	2100 1:50 yr storm	2100 1:100 yr storm	total length of dyke (km)
NS042	Amherst Point	NS042_02	0.0	0.0	0.7	98.7	98.7	99.3	100.0	3.7
NS044	Converse	NS044_01	0.0	0.0	46.1	99.6	100.0	100.0	100.0	5.7
NS045	Barronsfield	NS045_01	0.0	0.0	11.4	100.0	100.0	100.0	100.0	2.8
NS046	River Hebert	NS046_00	0.0	0.0	23.1	84.6	100.0	100.0	100.0	0.3
NS046	River Hebert	NS046_03	0.0	0.0	0.0	89.5	100.0	100.0	100.0	0.5
NS046	River Hebert	NS046_06	0.0	0.0	78.6	100.0	100.0	100.0	100.0	1.0
NS046	River Hebert	NS046_07	0.0	0.0	87.2	100.0	100.0	100.0	100.0	1.0
NS046	River Hebert	NS046_08	0.0	0.0	57.3	100.0	100.0	100.0	100.0	2.4
NS046	River Hebert	NS046_09	0.0	0.0	76.0	100.0	100.0	100.0	100.0	0.6
NS046	River Hebert	NS046_10	0.0	0.0	0.0	100.0	100.0	100.0	100.0	0.5
NS046	River Hebert	NS046_11	0.0	0.0	14.1	78.8	80.1	85.9	86.5	3.9
NS046	River Hebert	NS046_12	0.0	4.1	65.3	100.0	100.0	100.0	100.0	1.2
NS046	River Hebert	NS046_13	0.0	0.0	66.7	100.0	100.0	100.0	100.0	1.9
NS053	John Lusby	NS053_01	0.0	0.0	48.8	92.8	92.8	100.0	100.0	4.1
NS055	Seaman	NS055_01	0.0	0.0	52.5	90.0	90.0	92.5	92.5	1.0
NS063	Maccan	NS063_01	0.0	0.0	66.0	100.0	100.0	100.0	100.0	1.2

NS063	Maccan	NS063_03	0.0	0.0	37.9	100.0	100.0	100.0	100.0	1.4
NS115	Nappan-Maccan	NS115_01	0.0	0.0	25.7	86.4	92.9	100.0	100.0	3.5
NS119	Upper Maccan	NS119_02	0.0	0.0	8.6	96.6	100.0	100.0	100.0	1.4
NS127	Maccan Village	NS127_01	0.0	0.0	0.0	90.3	100.0	100.0	100.0	0.8
NS042	Amherst Point	NS042_01	0.0	0.0	14.5	98.7	100.0	100.0	100.0	3.8
NS042	Amherst Point	NS042_03	0.0	0.0	0.0	77.3	77.3	95.5	100.0	0.5
NS044	Converse	NS044_02	0.0	0.0	70.5	100.0	100.0	100.0	100.0	1.9
NS044	Converse	NS044_03	0.0	0.0	97.4	100.0	100.0	100.0	100.0	1.0
NS046	River Hebert	NS046_01	0.0	0.0	0.0	46.7	76.7	100.0	100.0	4.5
NS046	River Hebert	NS046_02	0.0	0.0	84.6	100.0	100.0	100.0	100.0	1.0
NS054	Minudie	NS054_01	0.0	0.0	54.3	99.5	100.0	100.0	100.0	10.4
NS055	Seaman	NS055_02	0.0	0.0	70.0	100.0	100.0	100.0	100.0	0.2
NS063	Maccan	NS063_02	0.0	0.0	74.6	100.0	100.0	100.0	100.0	1.6
NS078	Athol	NS078_01	0.0	0.0	4.1	100.0	100.0	100.0	100.0	1.2
NS078	Athol	NS078_03	0.0	0.0	89.3	100.0	100.0	100.0	100.0	0.7
NS087	Chignecto	NS087_01	0.0	0.0	3.9	88.2	96.1	100.0	100.0	1.3
NS119	Upper Maccan	NS119_01	0.0	0.0	17.6	100.0	100.0	100.0	100.0	0.8

