2.4.1 **Detailed Survey Data for Individual Land Parcels**

A historical survey by the USACE was utilized to assemble a database of seawall crest elevations and land elevations at home foundations. The data is summarized for 2310 to 2820 Edgemere Drive in Figure 2.25. In some locations, the seawall crest elevation is higher than the land surrounding the home, such as 2796 to 2820 Edgemere Drive. In other locations, the homes are higher than the seawall. In general, there is considerable spatial variability in both seawall crest elevation and land elevations around the homes for this section of Edgemere Drive.

![Surveyed Seawall Crest Elevation and Surrounding Land Elevations](image)

*Figure 2.25 Surveyed Seawall Crest Elevation and Surrounding Land Elevations*

The information in Figure 2.25 highlights the importance of developing a parcel by parcel database for the lakewide flooding investigation, since there is simply too much spatial variability in key variables that affect the magnitude of flooding damages, such as seawall crest elevation and land elevations.

2.4.2 **Overtopping Simulations for Legacy Plans**

Overtopping simulations were completed for the four legacy plans at three different sites along Edgemere Drive. The input profiles featured crest elevations of 2.6, 2.8 and 2.9 m to test the sensitivity of crest elevation and flooding damages. As with Study Sites #1 and #2, the predicted wave overtopping volumes are very sensitive to the water levels associated with each legacy plan and the actual crest and toe elevation for the input profile. This variability is investigated further.
2.4.3 Overtopping Simulations for a 2.14 m Crest Elevation

Section 2.4.3 and 2.4.4 will summarize the results of wave overtopping calculations for a typical profile along Edgemere Drive with different crest elevations. The results in this section were generated with a 2.14 m crest elevation for a vertical seawall with a toe elevation of 0.33 m below Chart Datum. A portion of the COSMOS input menu is presented in Figure 2.26 below.

The actual recorded lake levels from the Rochester Gage were used as input for this simulation. The gage data captures both the static lake conditions and storm surges.

![Edgemere COSMOS Menu (low crest section)](image)

**Figure 2.26 Input Profile for COSMOS Menu with 2.14 m Crest and –0.33 m Toe for Seawall**

The simulation covered the period of 1970 to 2000. With the input conditions described above and the hourly waves generated from the WAVAD hindcast (Baird, 200x), a total of 155 wave overtopping events were predicted with a minimum threshold of 3.0 m³/m/hr. The estimates were based on the output from the Ahrens and Heimbaugh (1988) equation.

The high lake levels in 1973 alone featured 27 wave overtopping events that exceeded the threshold of 3.0 m³/m/hr for six hours. This represents 17% of the total events predicted with the FEPS. The overtopping events predicted for 1973 are listed in Figure 2.27.
The results are further summarized for 1973 in a time series plot in Figure 2.28. The actual recorded water levels for the Rochester Gage are plotted (red line) along with the individual bars for the overtopping events (blue). The spring months of March to May are a particularly vulnerable period for wave overtopping and runup, since the lake is approaching the seasonal summer maximum level and severe storms are still possible. Conversely, in the month of January the lake is 0.75 m lower than the levels in May. The fall months of October to December are also historically a stormy period, however, the lake level for this period in 1973 was almost 1.0 m lower than the April - May 1973 levels when the majority of the overtopping events were predicted.

<table>
<thead>
<tr>
<th>Start</th>
<th>End</th>
<th>Duration (hrs)</th>
<th>Peak O/T Vol. (m3/m/hr)</th>
<th>Volume for Event (m3/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>06 Jan 1973 08PM</td>
<td>07 Jan 1973 04AM</td>
<td>9</td>
<td>4.19</td>
<td>14.84</td>
</tr>
<tr>
<td>20 Jan 1973 11AM</td>
<td>21 Jan 1973 02AM</td>
<td>16</td>
<td>8.44</td>
<td>95.87</td>
</tr>
<tr>
<td>27 Jan 1973 10PM</td>
<td>29 Jan 1973 11PM</td>
<td>50</td>
<td>19.54</td>
<td>115.54</td>
</tr>
<tr>
<td>06 Feb 1973 04AM</td>
<td>07 Feb 1973 12AM</td>
<td>21</td>
<td>13.60</td>
<td>167.59</td>
</tr>
<tr>
<td>08 Feb 1973 06PM</td>
<td>09 Feb 1973 10AM</td>
<td>17</td>
<td>21.05</td>
<td>240.28</td>
</tr>
<tr>
<td>10 Feb 1973 05PM</td>
<td>06 Mar 1973 09AM</td>
<td>569</td>
<td>24.15</td>
<td>578.91</td>
</tr>
<tr>
<td>09 Mar 1973 05PM</td>
<td>10 Mar 1973 03PM</td>
<td>23</td>
<td>14.46</td>
<td>341.41</td>
</tr>
<tr>
<td>17 Mar 1973 05AM</td>
<td>23 Mar 1973 01PM</td>
<td>153</td>
<td>182.13</td>
<td>1303.20</td>
</tr>
<tr>
<td>26 Mar 1973 01PM</td>
<td>28 Mar 1973 11AM</td>
<td>47</td>
<td>131.27</td>
<td>2644.48</td>
</tr>
<tr>
<td>01 Apr 1973 07AM</td>
<td>03 Apr 1973 02AM</td>
<td>44</td>
<td>196.17</td>
<td>3861.58</td>
</tr>
<tr>
<td>04 Apr 1973 05PM</td>
<td>05 Apr 1973 07PM</td>
<td>27</td>
<td>253.83</td>
<td>3634.99</td>
</tr>
<tr>
<td>07 Apr 1973 11PM</td>
<td>14 Apr 1973 09AM</td>
<td>155</td>
<td>722.98</td>
<td>347.47</td>
</tr>
<tr>
<td>19 Apr 1973 11PM</td>
<td>21 Apr 1973 09AM</td>
<td>35</td>
<td>302.82</td>
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<tr>
<td>25 Apr 1973 01PM</td>
<td>29 Apr 1973 07PM</td>
<td>103</td>
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<td>15150.08</td>
</tr>
<tr>
<td>30 Apr 1973 10PM</td>
<td>02 May 1973 05AM</td>
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<td>45.79</td>
<td>529.13</td>
</tr>
<tr>
<td>05 May 1973 12AM</td>
<td>06 May 1973 06AM</td>
<td>31</td>
<td>139.73</td>
<td>625.32</td>
</tr>
<tr>
<td>07 May 1973 04PM</td>
<td>08 May 1973 10AM</td>
<td>19</td>
<td>324.95</td>
<td>1656.92</td>
</tr>
<tr>
<td>13 May 1973 04AM</td>
<td>13 May 1973 09AM</td>
<td>6</td>
<td>31.15</td>
<td>114.51</td>
</tr>
<tr>
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<td>17 May 1973 05PM</td>
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<td>78.16</td>
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<tr>
<td>20 May 1973 05PM</td>
<td>21 May 1973 07PM</td>
<td>27</td>
<td>106.53</td>
<td>1008.19</td>
</tr>
<tr>
<td>24 May 1973 03PM</td>
<td>26 May 1973 02PM</td>
<td>48</td>
<td>39.89</td>
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</tr>
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<td>28 May 1973 08PM</td>
<td>28</td>
<td>23.16</td>
<td>96.47</td>
</tr>
<tr>
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<td>14 Jun 1973 09PM</td>
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<td>19.93</td>
<td>51.15</td>
</tr>
<tr>
<td>16 Jun 1973 10PM</td>
<td>18 Jun 1973 12PM</td>
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</tr>
<tr>
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<td>12 Jul 1973 05AM</td>
<td>16</td>
<td>131.48</td>
<td>656.64</td>
</tr>
<tr>
<td>21 Jul 1973 05PM</td>
<td>21 Jul 1973 11PM</td>
<td>7</td>
<td>6.52</td>
<td>31.86</td>
</tr>
</tbody>
</table>
2.4.4 Overtopping Simulations for a 2.54 m Crest Elevation

