Baird

oceans
engineering
lakes
design
rivers
science
watersheds
construction

Draft

Dynamic Beach Assessment
Sarnia (Reach 5)

9 October 2013
11502.201

Dynamic Beach Assessment
Sarnia (Reach 5)

Prepared for

St. Clair Region Conservation Authority

Prepared by

W.F. Baird & Associates Coastal Engineers Ltd.

For further information please contact
Jennifer Ogrodnick, M.Sc., P.Eng at (905) 845-5385

11502.201

Revision	Date	Status	Comments	Reviewed by	Approved by
0	9 Oct. 2013	Draft	Client review	FD	FD

TABLE OF CONTENTS

1.0 INTRODUCTION

1.1 Background

In 1996 the St. Clair Region Conservation Authority (SCRCA) developed the *Lake Huron Shoreline Management Plan* (SMP) for Point Edward, Sarnia and Plympton Wyoming. The SMP was updated in 2011 (Baird, 2011) to the current technical standards identified in the *MNR Technical Guide for the Great Lakes – St. Lawrence River System and Large Inland Lakes* (MNR, 2001), and to include Lambton Shores. The hazard limits for flooding, erosion and dynamic beaches were assessed and hazard mapping was prepared by SCRCA.

The Shoreline Management Plan (Baird, 2011) identifies Reach 5, L. Huron Parkway to Hillcrest Drive to Nesbit Drive, located in Sarnia (see Figure 1.1) as a dynamic beach. The "dynamic beach hazard" limit in the *Provincial Policy Statement* (PPS) (Ministry of Municipal Affairs and Housing, 2005) is intended to indicate the reasonably safe limit of the natural erosion and accretion of a beach/dune system in response to variable lake levels and storm events. In accordance with the *Technical Guide* (MNR 2001) published in support of the *PPS*, a flood hazard limit of 15 m measured horizontally from the 100-year flood level plus an additional dynamic beach hazard limit of 30 m landward from the flood hazard limit are the standard "default" values to be used if no studies using accepted scientific and engineering principles are undertaken. This was the methodology used to identify the dynamic beach hazard limit in the Shoreline Management Plan (Baird, 2011).

The Natural Hazards Training Manual (MNR 1997) states that mechanisms should be incorporated into the planning process to provide the flexibility to undertake a study using accepted scientific and engineering principles, to determine the landward limit of the dynamic beach hazard. The SCRCA retained Baird & Associates to further evaluate the dynamic beach hazard for Reach 5. This report presents the methodologies used and results of the study, along with recommendations for the dynamic beach hazard limit.

1.2 Study Scope

The methodology used to assess the dynamic beach hazard is as follows:

- Assemble and review existing data, including the 1:2000 topographic mapping, Canadian Hydrographic Services Field Sheet (offshore bottom elevations), historical water levels and MNR wave climate database;
- Undertake a site reconnaissance to assess the nature of the existing beach and complete beach profile survey;
- Collect beach sediment samples and test for grain size.

- Using the CHS hydrographic data and the MNR wave database as input, along with the surveyed profiles and beach sediment data, numerically model the beach profile response using COSMOS. The COSMOS model, developed by Baird, simulates cross-shore processes across a nearshore profile.
- Estimate the response of the beach profiles to storm events including the 20-year return waves at the MNR 100-year flood level.
- The results from the beach profile modeling are then assessed to estimate the dynamic beach hazard limit.

Figure 1.1 Site Location Map

2.0 DYNAMIC BEACH HAZARD

As outlined in the *Provincial Policy Statement* (Ministry of Municipal Affairs and Housing, 2005),

> *"Hazardous lands adjacent to the shorelines of the Great Lakes - St. Lawrence River System are those lands, which are impacted by flooding, erosion, and/or dynamic beach hazards."*

The dynamic beach hazard limit is defined in Figure 2.1. The "Flood Level" and the "Flooding Allowance" represent the flooding hazard. The flood level is the sum of the mean lake level and storm surge with a combined probability of a 100-year return period (i.e., on average, has a one percent probability of occurring in any given year). For the study area the MNR 100-year flood level is 178.0 m IGLD 1985. Further discussion of water levels is provided in Section 3.4.

The flooding allowance accommodates waves, which rush up the shoreline beyond the water level. The Technical Guide for Great Lakes – St. Lawrence River Shorelines (MNR 2001) requires a flooding allowance of 15 m, measured horizontally from the location of the flood level, if a study using accepted engineering and scientific principles is not undertaken.

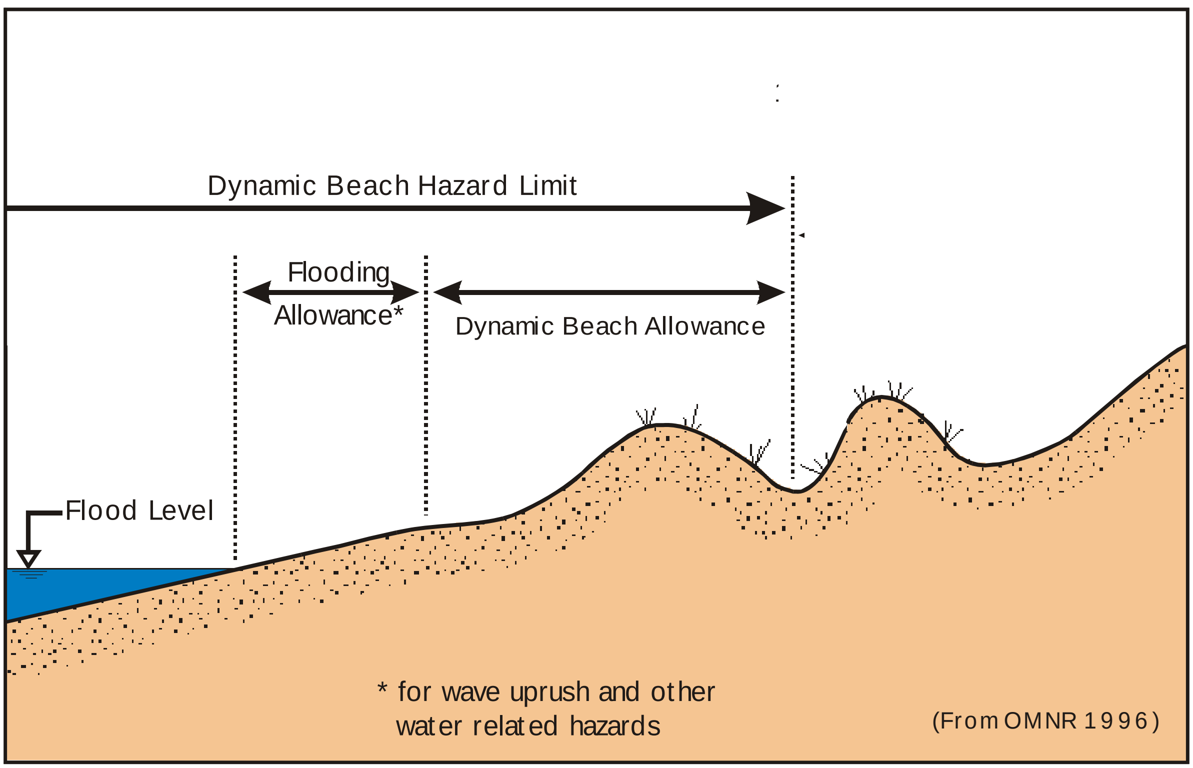

Figure 2.1 Dynamic Beach Hazard Limit

The dynamic beach allowance is intended to permit the natural erosion and accretion of the beach/dune system in response to variable lake levels and storm events. The Technical Guide requires a dynamic beach allowance of 30 m if no study using accepted engineering and scientific principles is undertaken. The sum of the combined flooding and dynamic beach hazard allowances is 45 m measured horizontally from the position of the 100-year flood level. In addition to the flooding and dynamic beach hazard allowances, an erosion allowance must also be considered where appropriate. The erosion allowance is intended to accommodate long-term recession of the shoreline.

The standard "default" values for the flooding and dynamic beach hazards are not necessarily representative of the study area but are values that would reasonably encompass most sites on the Great Lakes. In the development of the dynamic beach hazard limit, the landward side of the first main foredune was deemed to be a reasonable limit in most situations. The Technical Guide states:

> *"…where developments and site alterations have been directed to locations inland of the beach or dune features (i.e., landward of the first main foredune), these features often naturally prevent flood waters from reaching inland areas and absorb the erosive impacts and forces of wave action."*

The Natural Hazards Training Manual (MNR 1997) states that mechanisms should be incorporated into the planning process to provide the flexibility to undertake a study, using accepted scientific and engineering principles to determine the landward limit of the dynamic beach hazard.

3.0 DATA

This section provides a description of data used in this study including: beach profiles, bathymetry, sediment, wave and water level data. Field work undertaken for this study included beach profile surveys and sediment sampling.