Hants and Kings

NSDA No.	Marsh Name	Tract ID	Percent dykes overtopped (%) Current HHWLT	2050 SLR	SLR 2100	2050 1:50 yr storm	2050 1:100 yr storm	2100 1:50 yr storm	2100 1:100 yr storm	total length of dyke (km)
NS092	Avonport	NS092_02	0.9	21.6	98.3	100.0	100.0	100.0	100.0	2.9
NS101	Pereau	NS101_01	5.3	42.1	100.0	100.0	100.0	100.0	100.0	0.5
NS008	Grand Pré	NS008_02	0.0	0.0	79.9	97.3	97.8	100.0	100.0	4.6
NS027	Newport Town	NS027_02	0.0	0.0	66.7	100.0	100.0	100.0	100.0	0.6
NS038	St. Croix	NS038_01	0.0	0.0	78.9	100.0	100.0	100.0	100.0	0.5
NS038	St. Croix	NS038_02	0.0	0.0	93.3	100.0	100.0	100.0	100.0	0.4
NS038	St. Croix	NS038_04	0.0	0.0	100.0	100.0	100.0	100.0	100.0	0.9
NS038	St. Croix	NS038_05	0.0	0.0	94.6	100.0	100.0	100.0	100.0	0.9
NS038	St. Croix	NS038_06	0.0	0.0	100.0	100.0	100.0	100.0	100.0	1.2
NS038	St. Croix	NS038_07	0.0	0.0	83.3	100.0	100.0	100.0	100.0	0.7
NS038	St. Croix	NS038_08	0.0	0.0	72.0	100.0	100.0	100.0	100.0	0.6
NS038	St. Croix	NS038_09	0.0	0.0	96.2	100.0	100.0	100.0	100.0	0.6
NS038	St. Croix	NS038_11	0.0	0.0	96.0	100.0	100.0	100.0	100.0	0.6
NS038	St. Croix	NS038_15	0.0	0.0	81.8	100.0	100.0	100.0	100.0	0.3
NS041	Habitant	NS041_01	0.0	4.5	90.9	95.5	95.5	100.0	100.0	0.5
NS048	Centre Burlington	NS048_01	7.7	61.5	100.0	100.0	100.0	100.0	100.0	0.6
NS050	Herbert River	NS050_01	0.0	0.0	100.0	100.0	100.0	100.0	100.0	0.1
NS050	Herbert River	NS050_02	0.0	0.0	100.0	100.0	100.0	100.0	100.0	0.1
NS050	Herbert River	NS050_03	0.0	0.0	74.6	100.0	100.0	100.0	100.0	1.8
NS057	New Minas	NS057_01	0.0	16.7	97.2	100.0	100.0	100.0	100.0	0.9
NS057	New Minas	NS057_02	0.0	75.4	100.0	100.0	100.0	100.0	100.0	1.7
NS057	New Minas	NS057_03	2.0	60.0	100.0	100.0	100.0	100.0	100.0	1.2
NS057	New Minas	NS057_04	0.0	28.2	100.0	100.0	100.0	100.0	100.0	2.6
NS057	New Minas	NS057_05	0.0	61.9	100.0	100.0	100.0	100.0	100.0	0.5
NS065	Bishop Beckwith	NS065_01	0.0	15.7	84.3	100.0	100.0	100.0	100.0	4.8
NS065	Bishop Beckwith	NS065_02	0.0	0.0	89.1	100.0	100.0	100.0	100.0	1.1