The above mentioned simulations for a 2.14 m seawall crest were repeated with the same input wave and water level conditions but a higher crest elevation (2.54 m). The input profile for the COSMOS menu was plotted in Figure 2.2. With the 0.4 m increase in the seawall crest elevation, the total number of overtopping events with a minimum threshold of 3.0 m$^3$/m/hr for a total of six hours decreased to 23 from 155 for the same seawall with a crest of 2.14 m. This dramatic decrease in the number of overtopping events highlights the sensitivity of the equations to the crest input variable. It also highlights the importance of completing the flooding calculations for the lakewide assessment for individual properties parcels, not some aggregate condition for the 1 km shoreline reaches.

In addition to a dramatic overall reduction in the number of wave overtopping events predicted for the higher crest elevation, the overall magnitude of the overtopping volume also decreases dramatically. For example, the peak overtopping volume for the April 25 to 29, 1973 storm was over 800 m$^3$/m/h with a crest elevation of 2.14 m. With a crest elevation of only 0.4 m higher (2.54 m) the peak overtopping volume for the same storm event was reduced to 101 m$^3$/m/h. Refer to Figures 2.27 and 2.29 respectively for the results. This finding further exemplifies the need to calculate lakewide flooding damages on a property parcel by property parcel basis.
The 1973 overtopping predictions for a seawall with a toe elevation of 0.33 m below CD and a crest elevation of 2.54 m above CD are plotted in Figure 2.30 in a time series format. The March to May period continues to generate the majority of the overtopping events even for the higher crest elevation.

**Site #4 Edgemere Drive O/T Predictions with 2.54 m Crest**

*Time Series Plot of Wave Overtopping for Rochester Gage*

**Figure 2.30 1973 Time Series Plot of O/T (2.54 m Crest and –0.33 m Toe for Seawall)**
2.4.5 Flow Pathway Analysis

A flow pathway analysis was completed for the detailed topographic data available for Edgemere Drive. The results are presented in Figure 2.31a. The barrier beach drainage network indicated that water falling on the former barrier beach, whether as rainfall or wave overtopping, will drain towards the road. The water will ultimately collect in the center of the site, which is noted with the black dot.

These findings confirm the field observations that the road is lower than the building foundations, which was depicted visually in Figure 2.23. Thus, flooding events generally lead to road closures and sewer backups, not main floor flooding.
2.5  Site #3 – Sandy Point, Sodus Bay

Sandy Point is a narrow peninsula of land located inside of Sodus Bay, Wayne County. Refer to Figure 2.31b for a map of Sodus Bay, the barrier beach and harbor jetties.

Figure 2.31b  Regional Map of Sodus Bay and the Sandy Point Detailed Study Site (#3)
A picture of the shoreline conditions for the north side of the point is provided in Figure 2.32. The land elevations are low and the shoreline protection structures are not significant.

![Figure 2.32 Typical View of Sandy Point Shoreline (looking west)](image)

The detailed WAVAD modeling for Lake Ontario did not produce wave conditions inside of the embayments, such as Sodus Bay. Therefore, hourly wave data was not available for this detailed study site. As such, it was not possible to calculate wave overtopping or runup with the COSMOS model and FEPS. However, given the relative small fetch distances in the bay (approximately 1 km to the southwest, for example) large waves are not expected to impact the shoreline.

The primary mechanism for flooding damage for this detailed study site is direct inundation. Therefore, the study site was investigated as part of the lakewide investigation and the detailed algorithm developed in the FEPS database module.
3.0 EROSION SITES

Erosion is a natural long term process for much of the Great Lakes shorelines. Driving forces, such as turbulence due to breaking waves and direct wave attack on the bluff toe, erode the lake bottom and shoreline materials, such as glacial till and lacustrine clay. At a given site, the rate of shoreline recession is proportional to the magnitude of the driving forces and the resisting properties of the shore materials.

Water levels do not cause shoreline erosion. Rather, water levels control the spatial distribution of wave energy dissipation across the nearshore zone, beach and bluff face. In general, during periods of low lake levels, more wave energy is dissipated on the lake bottom and bluff recession rates are lower than average. Conversely, during periods of high lake levels, less energy is dissipated on the lake bottom and more energy reaches the bluff toe, leading to higher than average recession rates.