3.1 Beach Profiles and Bathymetry

Beach profiles were surveyed by Baird at seven locations in Reach 5 on August 8, 2013. The profile locations are shown in Figure 3.1. A photo of the profile locations and a plot of the survey data are provided in Appendix A. The vertical datum was referenced to the water level at the time of the survey, and the elevations were reduced to International Great Lakes Datum (IGLD) 1985. The average water level at Station 9041098 Fort Gratiot was 176.09 m IGLD'85 on August 8, 2013.

Bathymetry data from Canadian Hydrographic Services Field Sheet 8088 surveyed in 1981 with a 1:50,000 scale were used to extend the profiles offshore. Continuous beach profiles extending from the back of beach to approximately 1 km offshore were extracted from the compiled bathymetry and beach profile data.

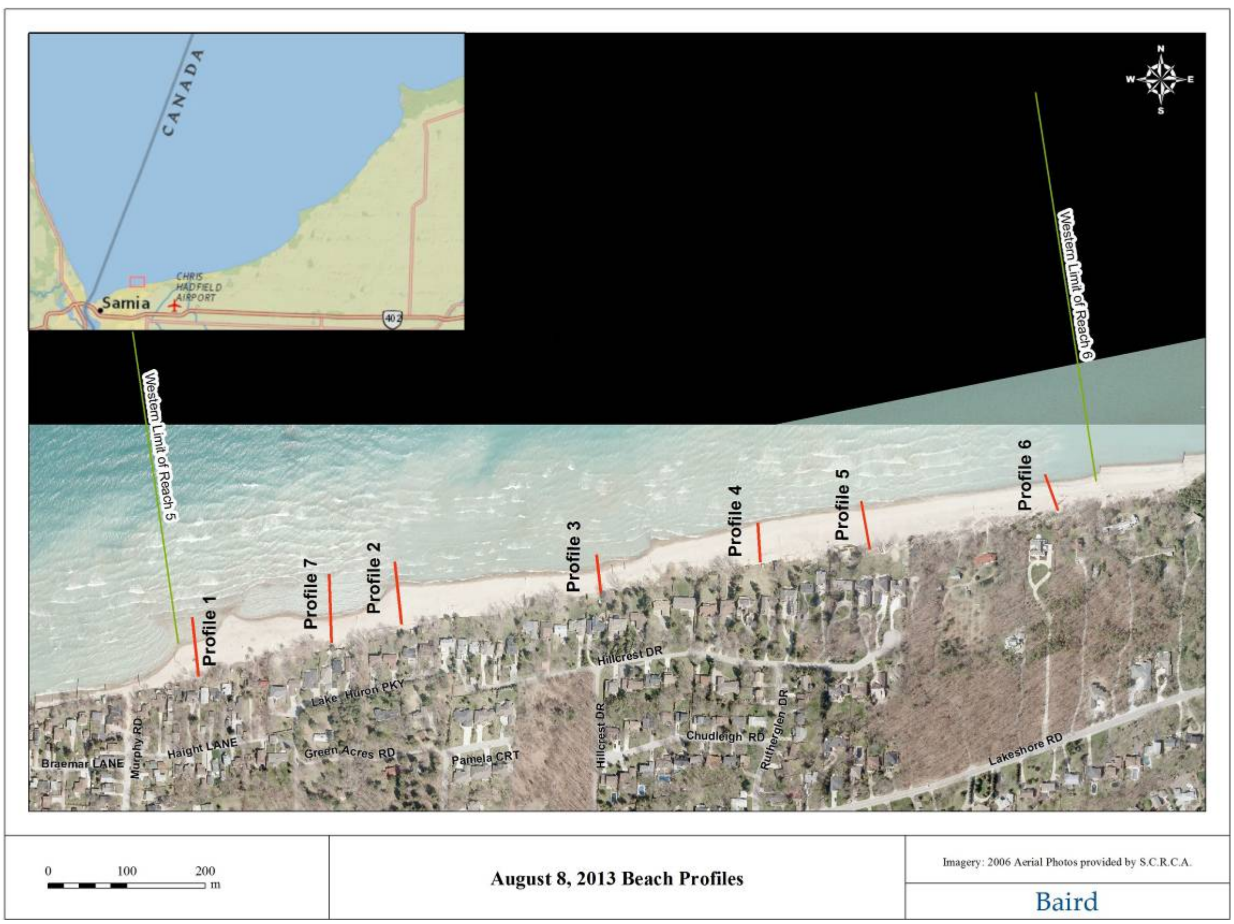

Figure 3.1 Beach Profile Locations

3.2 Sediment

Sediment samples were collected on August 8, 2013 at each of the seven profile locations in the nearshore and at various locations along the profile if the sediment particle size was variable. The sample locations are shown in Figure 3.2. A total of 20 sediment samples were collected and analyzed for particle size distribution (PSD).

The results of the particle size analysis including D_{10}, D_{50}, and D_{90} are shown in Figure 3.2. The grain size ranges from fine sand to coarse gravel. The swash zone tends to be characterized by coarser material ranging from coarse sand to very fine gravel; whereas, the top of beach tends to be finer material ranging from fine sand to very coarse sand. PSD results are provided in Appendix B.

Figure 3.2 Sediment Sample Locations and PSD

3.3 Waves

Offshore wave data from the MNR wave hindcast from 1953 to 1987 for Lake Huron were used in this study. Data were extracted for the hindcast location nearest to the project site; Station H01 (Sarnia). A peak over threshold (POT) analysis was performed on the data to establish extreme events. Table 3.1 lists significant wave heights and corresponding return periods for Station H01 as presented in Philpott (1988).

Table 3.1 Station H01 (Sarnia) Deep Water Significant Wave Heights for Varying Return Period (from Philpott, 1988)

Return Period (Years)	Significant Wave Height (m)
1	5.6
5	6.4
10	6.7
20	7.0
50	7.4
100	7.8

The largest wave event in the MNR hindcast occurred on November 29, 1966. Predicted waves offshore of Sarnia had a significant wave height (H_s) of 5.9 m with peak wave period (T_P) of 11.1 s from 20 degrees (NNE) as shown in Figure 3.3; this corresponds to a return period between 1 and 5 years.

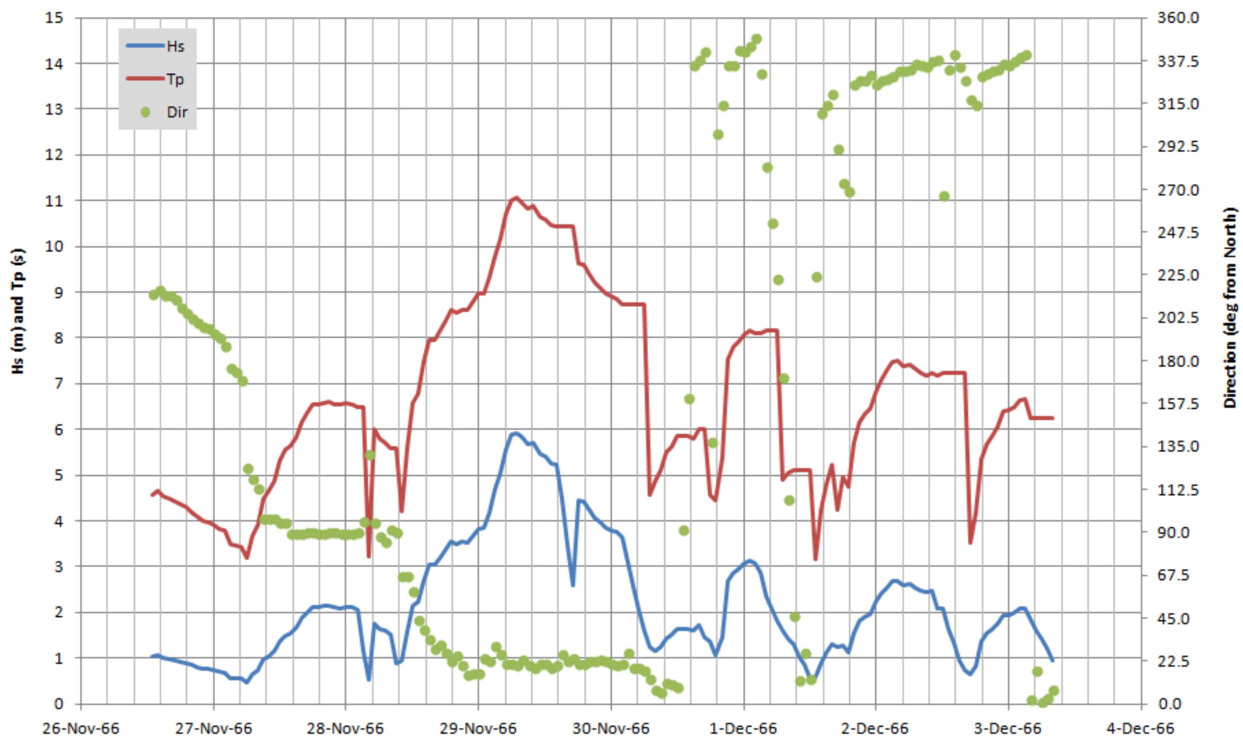

Figure 3.3 Wave Height, Period and Direction during 29 Nov 1966 Storm (from Philpott, 1988)

3.4 Water Levels

Water levels on Lake Huron vary in the long-term and seasonally in response to climatic conditions, and in the short term due to the passage of individual storm events. The typical seasonal variation on Lake Huron is approximately 0.3 m, with the average low monthly mean (176.3 m IGLD 1985) occurring in February and the average high monthly mean (176.6 m IGLD 1985) occurring in July. The fluctuation over any given year will vary due to longer-term variations in precipitation, evaporation, runoff, inflow from Lake Superior and outlet conditions at the St. Clair River.