NS065	Bishop Beckwith	NS065_99	0.0	0.0	100.0	100.0	100.0	100.0	100.0	0.1
NS068	Tregothic	NS068_02	0.0	0.0	9.5	33.3	52.4	95.2	100.0	0.5
NS072	Horton	NS072_01	0.0	48.8	100.0	100.0	100.0	100.0	100.0	2.0
NS072	Horton	NS072_02	0.0	47.8	95.7	95.7	100.0	100.0	100.0	0.6
NS072	Horton	NS072_03	0.0	11.0	89.0	98.6	98.6	100.0	100.0	1.8
NS072	Horton	NS072_04	0.0	20.0	98.5	100.0	100.0	100.0	100.0	1.6
NS076	Farnham	NS076_01	0.0	20.6	100.0	100.0	100.0	100.0	100.0	1.7
NS079	Chambers	NS079_01	0.0	0.0	97.7	100.0	100.0	100.0	100.0	1.1
NS082	Kentville	NS082_02	0.0	11.1	100.0	100.0	100.0	100.0	100.0	0.7
NS085	Mantua Poplar Grove	NS085_03	0.0	0.0	36.8	100.0	100.0	100.0	100.0	0.9
NS085	Mantua Poplar Grove	NS085_04	0.0	0.0	79.2	100.0	100.0	100.0	100.0	1.3
NS085	Mantua Poplar Grove	NS085_06	0.0	0.0	61.9	100.0	100.0	100.0	100.0	0.5
NS091	Belcher Street	NS091_01	4.0	24.8	100.0	100.0	100.0	100.0	100.0	2.5
NS091	Belcher Street	NS091_02	0.0	8.8	100.0	100.0	100.0	100.0	100.0	2.3
NS091	Belcher Street	NS091_03	0.0	0.0	84.2	100.0	100.0	100.0	100.0	0.9
NS091	Belcher Street	NS091_04	0.0	0.0	100.0	100.0	100.0	100.0	100.0	0.5
NS091	Belcher Street	NS091_05	0.0	0.0	87.0	100.0	100.0	100.0	100.0	1.3
NS092	Avonport	NS092_01	0.0	70.0	100.0	100.0	100.0	100.0	100.0	0.2
NS105	Belmont	NS105_02	0.0	0.0	100.0	100.0	100.0	100.0	100.0	0.5
NS105	Belmont	NS105_03	0.0	10.0	100.0	100.0	100.0	100.0	100.0	1.2
NS008	Grand Pré	NS008_01	0.0	5.4	57.5	71.9	81.4	100.0	100.0	4.2
NS014	Elderkin	NS014_01	0.0	0.0	100.0	100.0	100.0	100.0	100.0	0.5
NS014	Elderkin	NS014_02	0.0	0.0	0.0	29.1	63.6	100.0	100.0	1.4
NS027	Newport Town	NS027_01	0.0	0.0	100.0	100.0	100.0	100.0	100.0	1.8
NS038	St. Croix	NS038_03	0.0	0.0	87.5	100.0	100.0	100.0	100.0	0.2
NS049	Scotch Village	NS049_01	0.0	0.0	80.8	92.3	92.3	100.0	100.0	0.6
NS056	Wellington	NS056_01	0.0	1.7	53.4	100.0	100.0	100.0	100.0	1.4
NS056	Wellington	NS056_02	0.0	4.8	9.5	85.7	85.7	95.2	95.2	0.5
NS061	Kennetcook	NS061_01	0.0	2.8	70.6	97.2	97.2	99.1	99.1	2.7
NS068	Tregothic	NS068_01	0.0	0.0	56.3	68.8	75.0	100.0	100.0	0.4
NS068	Tregothic	NS068_03	0.0	0.0	0.0	87.5	87.5	100.0	100.0	0.2
NS068	Tregothic	NS068_04	0.0	0.0	4.8	95.2	97.6	100.0	100.0	1.0
NS072	Horton	NS072_07	0.0	0.0	83.3	100.0	100.0	100.0	100.0	0.6
NS080	Starr's Point	NS080_01	0.0	0.0	93.9	100.0	100.0	100.0	100.0	2.5
NS082	Kentville	NS082_01	0.0	31.6	100.0	100.0	100.0	100.0	100.0	1.4
NS085	Mantua Poplar Grove	NS085_01	0.0	0.0	100.0	100.0	100.0	100.0	100.0	0.2
NS085	Mantua Poplar Grove	NS085_02	0.0	0.0	77.2	100.0	100.0	100.0	100.0	2.5
NS085	Mantua Poplar Grove	NS085_05	0.0	0.0	83.3	100.0	100.0	100.0	100.0	0.6
NS088	Burlington	NS088_01	0.0	0.0	84.2	100.0	100.0	100.0	100.0	0.5
NS088	Burlington	NS088_02	0.0	0.0	100.0	100.0	100.0	100.0	100.0	0.3
NS088	Burlington	NS088_03	0.0	0.0	81.8	100.0	100.0	100.0	100.0	0.3
NS093	Greenhill	NS093_01	0.0	0.0	73.5	100.0	100.0	100.0	100.0	0.8
NS093	Greenhill	NS093_02	0.0	0.0	68.4	100.0	100.0	100.0	100.0	0.5
NS100	Wentworth	NS100_01	0.0	0.0	48.7	100.0	100.0	100.0	100.0	1.9
NS105	Belmont	NS105_01	0.0	0.0	100.0	100.0	100.0	100.0	100.0	0.7