Based on the 1 km reach classification generated for this study, approximately 40 % of the Lake Ontario and Upper St. Lawrence River shoreline features a cohesive shoreline. A total of five sites were selected to investigate water level impacts on shoreline recession, including 20 Mile Creek near Jordon, Ontario, Cherry Beach in Stoney Creek, East Bay, east of the chimney Bluffs, a 13 km stretch from New Castle to Port Granby and a group of sites on the US shoreline on the Upper St. Lawrence River. A site in Maumee Bay, Lake Erie was also studied since it featured sufficient data to calibrate and verify the predictive capabilities of the COSMOS model.

COSMOS is a deterministic numerical model capable of simulating erosion processes for cohesive shorelines in the Great Lakes. The following general steps are followed for each application of the COSMOS model to simulate erosion processes:

1. Collect existing data or new information on the local site conditions, including bathymetry and topography;

2. Collect or generate historical information on the position of the lakebed and bluff, ideally at two temporal periods;

3. Measure rates of change between the historical conditions and modern/present site data. For the lakebed, this is often accomplished by comparing shore perpendicular profiles to quantify downcutting rates to depths of 8 or 10 m below chart datum. Above the water, rates of bluff toe or crest retreat is measured between the historical position and present conditions, preferably at more than one location;

4. Time series data is required for lake levels, waves and ice cover. This information is processed to generate the required input files for the COSMOS model;
5. Calibration Phase: two coefficients, disfac (downcutting) and blerode (bluff recession), are calibrated based on the measure rates of change between the two historical datasets, such as 1960 to 1980. Refer to Figure 3.1 for an example; and

6. Verification Phase: the coefficients selected for the calibration phase are tested in a verification phase (e.g. 1980 to 2000), to evaluate the predictive capability of the model.

Figure 3.1  Erodibility Coefficients in the COSMOS Model

For additional details on the model coefficients and predictive capabilities of the COSMOS model, refer to Baird (1999 and 2001)
3.1 Site #5 – Maumee Bay

Maumee Bay is located at the western end of Lake Erie, in the State of Ohio. Refer to the location plan in Figure 3.2 below. A series of repetitive profiles were collected between October 1981 and October 1990 that captured high rates of lakebed downcutting and shoreline recession at this site, which features glacial sediment on the lakebed.

![Location Map for Site #5, Maumee Bay, Lucas County Lake Erie](image)

**Figure 3.2** Location Map for Site #5, Maumee Bay, Lucas County Lake Erie

### 3.1.1 Profile Data

The raw profile data, which captured the beach and bank, was obtained from the Ohio DNR. Of the eight surveys, three were selected for detailed numerical modeling with COSMOS: 1981, 1985 and 1990. These three profiles are presented in Figure 3.3 for reference. It should be noted that from 1981 and 1985 there was very little measured profile downcutting between the 0.0 to +0.5 m depth contour. However, between 1985 and 1990 there was significant profile downcutting in this region. The reason for this change is unknown.
The 1981 to 1985 period was used to calibrate the erodibility coefficients in the COSMOS model, while the 1985 to 1990 period was used to test the predictive capability of the coefficients.

![Repetitive Profile Data from 1981 to 1990](image)

**Figure 3.3** Repetitive Profile Data from 1981 to 1990

### 3.1.2 Lake Level Data

Hourly water level data was obtained from the Toledo gage for the period 1981 to 1990. A sample of the hourly data for 1987 is presented in Figure 3.4 below. Although there was a general downward trend in the lake levels, there was also considerable fluctuations on a day to day basis. This is particularly true for fall, winter and spring periods, when seiching is common due to storm surges and setdown.

![Hourly Lake Level Data from the Toledo Gage, Jan. to Dec. 1987 (m, IGLD’85)](image)

**Figure 3.4** Hourly Lake Level Data from the Toledo Gage, Jan. to Dec. 1987 (m, IGLD’85)
On December 15, 1987 a very large storm resulted in a large seiching event, when the initial storm surge at the Toledo gage reached approximately 1.25 m. This storm surge was followed by a large and long draw-down, when the lake level dropped approximately 2.0 m. Refer to Figure 3.5 for a plot of the December 1987 data.

![Figure 3.5 December 15, 1987 Storm Surge and Draw-down Recorded at the Toledo Gage](image)

### 3.1.3 Wave Data

A wind-wave hindcast was completed for a location at the mouth of Maumee Bay with input winds from Toledo. A 1D parametric hindcast model developed by Baird was used to predict the historic hourly wave conditions from 1981 to 1990.

The results of the hindcast are summarized in a wave height rose in Figure 3.6 below. The waves impacting this site are from the NNW to the ENE, and generally quite small due to the sheltered nature of the site.
3.1.4 Ice Data

Information on historical ice cover in the Great Lakes is available from the Great Lakes Environmental Research Laboratory. Animations of the ice cover data were downloaded and reviewed. For each time step, the individual lakes are covered with a series polygons representing different percentages of cover. For example, Maumee Bay could be covered with the no ice, 30%, and 40% up to 100%.

The historical ice cover animations were reviewed from 1981 to 1990 to determine when the site was covered with 50% or more ice cover. This information was converted into a time series record that is required for the X-Wave module of the FEPS.
3.1.5 \textit{COSMOS Model Calibration}

The first step in the COSMOS modeling was calibrating the two erodibility coefficients for the measured profile data from 1981 to 1985. The 1981 input profile (black line) and the 1985 target profile (red line) are provided in Figure 3.7 for reference. Following several adjustments, the downcutting and bluff recession coefficients were calibrated to within 5\% of the target data, which is the goal for this phase of the modeling. The actual measured downcutting is plotted on the Y2 axis (solid gray line) along with the estimated downcutting from the COSMOS model (black diamonds). The comparison is very good everywhere except 3,321 and 3,340 m on the X-axis. It appears a sand bar or beach ridge above the cohesive material was recorded in the 1985 survey. When the COSMOS model is applied to predict cohesive shore erosion, these type of mobile sand features are ignored.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure3.7.png}
\caption{\textit{COSMOS Model Calibration for 1981 and 1985}}
\end{figure}

3.1.6 \textit{COSMOS Model Verification}

The model coefficients used for the calibration run were re-applied to the wave and water level data from 1985 to 1990. The results are presented graphically in Figure 3.8. The model simulation is similar to the target 1990 profile but is not as close as the verification comparison (less than 5\%). There was very little downcutting in the 1981 to 1985 period and therefore the downcutting coefficient was small. When it was applied to the verification run, the amount of downcutting predicted was also small. However, the
actual downcutting between 1985 and 1990 was large. There is simply no numerical solution that would be correct for these two different rates of downcutting.