Short term changes occur in response to storm events (over a period of hours). When winds continue to blow over the lake surface in one direction for a number of hours, an increase in the water level against the downwind shoreline is produced, referred to as "wind setup" or "storm surge". Storm surge is added to the mean lake level to determine the peak instantaneous level (also referred to as still water level). The still water levels used in this study are based on the *Great Lakes System Flood Levels and Water Related Hazards* report (MNR, 1989), extracted at Brights Grove, which is the closest station to the project site. The still water level is the sum of the mean lake level and storm surge with a combined probability. For example a 100-year return period on average, has a one percent probability of occurring in any given-year. Table 3.2 lists flood levels and corresponding return periods for the study area.

Table 3.2 Brights Grove Peak Instantaneous Water Levels for Varying Return Periods (from Table A.2, MNR,1989)

Return Period (Years)	Water Level (m IGLD'85)
2	177.2
5	177.5
10	177.7
25	177.8
50	177.9
100	178.0
200	178.1

The flood levels determined by MNR (1989) were calculated using water levels for the period 1900 to 1987 adjusted to "Basis of Comparison" (BOC) conditions. BOC conditions include the effects of past regulation of Lake Superior outflows, which have some impact on the level of Lake Huron.

For the purposes of the study, it was assumed that the statistical evaluation of historic water level records provides a suitable basis for establishing the dynamic beach limit in accordance with the *Provincial Policy Statement*. However, it should be noted that other factors might influence future water levels such as: tectonic uplift, climate change, and erosion of the St. Clair river bed.

3.5 Shoreline Recession

No evidence of significant shoreline recession was identified from available studies including the shoreline comparison undertaken by SCRCA for the *Lake Huron Shoreline Management Plan Update – 2011*. As there is no distinct top of bluff, it is difficult to assess shoreline erosion from historical air photo comparison, the method used to evaluate shoreline recession for other shoreline reaches.

4.0 BEACH PROFILE MODELLING

4.1 COSMOS Model

The COSMOS model was used to estimate the beach profile response to storm conditions. COSMOS is a two-dimensional (2D) profile model that consists of several predictive routines that describe the following parameters across a shore-perpendicular profile:

- Random wave transformation (including refraction, bottom friction, shoaling, breaking, wave decay, runup, and overwash);
- Steady currents (including undertow, and wave and tide-induced cross-shore and longshore currents);
- Orbital velocities (linear and non-linear);
- Suspended sediment distribution through the vertical;
- Bed and suspended load sediment transport in cross-shore and longshore directions; and
- 2D profile response due to gradients in cross-shore sand transport.

The model has been applied in over 100 engineering projects throughout the world. For a detailed description of the model, refer to Nairn and Southgate (1993) and Southgate and Nairn (1993). The COSMOS model is based on accepted scientific and engineering principles.

4.2 Model Input

Three key inputs to the COSMOS model are required. The first is a two-dimensional bathymetric and topographic profile. This profile extends from the top of the bank to an offshore boundary where the waves are not influenced by the bathymetry (i.e. have not shoaled or refracted). A minimum water depth of 8 m was selected for the offshore boundary; however, the boundary water depth is greater for some profiles.

The second input is a time series of water levels and wave conditions. Hourly wave conditions from the hindcast (described in Section 3.3) were used as the deep water input waves for COSMOS. Generally the extreme events evaluated are larger than any event on record. Therefore, a typical storm profile was developed based on the November 29, 1966 event (refer to Figure 3.3) and the wave height was scaled to the required wave height. It is noted that generally the magnitude of the storm is related to the storm duration; however this analysis was outside of the current scope of work and thus the duration of the storm event was not scaled. A static water level corresponding to the required return period from Table 3.2 was used as input to COSMOS.

The third key input parameter to the COSMOS model is the grain size. At the project site, the grain size typically varies along the profile as discussed in Section 3.2 and shown in Figure 3.2. The grain size used in COSMOS should be representative of the sand being transported. Based on the sediment samples, a grain size of 0.4 mm was selected for the COSMOS model profile. Sensitivity testing was also done, using different grain sizes, both larger (0.72 mm) and smaller (0.32 mm) than 0.4 mm to assess the effect of grain size on beach profile response.

4.3 Model Runs

The COSMOS model was used to evaluate the beach response at each of the profile locations shown in Figure 3.1. Insufficient data including, pre and post storm profiles were available to calibrate the model. Sensitivity testing was therefore used to evaluate the range in beach profile change for varying waves, water levels and grain sizes.

Profile 1 (located at the west end of the site) was used for the sensitivity testing. This profile was selected because it is typical of the study area, with a wide gentle sloping beach. A baseline model run was selected for the sensitivity testing, using the 100-year water level with the waves from the 29 November 1966 storm (between 1 year and 5 year return period event).

The sensitivity of the beach profile response to grain size was evaluated by running the COSMOS model for grain sizes larger and smaller than the base case (0.40 mm) as discussed in Section 4.2. Figure 4.1 shows the predicted beach profile response at Profile 1, for the various grain sizes modelled. Erosion measured at the location where the profile intersects the 100 year water level varied from 11.7 m for 0.32 mm grain size to 7.7 m for 0.72 mm grain size.

Sensitivity to wave height and water level was also evaluated. The *Technical Guide* (MNR 2001) suggests a 10-year to 20-year wave height be used along with the 100-year flood level to assess the dynamic beach hazard. A joint probability analysis (JPA) would be required to determine the probability of these two variables occurring at the same time, and thereby define events with a similar joint probability for the sensitivity analysis. This is outside of the current scope of work; however, four different model scenarios were run with varying water levels and wave heights as outlined in Table 4.1.

Table 4.1 COSMOS Runs to Evaluate Sensitivity to Water Level and Wave Conditions

COSMOS Simulation	Water Level Return Period	Water Level (m IGLD'85)	Wave Height Return Period	Wave Height (m)
1	100-year	178.0	>1-year & < 5-year	5.9
2	10-year	177.7	20-year	7.0
3	25-year	177.8	10-year	6.7
4	100-year	178.0	20-year	7.0

Figure 4.2 shows the predicted beach profile response at Profile 1, for the wave and water level conditions listed in Table 4.1. The COSMOS model predicted that the pre-storm water's edge

would erode 11.7 m horizontally at Profile 1, for the 100-year water level with the 20-year wave. It can be seen that the profile response is relatively sensitive to water level. Erosion was significantly reduced for the 10 year water level with the 20 year wave (the profile eroded 6.5 m measured horizontally from the 100-year water level intersection with the existing profile). The profile response is less sensitive to wave height as can be seen by comparing the erosion for the 100 year water level and 20 year wave, with the 100 year water level and 1 to 5 year wave.