Appendix F: Data Layers Created for Web Viewer

The following is the list of the provided datasets and number of feature classes for the AgriRisk Web Viewer:

- ***Dyke Centerlines*** - 1
- ***Nova Scotia Marshland Flood Vulnerability*** – 7 (extents only)
- ***Foreshore Change Rates*** – 1
- ***Foreshore Marsh*** - 1
- ***Legislated Marsh Boundaries*** - 1
- ***Dyke Overtopping*** - 7

The following tables provide a brief data dictionary for each feature class.

Dyke Centerline Feature Class

Feature Class Details							
Feature Class Name:	Dyke Centrelines		Suggest a Filename:		Water_NS_DykeCentrelines		
Data Structure at Authoritative Source (for maintenance purposes)			Data Structure for Publication				Field Description
Column Name	Data Type	Length	Column Name	Data Type	Length	Requires Index? [Yes/No]	Description of field
marshNumber	Text	5					The Marsh number used by NSDA to identify marshes/dykes.
tractID	Text	10					Dyke tract identification number.
tractNum	Short Integer	N/A					Dyke tract number.

Foreshore Change Rate Feature Class

Feature Class Details							
Feature Class Name:	Foreshore Change Rates		Suggest a Filename:		Water_NS_Foreshore_ChangeRates		
Data Structure at Authoritative Source (for maintenance purposes)			Data Structure for Publication				Field Description
Column Name	Data Type	Length	Column Name	Data Type	Length	Requires Index? [Yes/No]	Description of field
ChangeRateClassification	Text	25					Foreshore rate classification type.

Foreshore Marsh Feature Class

Feature Class Details			
Feature Class Name:	Foreshore Marsh	Suggest a Filename:	Water_NS_Foreshore_Marsh

Data Structure at Authoritative Source (for maintenance purposes)			Data Structure for Publication				Field Description
Column Name	Data Type	Length	Column Name	Data Type	Length	Requires Index? [Yes/No]	Description of field
marshNumber	Text	5					The Marsh number used by NSDA to identify marshes/dykes.
imagery_year_dig	Text	4					Year of imagery which foreshore was digitized from.
marshCode	Text	25					Identification code describing the marsh feature type.
source	Text	2					The source type used to digitize foreshore marsh features.
Area_Hectares	Double	N/A					Area of foreshore marsh, in hectares.

Legislated Marsh Boundaries Feature Class

Feature Class Details							
Feature Class Name:	Legislated Marsh Boundaries		Suggest a Filename:		Water_NS_Legislated_Marsh_Boundaries		
Data Structure at Authoritative Source (for maintenance purposes)			Data Structure for Publication				Field Description
Column Name	Data Type	Length	Column Name	Data Type	Length	Requires Index? [Yes/No]	Description of field
marshCode	Text	25					Identification code describing the marsh feature type.
Hectares	Double	N/A					Area of feature, in hectares.
marshNumber	Text	6					The Marsh number used by NSDA to identify marshes/dykes.
Name	Text	50					The name of the Marshbody.