Similarly, the bluff recession is in the right order of magnitude but definitely not within 5%. The bank slopes in 1985 and 1990 were different. Since the COSMOS model simply shifts the bluff slope landward, no changes in slope are predicted. Therefore, when the input and target profile feature a different bluff slope, it will not be possible to get an accurate calibration.

It is worth noting that in the critical zone of breaking waves, from 0.5 to 1.0 m above chart datum, the amount of downcutting predicted with COSMOS compares well with the model. From +1.0 to +2.5, the relatively poor comparison between the prediction and the target profile are due to differences in bank slope.

![Figure 3.8 COSMOS Model Verification, 1985 and 1990](image-url)
3.2 Site #6 – East of 20 Mile Creek

Study Site 6 includes the bluffs east of 20 Mile Creek, which outlets into Lake Ontario at Jordan Harbour. Refer to the location map in Figure 3.9. The bluffs at this study site are actively eroding, however, approximately half of the site has been armored with shoreline protection. Reach 1277 features a long segment of unprotected bluff and was selected for detailed analysis. At this site, bluffs are 12 m in height and very steep.

Site 6: East of Twenty Mile Creek, Jordon (Reach 1276 -1279)

An aerial view of the bluffs was taken in August 2003, as seen in Figure 3.10. The bluff face is generally unvegetated. The tablelands are flat and undeveloped. Only a narrow strip of land now separates the North Service Road of the QEW from the top of the bank. A neighboring home is protected from toe erosion by shore protection but is now vulnerable to flanking erosion. When the site conditions were observed in December 2002 active toe erosion was observed, as well as mini block failures and talus deposits (Figure 3.11). The material eroded from the bluff face is quickly washed away by storm waves.
Figure 3.10  Oblique Aerial Photograph of Reach 1277 (August 9, 2003) looking southeast

Figure 3.11  Ground Level Photograph of Reach 1277 (December 12, 2002)
3.2.1 **Bluff Recession Rates**

Two sets of historical aerial photographs for Site 6 were obtained (1973 and 1986), scanned and geo-referenced to the 2002 orthophotograph. The top of bluff was digitized for the 1973 and 1986 imagery for comparisons to the 2002 bluff mapping generated for the study.

A custom GIS software module known as ‘Baird Shoretools’ was applied to calculate historical rates of bluff top recession. For additional details on Baird Shoretools, refer to Zuzek et al (2003). Shore perpendicular transects were measured at 5 m intervals between the historical and modern bluff crest for a 200 m section of shoreline in Reach 1277. The results are summarized in Table 3.1.

**Table 3.1  Historical Recession Rates for an Unprotected Section of Reach 1277**

<table>
<thead>
<tr>
<th>Start Year</th>
<th>End Year</th>
<th>No. of Years</th>
<th>Total Recession (m)</th>
<th>AARR (m/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1973</td>
<td>1986</td>
<td>13</td>
<td>19.33</td>
<td>1.49</td>
</tr>
<tr>
<td>1986</td>
<td>2002</td>
<td>16</td>
<td>9.53</td>
<td>0.60</td>
</tr>
<tr>
<td>1973</td>
<td>2002</td>
<td>29</td>
<td>28.02</td>
<td>0.97</td>
</tr>
</tbody>
</table>

For the period 1973 to 1986, the average annual recession rate (AARR) was 1.49 m/yr. This is a severe erosion rate according to the MNR Lake Ontario – St. Lawrence River Technical Guide. This period was also characterized by very high lake levels.

From 1986 to 2002, a period of lower lake levels resulted in an AARR of 0.6 m/yr at Site #6. When the total recession between 1973 and 2002 was considered, the long term AARR for Site #6 was 0.97 m/yr.

3.2.2 **2002 Shoals Bathymetry**

Detailed bathymetric data was collected in several of the shore units by the USACE for this study, including CND1. The USACE utilized an airborne sensor mounted on the bottom of a fixed wing aircraft. The technology is known as Light Detection And Ranging (LiDAR) and was applied to this study.

A series of lakebed profiles for eight consecutive shoreline reaches are presented in Figure 3.12. The elevation data extends from Chart Datum (0.0 m) to the 10 m contour depth. The profile for Reach 1277 is highlighted with a thick gray line and is representative for several of the adjacent profiles, which feature a steep nearshore slope of approximately 1:50 (V:H). There is a second population of profiles that features a nearshore slope of approximately 1:100 (V:H), including reaches 1271 to 1273.
3.2.3 Waves

The output from the lakewide wind-wave hindcast completed with the WAVAD model (Baird, 2003) was utilized for the erosion modeling at Study Site #6. WAVAD point 585 was selected for the analysis. The waves were transformed from a depth of 27.5 m below Chart Datum to the 10 m depth contour with the X-Wave module of the FEPS. The transformation considers the shoreline and contour orientation when applying linear refraction theory, shoaling calculations and Miche H/L breaking routine.

Figure 3.13 presents a wave rose for the nearshore wave climate from 1961 to 2000 at the 10 m depth contour. The site is exposed to waves from the WNW over to then ENE, however, the majority of the big storm events come from the NE. It should also be noted that the historical ice conditions have been considered and all waves are ignored when shoreline ice was present.

X-Wave calculates wave energy density as joules per square meter at a user specified contour depth. Wave energy density is plotted for Site #6 in Figure 3.14. There is considerable annual variability in the total wave energy, with the year to year maximum of 1.12 million joules/m² and minimum of 0.48 million joules/m².
Figure 3.13 Wave Height Rose for WAVAD Point 585 (10 m depth offshore of Site #6)

The average monthly wave energy density for WAVAD Point 585, transformed to the 10 m depth contour, is presented in Figure 3.15. The results for the other three cohesive bluff sites on Lake Ontario are also plotted for reference. A trend of high wave energy in the fall, winter and spring is clearly seen at the four sites, which are spread around the lake. The month to month variability is not due to geographic location around the lake but rather the continental (meso-scale) climatic patterns for North America. The summer period features the calmest conditions, with storm intensity increasing in the fall, reaching a maximum in the winter and decreasing through the spring.
Figure 3.14  Annual Wave Energy at Study Site #6 (Joules per m²)

Figure 3.15  Annual Wave Energy at Study Site #6 (Joules per m²)
3.2.4 Calibration of Erodibility Coefficients at Site #6

The input profile condition for Site #6 was a combination of the Shoals bathymetry described in Section 3.2.2 and the top of bluff mapping described in Section 3.2.1. The profile extended from the tablelands above the bluff to the 10 m depth contour. Refer to Figure 3.16 for a zoom of the profile, including the shallow nearshore zone, beach and bluff.