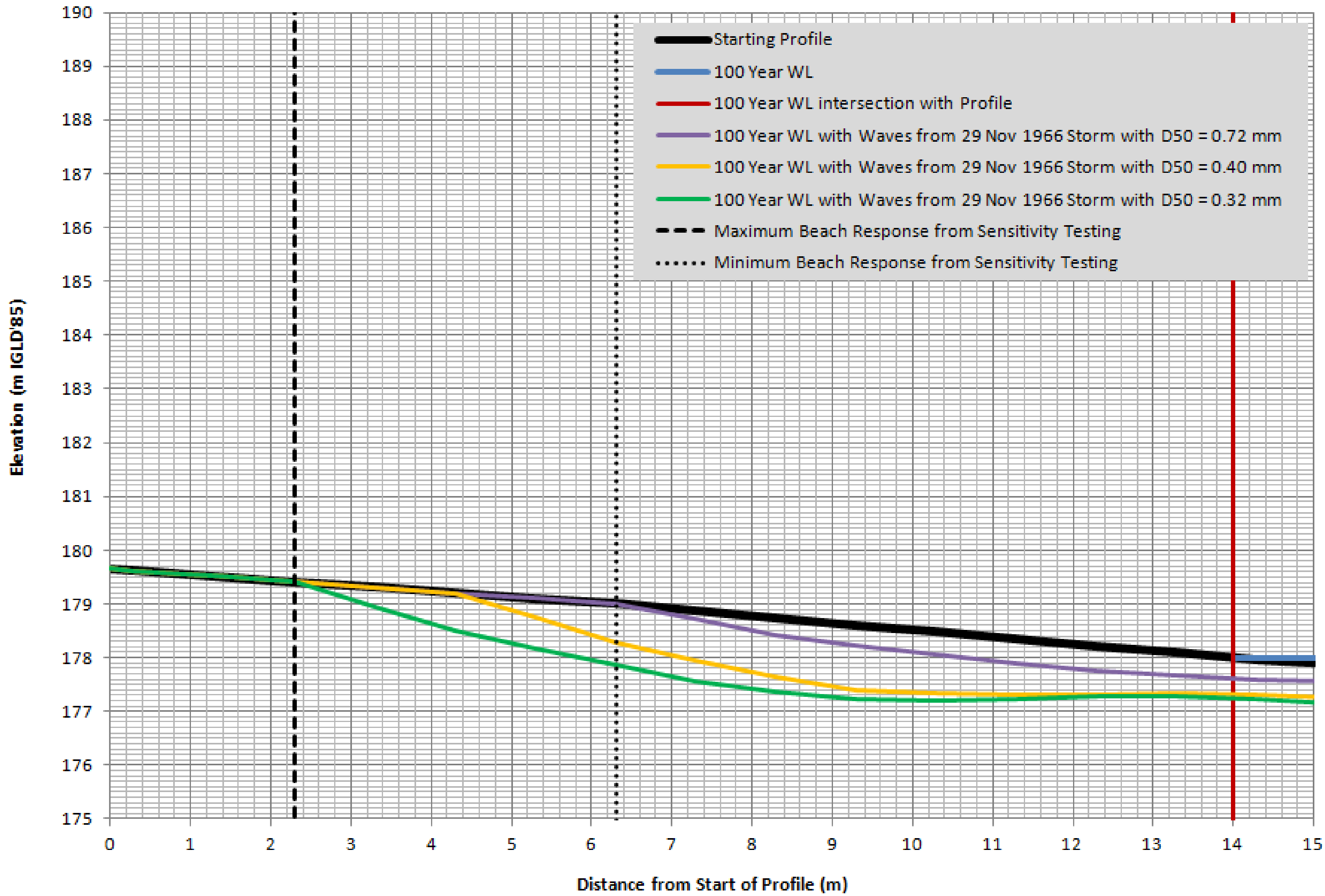

Figure 4.1 Profile 1 COSMOS Sensitivity Testing to Grain Size

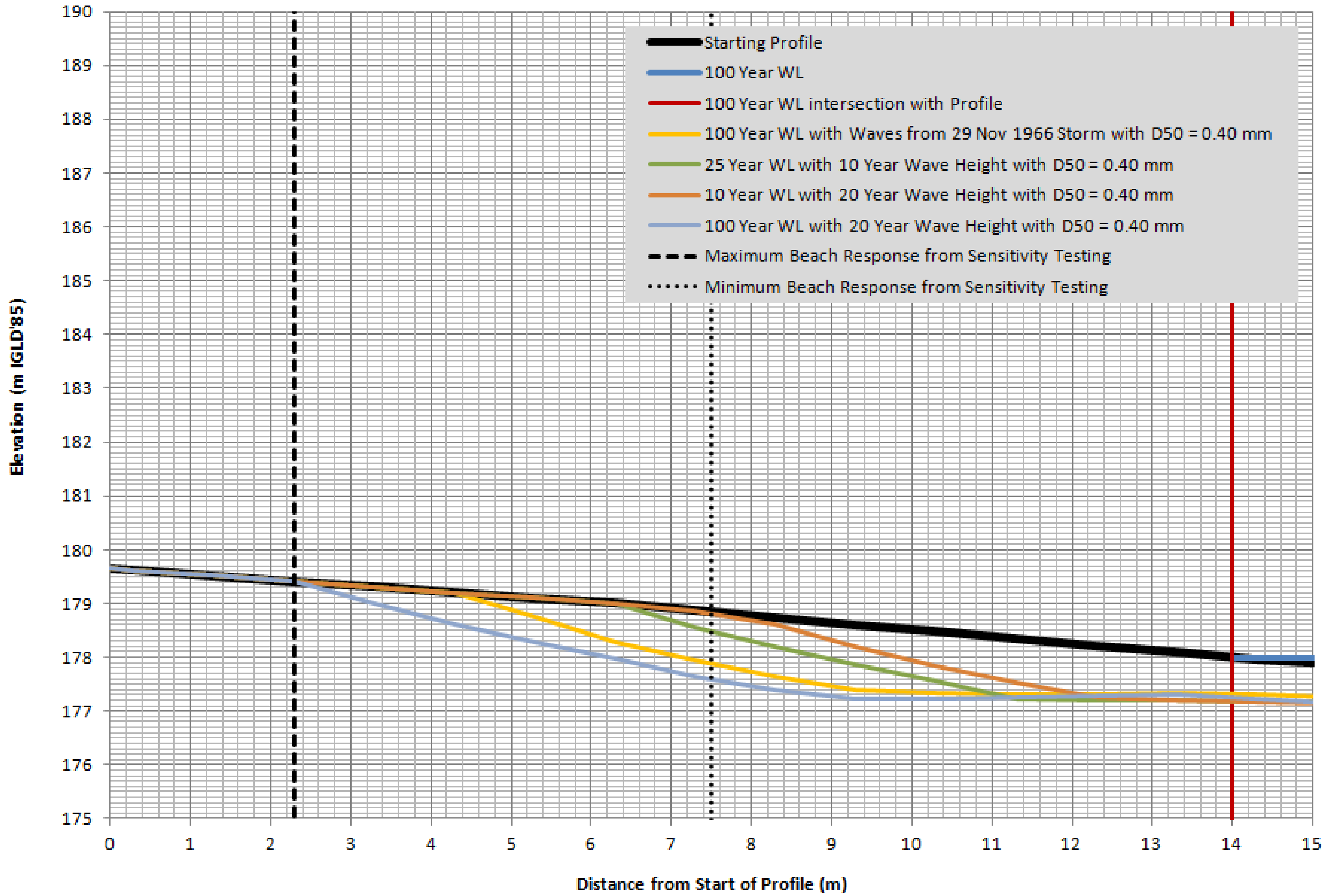

Figure 4.2 Profile 1 COSMOS Sensitivity Testing to Water Level and Wave Height

4.4 Model Results

The *Technical Guide* (MNR 2001) suggests using a 10-year to 20-year wave height with the 100-year flood level to assess the dynamic beach hazard. The COSMOS model was run for each of the seven profiles, with the 20-year wave height and 100-year water level. A grain size of 0.4 mm was used.

The predicted beach profile erosion is shown for the seven profiles in Figure 4.3. The predicted erosion measured horizontally from the pre-storm water's edge (178.0 m IGLD 1985) was a maximum of 14 m with a standard deviation of 3 m. It is recommended that a beach profile erosion allowance of 17 m is used. This corresponds to the maximum erosion plus one standard deviation and allows for variability in profile response, changes in the profile over time and variability in grain size.