Dyke Overtopping Feature Classes

Feature Class Details			
Feature Class Name:	Overtopping Higher High Water Large Tide Contemporary	Suggest a Filename:	Water_Dyke_Overtopping_HHWLT_Contemporary
Data Structure at Authoritative Source (for maintenance purposes)	Data Structure for Publication	Field Description	

Column Name	Data Type	Length	Column Name	Data Type	Length	Requires Index? [Yes/No]	Description of field
Overtop_HHWLTContemp	Text	3					Confirmation of overtopping or not (Yes/No).
Feature Class Name:	Overtopping Higher High Water Large Tide Sea Level Rise 2050			Suggest a Filename:		Water_Dyke_Overtopping_HHWLT_SLR2050	
Data Structure at Authoritative Source (for maintenance purposes)			Data Structure for Publication				Field Description
Column Name	Data Type	Length	Column Name	Data Type	Length	Requires Index? [Yes/No]	Description of field
Overtop_HHWLTSLR20502055	Text	3					Confirmation of overtopping or not (Yes/No).
Feature Class Name:	Overtopping Higher High Water Large Tide Sea Level Rise 2050 Storm Surge 100 Year			Suggest a Filename:		Water_Dyke_Overtopping_HHWLT_SLR2050_SS100YR	
Data Structure at Authoritative Source (for maintenance purposes)			Data Structure for Publication				Field Description
Column Name	Data Type	Length	Column Name	Data Type	Length	Requires Index? [Yes/No]	Description of field
Overtop_HHWLTSLR20502055SS100YR	Text	3					Confirmation of overtopping or not (Yes/No).
Feature Class Name:	Overtopping Higher High Water Large Tide Sea Level Rise 2050 Storm Surge 50 Year			Suggest a Filename:		Water_Dyke_Overtopping_HHWLT_SLR2050_SS50YR	
Data Structure at Authoritative Source (for maintenance purposes)			Data Structure for Publication				Field Description
Column Name	Data Type	Length	Column Name	Data Type	Length	Requires Index? [Yes/No]	Description of field
Overtop_HHWLTSLR20502055SS50YR	Text	3					Confirmation of overtopping or not (Yes/No).

Feature Class Name:	Overtopping Higher High Water Large Tide Sea Level Rise 2100			Suggest a Filename:		Water_Dyke_Overtopping_HHWLT_SLR2100	
Data Structure at Authoritative Source (for maintenance purposes)			Data Structure for Publication				Field Description
Column Name	Data Type	Length	Column Name	Data Type	Length	Requires Index? [Yes/No]	Description of field
Overtop_HHWLTSLR2100	Text	3					Confirmation of overtopping or not (Yes/No).

Feature Class Name:	Overtopping Higher High Water Large Tide Sea Level Rise 2100 Storm Surge 100 Year			Suggest a Filename:		Water_Dyke_Overtopping_HHWLT_SLR2100_SS100YR	
Data Structure at Authoritative Source (for maintenance purposes)			Data Structure for Publication				Field Description
Column Name	Data Type	Length	Column Name	Data Type	Length	Requires Index? [Yes/No]	Description of field
Overtop_HHWLTSLR2100SS100YR	Text	3					Confirmation of overtopping or not (Yes/No).

Feature Class Name:	Overtopping Higher High Water Large Tide Sea Level Rise 2100 Storm Surge 50 Year			Suggest a Filename:		Water_Dyke_Overtopping_HHWLT_SLR2050_SS50YR	
Data Structure at Authoritative Source (for maintenance purposes)			Data Structure for Publication				Field Description
Column Name	Data Type	Length	Column Name	Data Type	Length	Requires Index? [Yes/No]	Description of field
Overtop_HHWLTSLR2100SS50YR	Text	3					Confirmation of overtopping or not (Yes/No).