![Figure 3.16 COSMOS Model Calibration at Reach 1277 (1961 to 2000)](image)

The target profile was generated by shifting the input profile landward 40 times the AARR of 0.97 m/yr. This approach assumes the profile shape is maintained while the bluff migrates inland.

The final COSMOS prediction for the calibration is presented in Figure 3.16 as the estimated profile (Y1 axis) and the magnitude of the downcutting (Y2 axis). In the shallow nearshore zone, the comparison between the target profile and COSMOS is very good. As the bluff migrates inland in the simulation, the magnitude of the downcutting around the 0.0 m contour is slightly underestimated in the model. However, the amount of bluff recession compares well to the target profile.

Overall, the COSMOS model coefficients were successfully calibrated at Reach 1277 and the magnitude of historic recession was reproduced with the historical lake levels and waves.
3.2.5 **Prediction of Future Recession for Legacy Plans**

Once the erodibility coefficients in COSMOS were successfully calibrated, a 35 year simulation was completed with the three legacy plans, pre-project and three old climate change hydrographs from an earlier Environment Canada study (Mortsch, 2000). The horizontal retreat of the bluff is plotted in Figure 3.17.

The amount of bluff recession over the 35 year simulation was greatest for the pre-project water levels, followed by 1958D without deviations, then 1958D with deviations. The climate change water levels produced the least amount of recession. It is interesting to note, however, that the climate change scenarios produced the greatest amount of nearshore downcutting. In other words, erosion still occurred for the climate change hydrographs, it was just focused on the lake bottom rather than the bluff. For reference, the water level hydrographs are organized in the graph legend based on the magnitude of the recession (highest to lowest).

![Figure 3.17 Estimate of Bluff Recession at Reach 1277 for Legacy Plans and Climate Change Water Levels](image)

In addition to estimating the future bluff profile, the COSMOS model also tracks the cumulative bluff recession for a simulation. The results for the legacy plans and climate change water levels are presented graphically in Figure 3.18. The results highlight the non-linear rates of recession at the site for the simulations. Recall from the earlier discussion that bluff recession is controlled by the magnitude of incoming wave energy.
and lake levels. The plans that featured the higher lake levels had higher rates of bluff recession for the 35 year simulation. The identical wave climate was used for all the simulations, so the only difference was the lake levels. In other words, lake levels influenced which part of the profile eroded during the simulation, the lakebed or bluff.

Figure 3.18  Cumulative Bluff Recession at Site #6 for Legacy Plans and Climate Change
3.3 Site #7 – Cherry Beach, Stoney Creek

Cherry Beach is located along the south-west shoreline of Lake Ontario, east Hamilton Harbour, west of Grimsby, in the former Town of Stoney Creek. The site covers Reaches 1318 and 1319. The site is now part of the City of Hamilton. Refer to the location map in Figure 3.19. Reach 1318 and 1319 represented one of the few locations along the Niagara and Hamilton shorelines that remained undeveloped and suitable for the detailed COSMOS erosion modeling. Since these sites were selected in 2002 two development projects are in various stages of implementation and the shoreline will soon be fully armored.

![Site 7: Cherry Beach, Stoney Creek (Reach 1318-1319)](image)

**Figure 3.19 Location Map for Site #7, Cherry Beach**

Figure 3.20 provides an aerial view of the site taken in August 2003. To the left of the image, the eroding bank has been covered with an armor stone revetment. The sales trailer for the new development can also been seen. For the center and right hand side of the photograph, the eroding bank is still visible. An application to protect this eroding shoreline and develop the land is ongoing.
A ground level view of the eroding bank in December 2002 is presented in Figure 3.21. The beach consists of natural cobbles and boulders eroded from the glacial till, plus a large volume of concrete rubble and other construction debris.

Figure 3.20   Oblique Digital Photograph of Reach 1319 (August 9, 2003)

Figure 3.21   Ground Level Photograph of Eroding Bank at Reach 1319 (Dec. 13, 2002)
3.3.1 Bluff Recession Rates

Historical aerial photographs at Site #7 were available for 1954 and 1989. When compared to the 2002 high resolution orthophotograph for the site, 48 years of bluff recession information was generated.

The erosion transects for the site were measured and analyzed with Baird Shoretools. From 1954 to 1989, the AARR for the site was 0.55 m/yr. Between 1989 and 2002, this rate decreased slightly to 0.46 m/yr. The long term AARR between 1954 and 2002 was 0.53 m/yr. This rate was used for the COSMOS modeling. Refer to Table 3.2 for additional details.

Table 3.2 Historical Recession Rates for Unprotected Sections of Reach 1319

<table>
<thead>
<tr>
<th>Start Year</th>
<th>End Year</th>
<th>No. of Years</th>
<th>Total Recession (m)</th>
<th>AARR (m/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1954</td>
<td>1989</td>
<td>35</td>
<td>19.21</td>
<td>0.55</td>
</tr>
<tr>
<td>1989</td>
<td>2002</td>
<td>14</td>
<td>5.99</td>
<td>0.46</td>
</tr>
<tr>
<td>1954</td>
<td>2002</td>
<td>48</td>
<td>28.02</td>
<td>0.53</td>
</tr>
</tbody>
</table>

3.3.2 Bathymetry and Lakebed Profiles

High resolution SHOALS bathymetry was available for this detailed study area. Profiles for nine shoreline reaches, seven of which are located to the east of this site, are presented in Figure 3.22. The Reach 1319 profile is highlighted with a thick red line for reference. The profile features the classic concave shape observed for eroding cohesive shorelines.