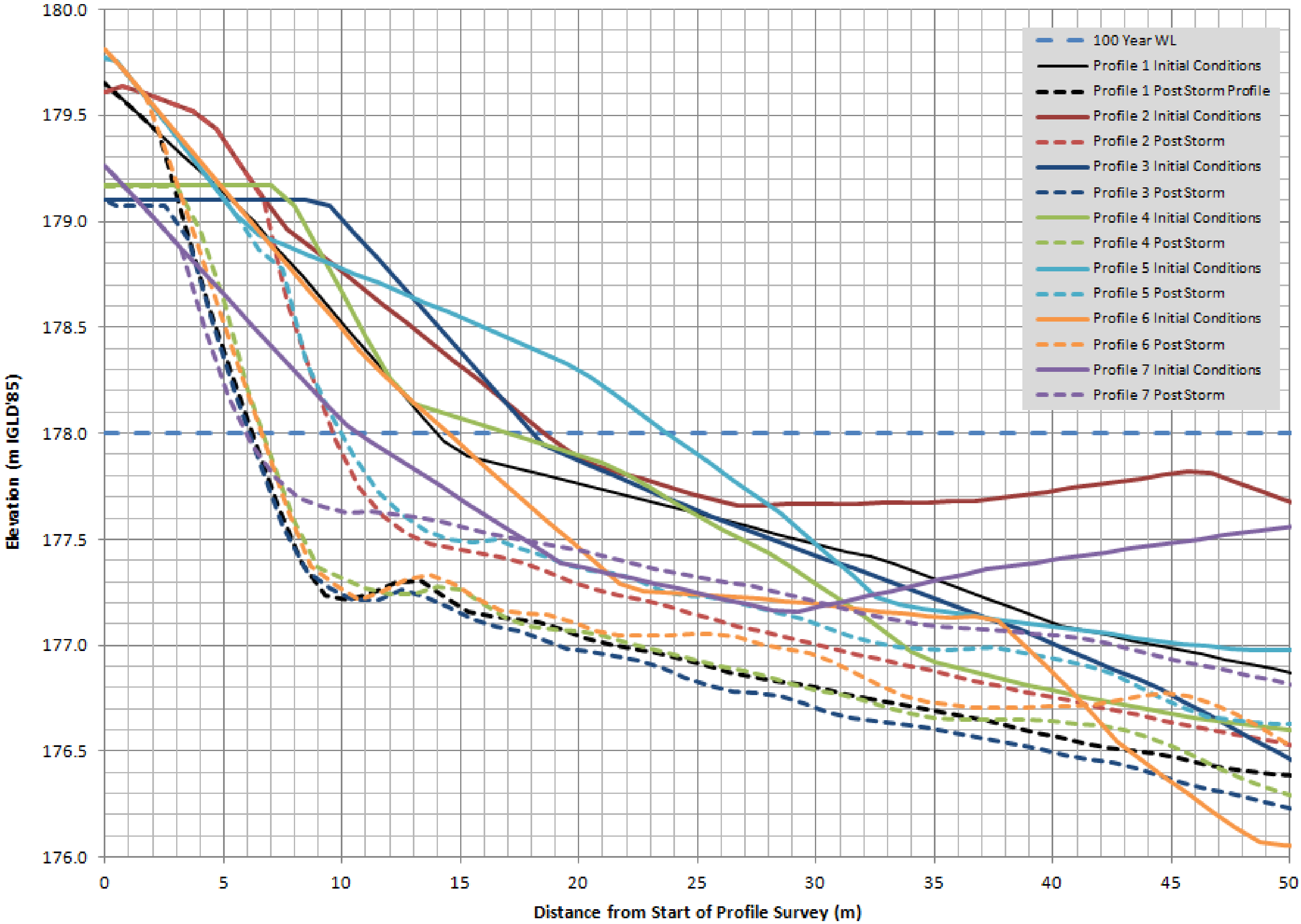

Figure 4.3 Comparison of COSMOS Results for Profiles
(Note: Vertical Scale Exaggerated)

5.0 WAVE UPRUSH

Wave uprush (i.e, runup) is the vertical distance that waves will runup a shoreline above the still water level (SWL). In addition to the profile erosion presented in Section 4.4, an allowance for wave uprush must be included in the dynamic beach hazard as discussed in Section 2.

The *Technical Guide* (MNR, 2001) and EurOtop (2007) suggest R2% as a value that indicates the limit of wave uprush. R2% is the runup value exceeded by 2% of the runup values during a particular storm. In addition, the EurOtop report (2007) also recommends the addition of one standard deviation to the predicted uprush for deterministic design and safety assessments. This approach ensures the wave uprush prediction incorporates a factor of safety to account for the scatter in the test results on which the equations are based.

The formulation from Mase (1989) was selected to be the most appropriate for the present application as it was developed for natural beaches with gentle slopes ranging from about 2° to 11°. The nearshore slope of the existing profiles surveyed in August 2013 ranged from 6° to 11°. Wave uprush is measured vertically from the SWL, in this case the 100-year flood level (178.0 m IGLD 1985). The "R2%" runup estimates, based on Mase (1989) ranged from 1.2 m to 2.6 m with an average of 1.9 m above the SWL. In relation to the eroded profiles, the uprush extended approximately to 14 m horizontally inland from the position where the 178.0 m IGLD 1985 water level intersected the eroded profile with a standard deviation of 3 m. It is recommended that a wave uprush allowance of 17 m measured horizontally from where the 178.0 m IGLD 1985 water level intersected the eroded profile is used. This corresponds to the maximum wave uprush plus one standard deviation.

6.0 DYNAMIC BEACH HAZARD LIMIT

The combined effect of beach profile erosion (see Section 4.0) and wave uprush (see Section 5.0) during a storm with a 20-year return period wave condition at the 100-year flood level (178 m IGLD’85) is 34 m. The 34 m allowance is measured horizontally from the pre-storm position of the elevation contour equivalent to the 100 year flood level (178.0 m IGLD 1985) and represents the minimum limit of the dynamic beach hazard.

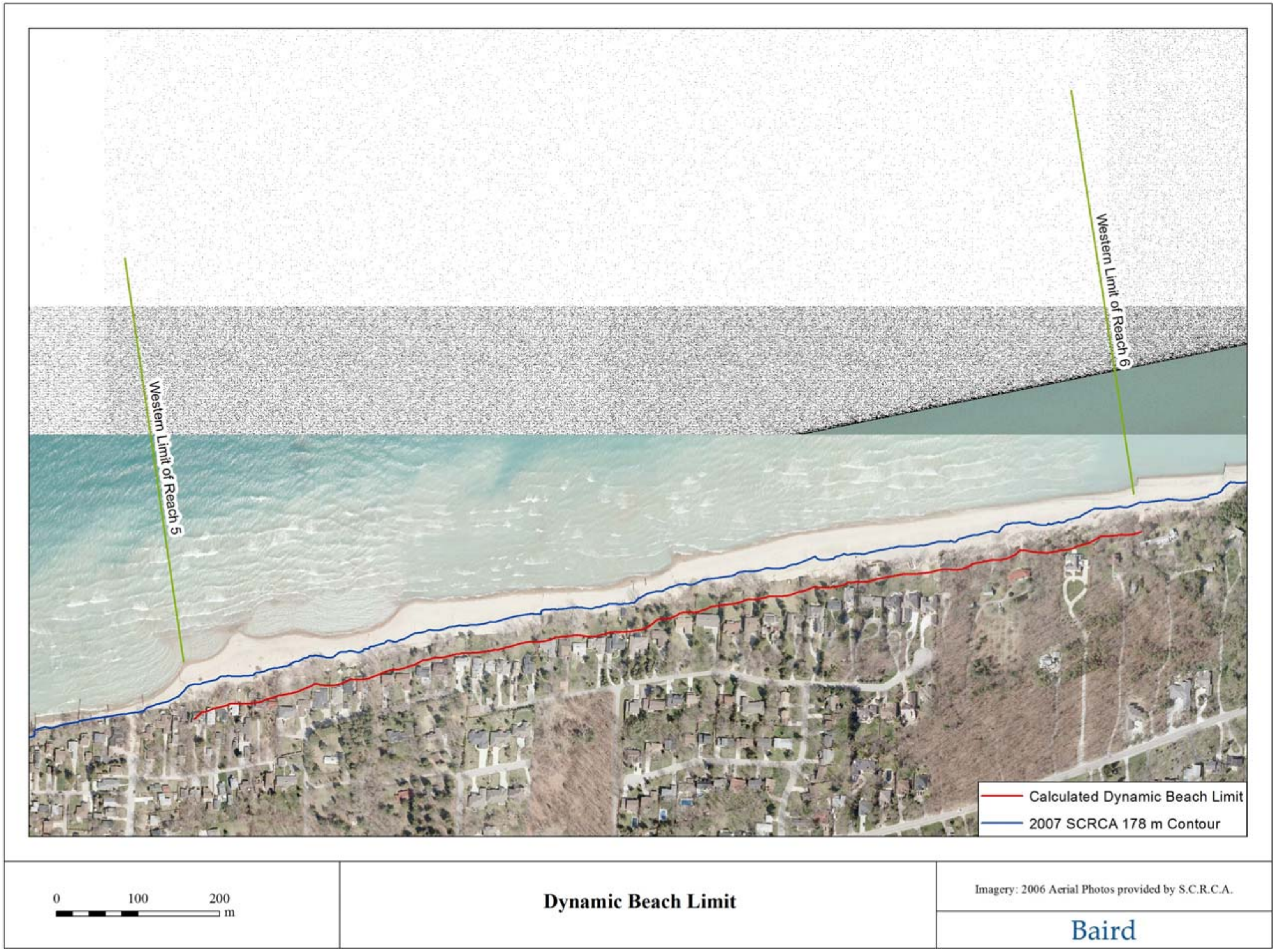

Figure 6.1 Recommended Minimum Dynamic Beach Hazard Limit

7.0 CONCLUSIONS AND RECOMMENDATIONS

The *SCRCA Lake Huron Shoreline Management Plan Update – 2011* includes mapping for the erosion, flood and dynamic beach hazards. Reach 5 is classified as a dynamic beach. In the Shoreline Management Plan, the dynamic beach hazard limit was delineated in accordance with the Technical Guide (MNR 2001), which includes a flooding allowance of 15 m measured horizontally from the 100-year flood level plus a dynamic beach allowance of 30 m.

This study provides a site specific assessment of the dynamic beach hazard in Reach 5. The methodologies used in this study, to estimate the dynamic beach hazard limit are based on accepted engineering and scientific principles and are consistent with the requirements of the Provincial Policy Statement (2005) and the Technical Guideline (MNR, 2001).

7.1 Dynamic Beach Hazard Recommendations

1. The limit of the dynamic beach hazard allowance can reasonably be established as a minimum 34 m from the 100 year flood level for Reach 5, based on the shoreline characteristics of the study area and the shoreline profile modeling. The 34 m allowance is measured horizontally from the pre-storm position of the elevation contour equivalent to the 100 year flood level (178.0 m IGLD 1985) and represents the combined effect of storm erosion of the beach profile and wave uprush.

2. It should be noted that the 34 m dynamic beach hazard allowance is the minimum allowance in accordance with the provisions of the *Provincial Policy Statement* and supporting *Technical Guide.* The dynamic beach hazard is determined at the 100 year flood level and with an offshore wave condition with approximately a 20 year return period. There is a risk that water levels could be higher and that wave conditions could be more severe and that the dynamic beach hazard could extend further than 34 m inland over a period of 100 years. Shore owners must recognize that there are inherent risks associated with flooding, erosion and dynamic beach hazards along the shorelines of the Great Lakes and that these hazards cannot be entirely eliminated.