It is also very steep, with the nearshore slope of 1:14 (V:H) between the 0 and –2 m depth contour. From 0 to –4 m, the average slope is gentler, at 1:30 (V:H). For comparison, the nearshore slope between the 0 and –2 m depth contour at Reach 1277 (Study Site #6) is 1:50 (V:H).
3.3.3 Waves

The wave output from the WAVAD model application for Lake Ontario was utilized as one of the inputs for the erosion modeling at Reach 1319. Grid point 853 was selected and the waves were transformed inshore to a depth of 10 m using X-Wave. A rose plot for the hourly wave heights is presented in Figure 3.23 below.

Figure 3.22 Lakebed Profiles for Reaches 1308 to 1320 Based on 2001 SHOALS Data

Figure 3.23 Wave Rose for Reach 1319 (10 m depth)
3.3.4  Calibration of Erodibility Coefficients at Site #7

The nearshore profile, beach and bank for Site #7 are presented in Figure 3.24 (input profile). The target profile is the product of the input profile shifted in a landward direction 40 times the AARR. The erodibility coefficients were then calibrated to produce the required amount of lakebed downcutting and bank recession at Site #7. The goal is bluff recession from the COSMOS model that is within 5% of the target (40 times the AARR). As seen in Figure 3.24, the calibration at Site 7 was very successful, with the predicted bluff recession within 5% of the target.

![Figure 3.24 Calibration of COSMOS at Reach 1319 (1961 to 2000 waves)](image)

3.3.5  Prediction of Future Recession for Legacy Plans

Future bluff recession at Reach 1319 was predicted for the three legacy plans, pre-project and the three EC climate change sequences. The results are presented in Figure 3.25. The pre-project hydrograph featured the largest recession rate (0.76 m/yr), followed closely by 1958D with deviations and 1958D without deviations. The climate change hydrographs featured the smallest recession rates, with the rate for 2090 being only 0.20 m/yr.

It is worth noting that the model simulations became unstable for the climate change water levels and predicted a depression or hole in the lakebed around 1,170 m on the X-
axis. This feature is a modeling artifact and not considered to be a true representation of the actual field response to these hydrographs.

![Graph showing lakebed downcutting and bank recession at Reach 1319].

**Figure 3.25  Lakebed Downcutting and Bank Recession at Reach 1319**

The cumulative bank recession at Reach 1319 for the 35 year simulation is plotted in Figure 3.26. A similar trend emerges as observed at Site #6, however, the rates are considerably more linear at Site #7. In other words, there is less year to year variability in the recession rates and therefore less sensitivity to yearly lake level fluctuations.

The average annual recession rate for the seven predictions of future bank recession at Site #7 was 0.52 m/yr and the standard deviation of the population was 0.2. The standard deviation is an indicator of the spread or variability in the recession rates for the various hydrographs. It is interesting to note that standard deviation in the AARR for the 35 year simulations at Site #6 was considerably higher, at 0.51. In other words, there was more variability in the erosion response at Site 6 than Site 7.

Recall that the identical wave climate is used for each water level hydrograph. The variability can also be assessed by comparing the amount of recession for pre-project (largest recession rate) versus climate change 2090 (smallest) recession rates. At Site #6, the amount of bluff recession predicted for pre-project was 8.7 times greater than climate change 2090. However, at Site #7 pre-project was only 3.8 greater than climate change 2090. The difference in the nearshore profile slope between the two sites is the most logical explanation for the differences in the recession rates at the two sites. At Site #6, there is more energy dissipation on the gentler nearshore slope and thus bluff recession is
very sensitive to water levels. At Site #7, the nearshore is much steeper and deeper, resulting in less energy dissipation on the lakebed and more energy focused on bank recession.

Figure 3.26 Cumulative Bank Recession for a 35 Year Simulation at Reach 1319
3.4 Site #8 – East Bay, East of Chimney Bluffs

Study Site #8 features an eroding cohesive bluff with residential development on the tablelands. The site is located in Wayne County, New York. East of the site, the bluffs grade out to a barrier beach that shelters a drowned river valley and marsh. Reach 860 is the focus of this detailed study site. A map of the area is presented in Figure 3.27. The Chimney Bluffs are located to the southwest of the reach centroid for reach 861 and formed as the shoreline eroded through a large drumlin. The dramatic rills and gullies associated with this eroding bluff face can clearly been seen, along with the general morphology of the forested drumlin inland.

Figure 3.27 Map of Study Site #8, East Bay, Wayne County, New York

An aerial view of the site is provided in Figure 3.28. The image was taken on August 6, 2003. The bluff stratigraphy appears to be very homogeneous and is mostly void of vegetation. Small gullies create a scalloped bluff crest in some locations and the beach is very narrow. Since this image was taken, several of the homes that were located at the bluff crest were condemned by officials from Wayne County for unsafe occupancy.
Figure 3.28  Eroding Bluffs and Residential Development at East Bay (taken August 6, 2003)

A ground level image of the beach and bluff conditions at East Bay is presented in Figure 3.29. The narrow beaches, steep bluff face and proximity of existing development to the bluff crest is clearly evident in the photograph.

Figure 3.29  Ground Level Photograph of Site #8 Looking East (taken April 11, 2002)
The beach and shallow nearshore conditions at the site were captured with a photograph from April 11, 2002. Refer to Figure 3.30. The waterline and nearshore is covered with boulders, cobbles, pebbles and shingle. This material is a relic deposit from the erosion of the glacial till in the bluffs and it partially armors the nearshore zone from lakebed downcutting.

Figure 3.30  Beach and Nearshore Lakebed Conditions at Site #8 (taken April 11, 2002)
3.4.1 Bluff Recession Rates

A historical 1973 aerial photograph was registered to the recent 2002 orthophotograph for Site #8. Once registered, the 1973 top of bank and toe of bank were digitized in GIS. The 1973 and 2002 top of bank lines are presented in Figure 3.31, along with the baseline for the erosion transects (black line) and the shore perpendicular transects (yellow lines) calculated with Baird Shoretools. A 1983 aerial photograph was also registered for the analysis.