7.2 General Recommendations

1. While the shoreline contains specialized vegetation and habitat, these natural features are not specifically addressed in this report. Important natural heritage elements should not be disregarded when new development is proposed. Within the dynamic beach hazard limit, retain the natural heritage features (e.g. existing vegetation), regenerate additional native vegetation and encourage additional dune development.

2. Maintain the natural dune height where it is undisturbed. Where the natural dune height has been lowered, restore the dune height with native or comparable sand and provide

controlled access to the beach (e.g. dune walkovers) to minimize disturbances to the dune profile and vegetation. Where possible, it is recommended that the slope of the lakeward side of the dune should be 1:5 (vertical: horizontal) or flatter.

8.0 REFERENCES

Baird & Associates, 2011. Lake Huron Shoreline Management Plan Update – 2011. Report prepared for the St. Clair Region Conservation Authority dated 5 December 2011.

Baird, 2005. Regime Change (Man Made Intervention) and Ongoing Erosion in the St. Clair River and Impacts on Lake Michigan-Huron Lake Level. Report prepared by W.F. Baird and Associates Coastal Engineers Ltd. for the Georgian Bay Association.

Environment Canada and Ministry of Natural Resources, 1976. Canada – Ontario, Great Lakes Shore Damage Survey.

EurOtop, 2007. Wave Overtopping of Sea Defences and Related Structures: Assessment Manual. Prepared by the Environment Agency, UK, Expertise Netwerk Waterkeren, NL, and Kuratorium fur Forschung im Kusteningenieurwesen, DE.

Mase, H. (1989) "Random Wave Runup Height on Gentle Slopes," Journal of Waterway, Port, Coastal, and Ocean Engineering, Vol. 115, No. 5, pp. 649-661.

Ministry of Municipal Affairs and Housing, 2005. Provincial Policy Statement dated Mar. 1, 2005 under Section 3 of the Planning Act.

Ministry of Natural Resources, 2001. Technical Guide for Great Lakes – St. Lawrence River Shorelines, Flooding, Erosion and Dynamic Beaches.

Ministry of Natural Resources, 1997. Natural Hazards Training Manual. Provincial Policy Statement, Public Health and Safety Policies 3.1.

Ministry of Natural Resources, 1989. Great Lakes System Flood Levels and Water Related Hazards.

Nairn, R.B., 1992. Study of toe scour and downcutting of cohesive shores protected with revetment. Final report prepared for Metro Toronto and Region Conservation Authority, January.

Nairn, R.B. and Southgate, H.N., 1993. Deterministic Profile Modelling of Nearshore Processes. Part 2. Sediment Transport and Beach Profile Development. Coastal Engineering, Elsevier. Vol. 19. p.57-96.

Philpott, 1988. Lake Huron Wave Database, report prepared for Ministry of Natural Resources.

PIANC. 2003. *Breakwaters with Vertical and Inclined Concrete Walls.* Report of Working Group 28 of the Maritime Navigation Commission.

Reinders, 1989. Lake Huron Shoreline Processes Study. A report prepared for Ausable Bayfield, Maitland Valley, St. Clair Region and Saugeen Valley Conservations Authorities.

Tushingham, A.M., 1992. Postglacial uplift predictions and historical water levels in the Great Lakes. Journal of Great Lakes Research, 18, 440-455.

Zuzek, P.J., Nairn, R.B., and Thieme, S.J., 2003. Spatial and Temporal Considerations for Calculating Shoreline Change Rates in the Great Lakes Basin. Journal of Coastal Research, Special Edition 38, p.125-146.

APPENDIX A

Surveyed Profiles

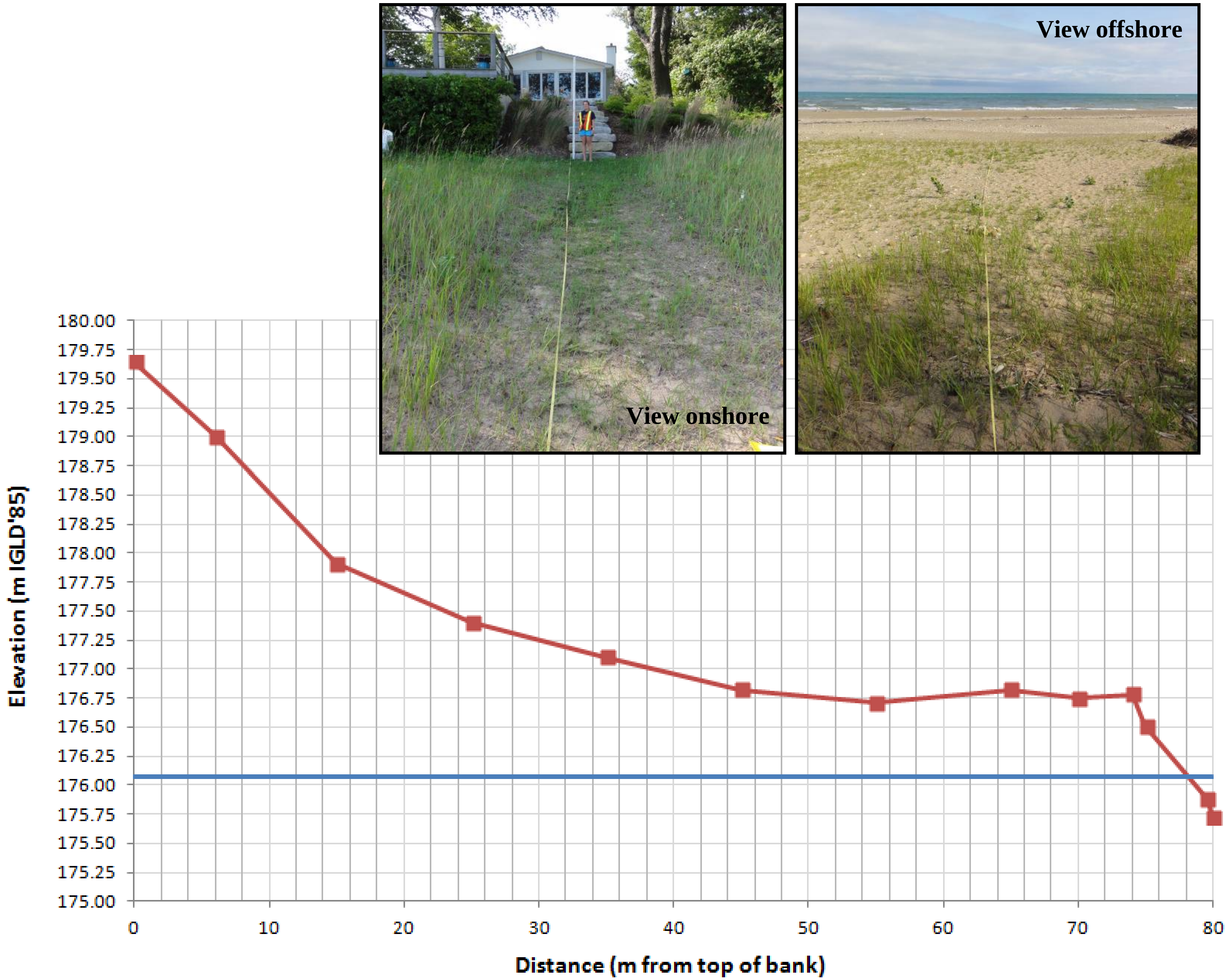

Figure A.1 Profile 1
(Note: Vertical Scale Exaggerated)