Figure 3.31 1973 and 2002 Bluff Crest Lines and Recession Measurements for Site #8

The bluff recession rates calculated with Baird Shoretools are summarized in Table 3.3 for various temporal periods. From 1973 to 1983, the average annual recession rate was 0.31 m/yr for Reach 860. Between 1983 and 2002, the AARR was 0.27 m/yr. The combined rate between 1973 and 2002 was 0.3 m/yr. Collectively, the annual recession rate was very linear for this study site.

The homogeneous nature of the bluff stratigraphy at Reach 860 leads to shallow slope failures and translational slides. This process is continuous and happens at a fairly constant rate. For high bluffs with complex stratigraphy and perched water tables, the
rate of retreat is often dominated by large rotational failures and the recession rate trend over time is not as linear (Zuzek et al., 2003).

### Table 3.3  Historical Bluff Recession Rates for Reach 860

<table>
<thead>
<tr>
<th>Start Year</th>
<th>End Year</th>
<th>No. of Years</th>
<th>AARR (m/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1973</td>
<td>1983</td>
<td>10</td>
<td>0.31</td>
</tr>
<tr>
<td>1983</td>
<td>2002</td>
<td>19</td>
<td>0.27</td>
</tr>
<tr>
<td>1973</td>
<td>2002</td>
<td>29</td>
<td>0.30</td>
</tr>
</tbody>
</table>

#### 3.4.2 Bathymetry and Lakebed Profile

Detailed SHOALS bathymetry for Wayne County was collected for the study in the summer of 2001. The shore perpendicular profile for Reach 860 and six adjacent reaches to the west are presented in Figure 3.32. The profile for Reach 860 is highlighted with a thick black line for reference. Between the waterline and the 2 m depth contour, Reach 860 features a concave profile shape. The slope between these two contours is approximately 1:100 (V:H).

![Figure 3.32  2001 SHOALS Profiles, Reaches 860 to 866](image)
This is considerably flatter than Sites 6 and 7 located in the west in the Regional Municipality of Niagara. From the 2 to 10 m depth contour, the lakebed profile features a convex shape, which may be attributed to the high percentage of cobbles and boulders in the glacial till at the site (refer to the nearshore conditions in Figure 3.31. The absence of a strong shelf profile at Reach 860 may be attributed to the long term isostatic rebound rates for this region of Lake Ontario. In other words, the shelf cannot form at a constant level (such as the 2 m depth contour) since the lake bed is decreasing in elevation very slowly.

### 3.4.3 Waves

The WAVAD grid point selected for the Site #8 modeling was located at the 40 m depth contour. The wave height rose for these offshore waves is presented in Figure 3.33. The site is dominated by large waves from the west to northwest, due to the long fetch of Lake Ontario in these directions. X-Wave was used to transform these waves to represent the conditions at the 10 m depth contour and the local shoreline orientation.

Figure 3.33 1961 to 2000 Wave Data Offshore of Site #8, East Bay, Wayne County
### 3.4.4 Calibration of Erodibility Coefficients at Site #8

The temporal period for the calibration of the erodibility coefficients at Site #8 was 1973 to 2002, which corresponds to the period of measure bluff recession. The input and target profile are presented in Figure 3.34. The two coefficients were successfully calibrated and the predicted bluff recession was within 1% of the target. The magnitude of the downcutting matched very well, particularly in the critical nearshore area from the 2 m depth contour to the waterline.

![Figure 3.34 Results from COSMOS Model Calibration at Reach 860, 1973 to 2002](image)

### 3.4.5 Prediction of Future Recession Rates for Legacy Plans

Future shoreline estimates were completed at Site #8 for a 35 year temporal period, which corresponded to the duration of the EC climate change water levels. The input wave data from 1961 to 1995 was selected and combined with the legacy plan water levels with X-Wave. The future bluff recession rates are presented in Figure 3.35. As with the two previous erosion sites (Site 6 and 7), there was considerable variability in the predicted rates of bluff recession despite the fact that the identical wave climate was used for all the simulations. The water levels for the pre-project condition resulted in the most bluff recession, followed by 1958D without deviations, 1958D with deviations and 1998. The climate change water levels resulted in the least amount of bluff recession, particularly the 2090 conditions. As seen in Figure 3.35, the very low levels for the 2090...
hydrograph resulted in the erosion of a new bank at 1,140 m on the x-axis and very little wave energy actually reached the bluff toe to cause bank recession. It should also be mentioned that although the 2090 hydrograph produced the least amount of bluff recession for the 35 year simulation, it resulted in the largest amount of lakebed downcutting in the shallow nearshore environment.

[Graph showing cumulative bluff recession estimates for Reach 860 plotted in Figure 3.36 for the same 35 simulation. From the early 1970s to 1995, the COSMOS prediction for the water levels associated with 1958D with deviations, the actual regulation plan, was a linear rate of recession. This result supports the findings from the bluff recession analysis, which suggested the annual rate of retreat has not changed substantially between 1973 and 2002.

The amount of recession predicted for the pre-project hydrograph was almost double the bluff retreat for 1958D with deviations, the current regulation plan. This finding highlights the beneficial impacts of Lake Ontario regulation on shoreline recession. In other words, without the project the amount of annual bluff recession at Reach 860 would have been almost double the actual rate of 0.3 m/yr.

Through the first ten years of the simulation (decade of the 1960s), the climate change hydrographs resulted in almost no bluff recession. In other words, during these very low
lake level periods all of the erosive wave energy was focused on lakebed downcutting and the bluff was relatively stable.

![Figure 3.36 Cumulative Bluff Recession at Reach 860 for the Legacy Plans and Climate Change Water Levels](image)

### 3.4.6 Prediction for Candidate Plans (as of August 2005)

In August 2005 a series of four candidate plans were available for testing at the detailed study sites, including Plan A, B, C and D. Refer to Section 1.2.6 of the report for additional details on the water levels associated with these new plans.

To test the impacts of the four candidate plans on shoreline erosion, a series of 101 year simulations were completed at Site #8. The original wave climate from 1961 to 2000 was extended to cover 101 years and attached to each water level hydrograph. In other words, the hydrograph for each water level plan featured the identical wave climate.

Figure 3.37 presents the results for the four candidate plans and the current regulation plan (1958D with deviations) as a cumulative recession plot. Although the x-axis is labeled January 1900 to January 2000, the simulation represents 101 years of future recession at the site for each plan.

The 101 year simulation for Plan 1958DD resulted in 20.8 m of recession. This is the base scenario, since it represents the hypothetical future if the current regulation plan is adopted for the next 101 years. Bluff recession associated with Plans A and B increased
an average of 32% for the 101 year simulation. Plan D was 4% greater than 1958DD and Plan C was slightly lower.

Figure 3.37  Cumulative Bluff Recession at Reach 860 for Candidate Plans

The predicted bluff recession for 1958DD and the four candidate plans is plotted spatially in Figure 3.38 as estimated future top of bluff lines after the 101 year simulation. The existing top of bank is plotted as the black line. The first cluster of lines represents the prediction for 1958DD and Plans D and C. Plans A and B result in more bluff recession and therefore the future top of bluff line is further inland for this simulation.

At this particular section of Reach 860, several homes would be lost to erosion over the 101 year simulation. For Plans A and B, the homes would be lost sooner, since the predicted recession rate is higher.
Figure 3.38 101 Year Estimate of Future Top of Bluff for Candidate Plans at Reach 860
3.5 Site #9 – New Castle to Port Granby

Site #9 features 13 km of actively eroding high bluff coast and is classified as a cohesive shoreline. The study site is bounded by the communities of New Castle and Port Granby, in the Regional Municipality (RM) of Durham. Refer to the location map in Figure 3.39. The site is located on the north shore of Lake Ontario, approximately half way between Toronto and Prince Edward County. Detailed erosion modeling was completed at all 13 reaches for Study Site #9. The results from Reach 1695 will be described.

![Site 9: Newcastle to Port Granby, Clarington (Reach 1693-1705)](image_url)

Figure 3.39 Location Map for Detailed Study Site #9, Newcastle to Port Granby

Digital oblique photographs of Durham RM were collected on August 9, 2003 from the US Coast Guard helicopter. Reach 1695 is developed with large estate lots and the homes are setback from the bluff crest. There is no shore protection. Refer to the image in Figure 3.40.

The bluffs are steep, feature small local gullies and very little vegetation. The beach is narrow and features cobbles and boulders. The nearshore also features scattered boulders.
that are a relic deposit from bluff recession. In other words, as the glacial till is eroded from the bluffs, the cobbles and boulders remain at the site while the sands and fines (silts and clays) are transported away from the site.

Figure 3.40 Oblique Aerial Photograph of Reach 1695

The beach conditions at Site #9 were observed on November 28, 2002. Refer to a typical shot of the beach, looking west, in Figure 3.41. The beach consists of pebbles, cobbles and boulders and is very narrow. Boulders can also been seen in the nearshore zone.

Figure 3.41 Typical Beach and Bluff Conditions from the waterline, November 28, 2002
3.5.1  **Bluff Recession Rates**

A series of 1954 aerial photographs were geo-referenced to the 2000 orthophotograph for Site #9. The top of bluff line was screen digitized from the 1954 image and compared to the 2000 condition with Baird Shoretools. Since Reach 1695 featured a gentle curve in the shoreline, a curved baseline was used to draw the recession transects in ArcGIS. Refer to Figure 3.42. Locations along the bluff crest that featured large gullies were omitted from the calculation.

Figure 3.42  **1954 and 2000 Top of Bluff Lines and Recession Transects**

The average annual recession rate for the entire reach was 0.19 m/yr. When only the actively eroding segments of Reach 1695 were evaluated, the AARR was 0.28 m/yr.

3.5.2  **Bathymetry and Lakebed Profile**

The lakebed profile for Reach 1695 and the adjacent reaches to the east are presented in Figure 3.43. Reach 1695 features one of the steepest profiles in this group, with a
nearshore slope of 1:32 (V:H) between the 0 and 2 m depth contour. The profiles are generally quite flat and do not fall into either of the concave or convex category.

![Lakebed Profiles from Detailed SHOALS Bathymetry Collected in 2001](image)

**Figure 3.43** Lakebed Profiles from Detailed SHOALS Bathymetry Collected in 2001

### 3.5.3 Waves

Wave data for the calibration of the COSMOS model at Reach 1695 was required from 1954 to 2000. Therefore, the original hindcast from 1961 to 2000 was extended statistically to cover these additional years. A plot of the deep water wave rose used for Reach 1695 is presented in Figure 3.44. The largest waves approach the site from the southwest, which is due to the long axis of the lake in this direction and the strong west to east moving storms.
3.5.4 Calibration of Erodibility Coefficients at Reach 1695, Site #9

The COSMOS erodibility coefficients were calibrated at Reach 1695 for the 1954 to 2000 temporal period, which corresponds to the measured recession data. The results are presented in Figure 3.45. The downcutting and bluff recession predicted with COSMOS matched the target profile very well and the error was less than 5%.

3.5.5 Prediction of Future Recession Rates for Legacy Plans

Once the erodibility coefficients were calibrated, the model was re-run with 35 years of lake level data for the legacy plans, pre-project and the three climate change scenarios. Refer to Figure 3.46 for a plot of the results. As with the previous erosion sites discussed in Section 3.0 of the report, pre-project featured the highest recession rates, followed by 1958D without deviations, Plan 1998 and 1958D with deviations.

The climate change water levels resulted in very little recession, particularly scenario 2090.
Figure 3.45  Target Profile and COSMOS Prediction for Reach 1695 (1954 to 2000)

Figure 3.46  35 Year Prediction of Future Bluff Recession for Legacy Plans and Climate Change
3.5.6 Prediction for Candidate Plans (as of August 2005)

The four candidate plans described in Section 1.2.6 of the report were used at Reach 1695 for a 101 year simulation. A model simulation was also completed with the 101 year water level hydrograph for the current regulation plan (1958D with deviations) as a basis for comparison.

The results are plotted spatially in Figure 3.47 in plan view and as cumulative recession rates in Figure 3.48. When compared to the baseline recession for 1958D with deviations, estimated bluff recession increases by 41% for Plan A, 30% for Plan B, and 8% for Plan D at Reach 1695. The predicted recession over the 101 year simulation for Plan C and 1958D with deviations are approximately equal.

Figure 3.47 101 Year Simulation at Reach 1695 Candidate Plans (A to D)
Figure 3.48  Cumulative Bluff Recession for Candidate Plans over 101 Year Simulation