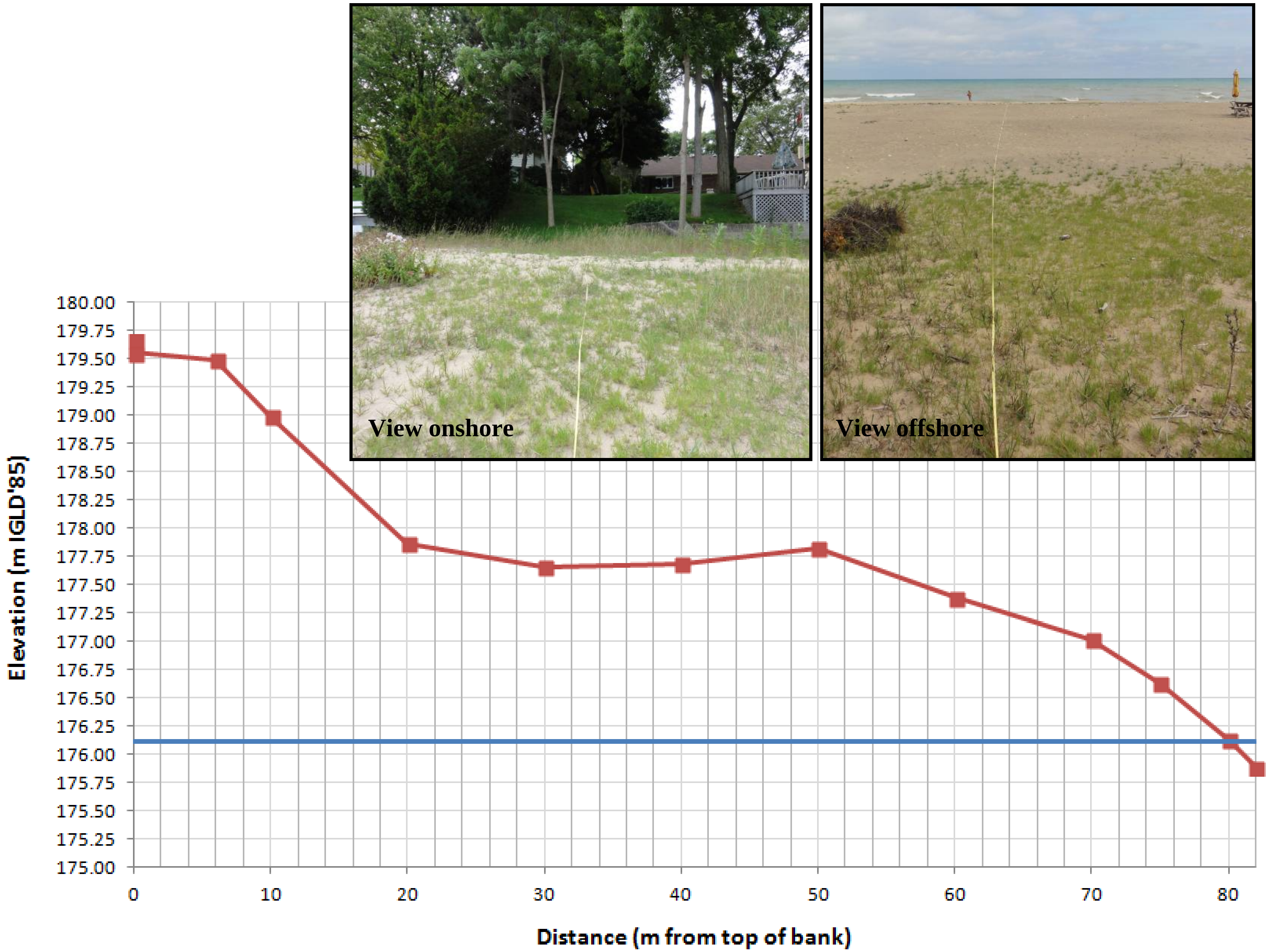

Figure A.2 Profile 2
(Note: Vertical Scale Exaggerated)

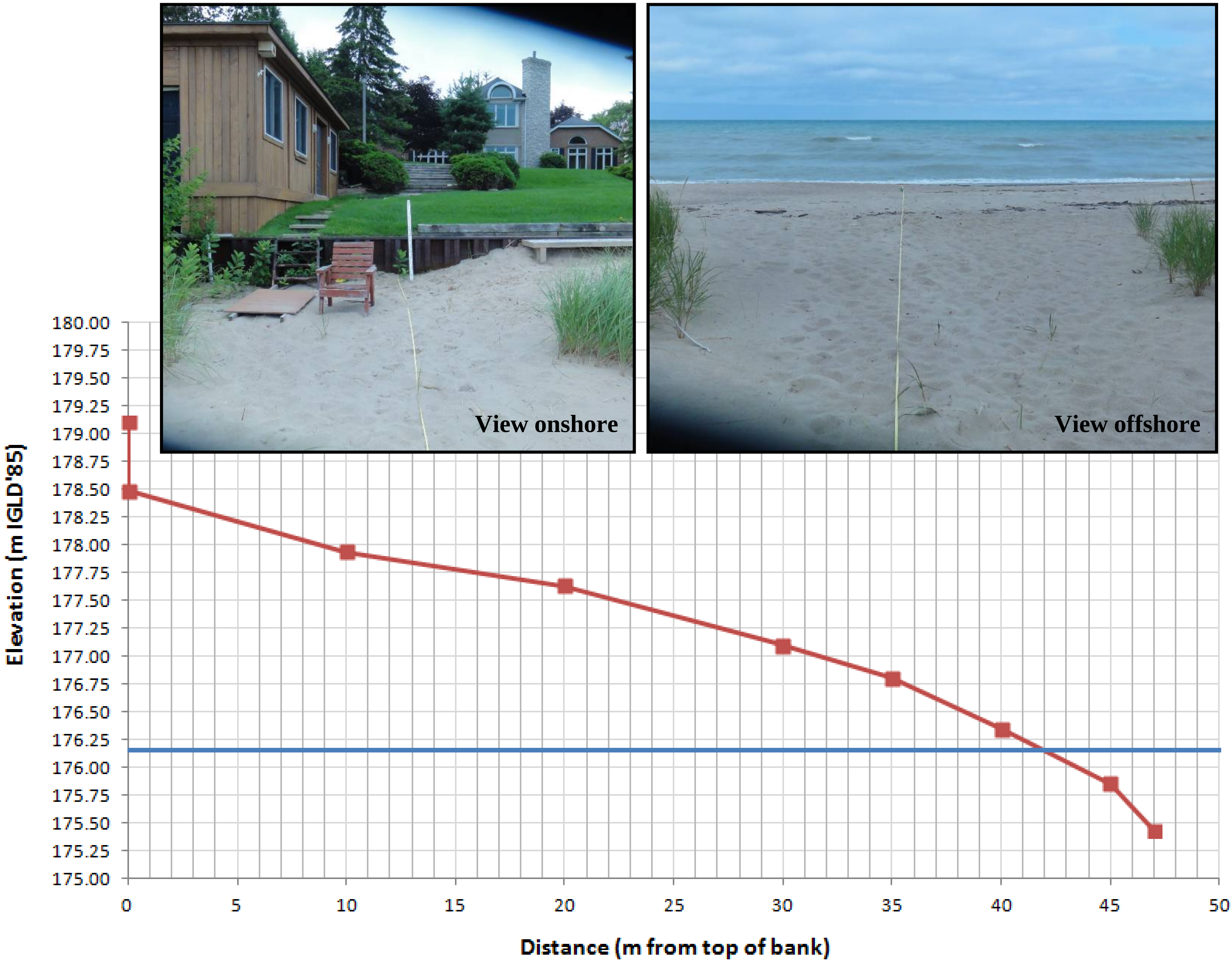

Figure A.3 Profile 3
(Note: Vertical Scale Exaggerated)

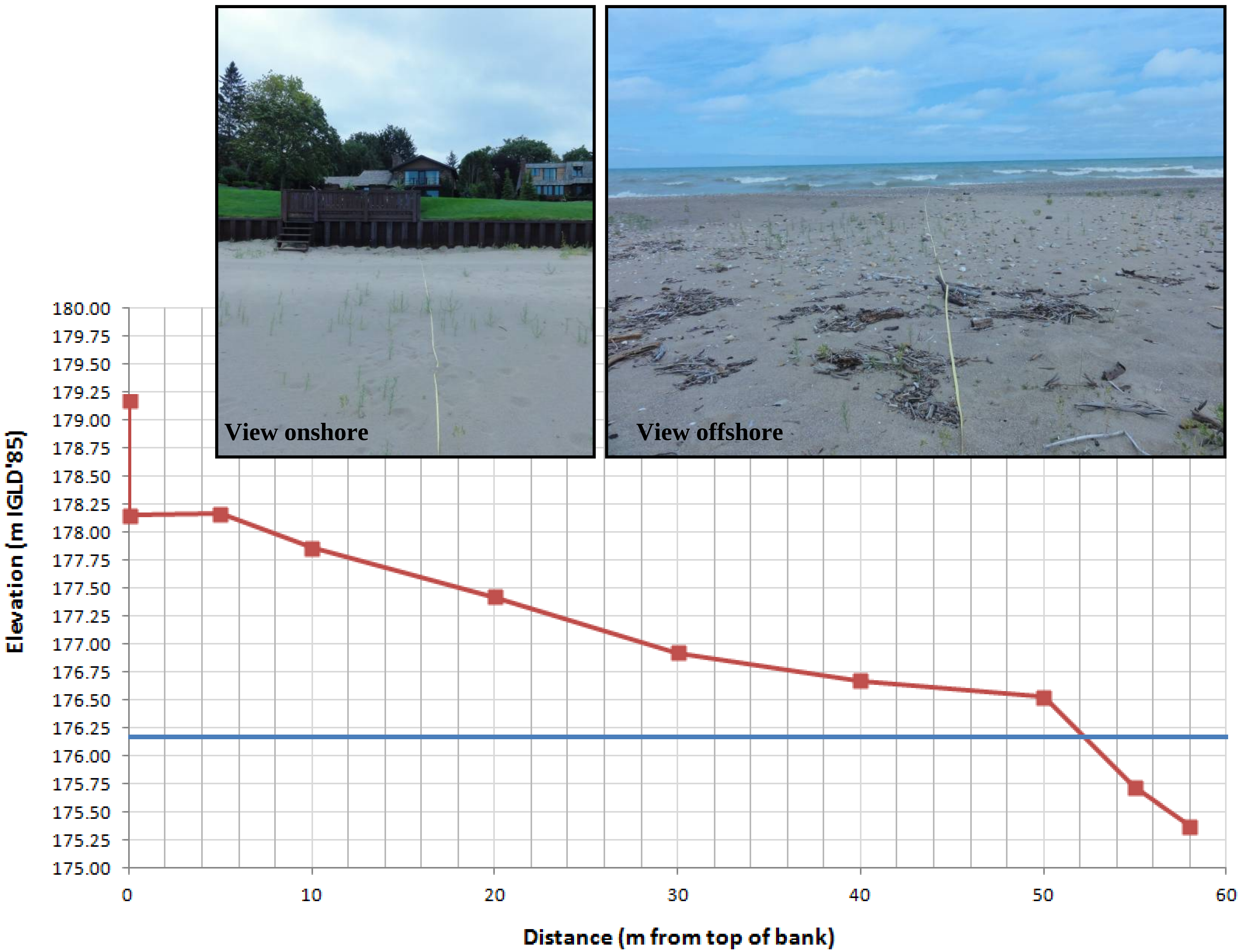

Figure A.4 Profile 4
(Note: Vertical Scale Exaggerated)

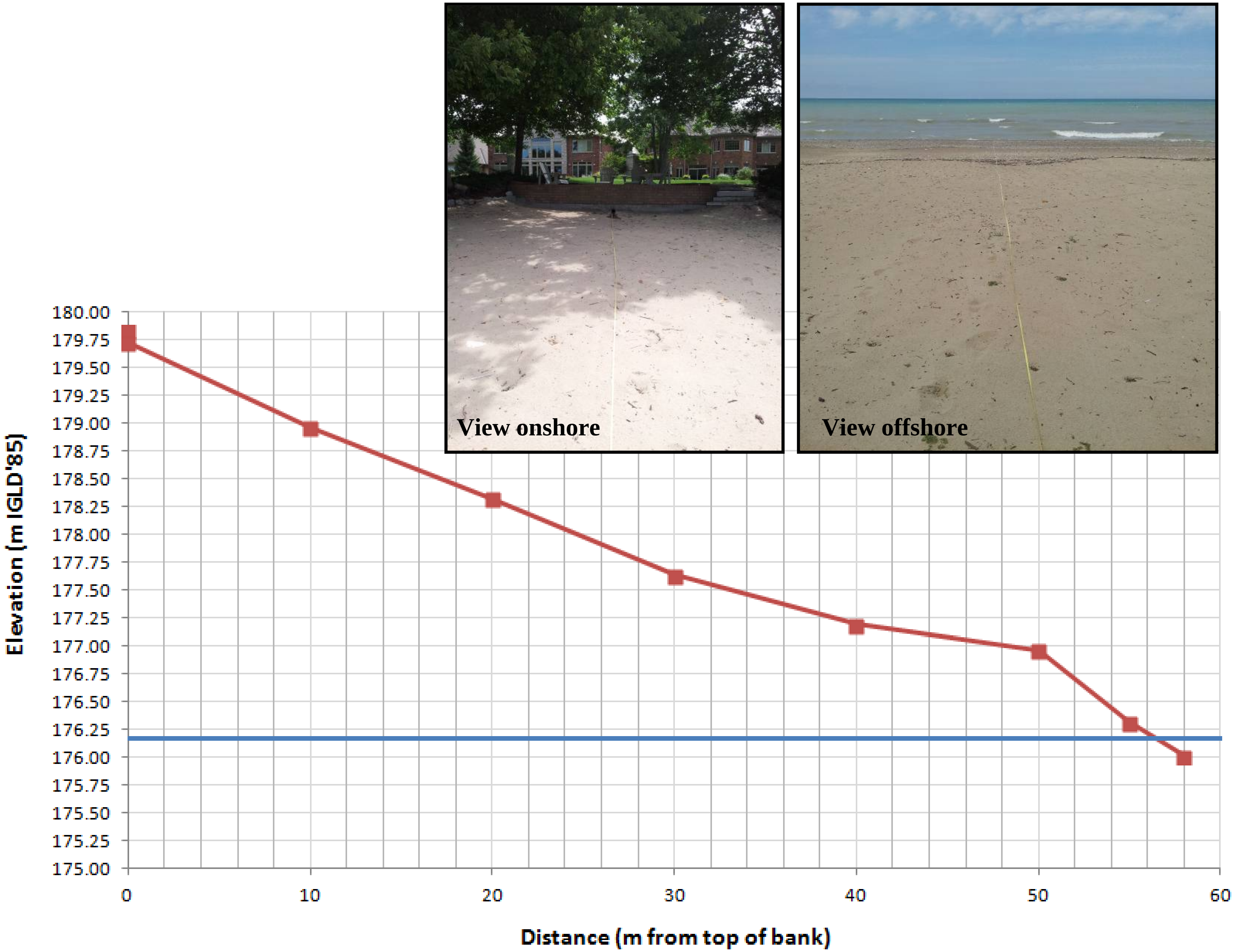

Figure A.5 Profile 5
(Note: Vertical Scale Exaggerated)

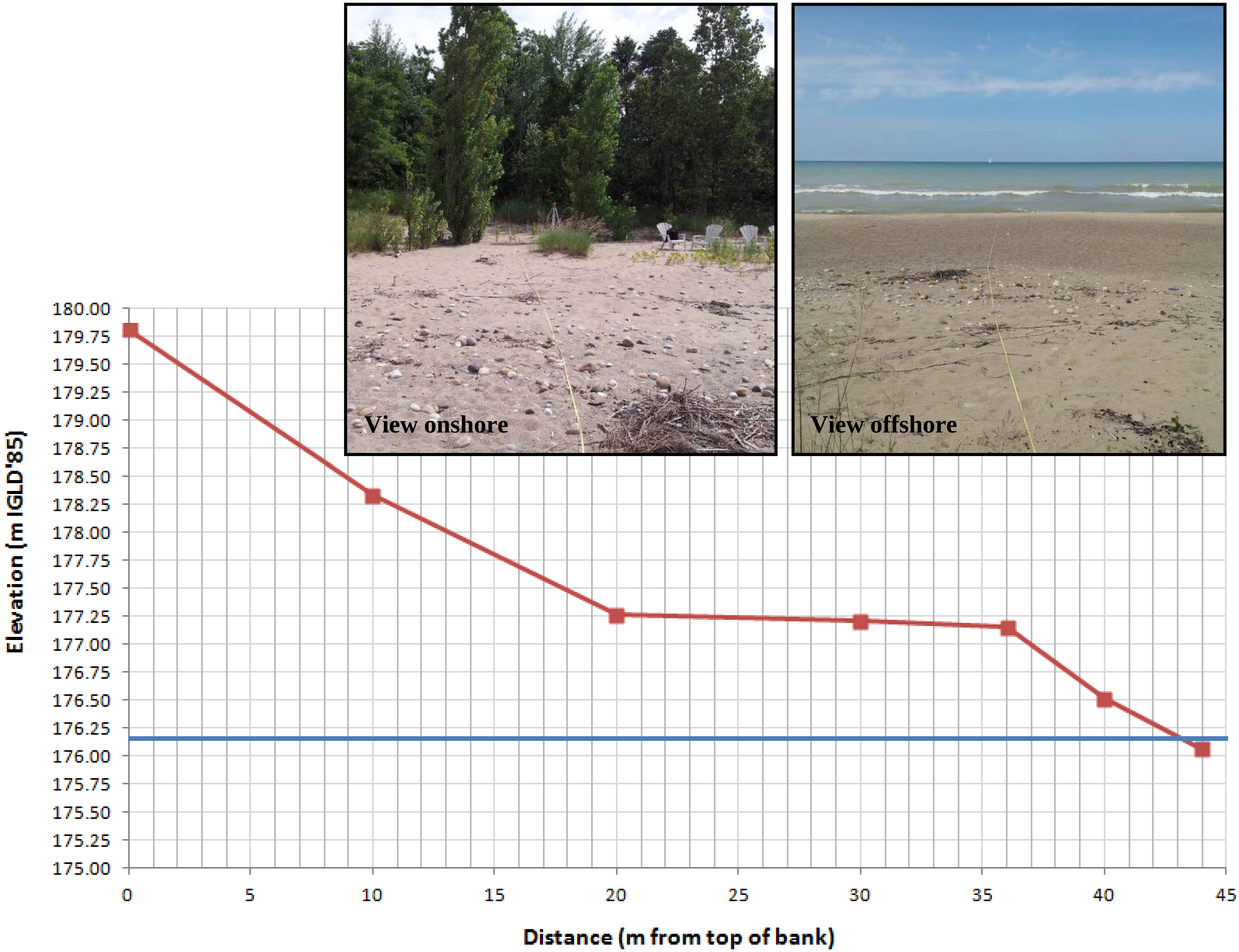

Figure A.6 Profile 6
(Note: Vertical Scale Exaggerated)

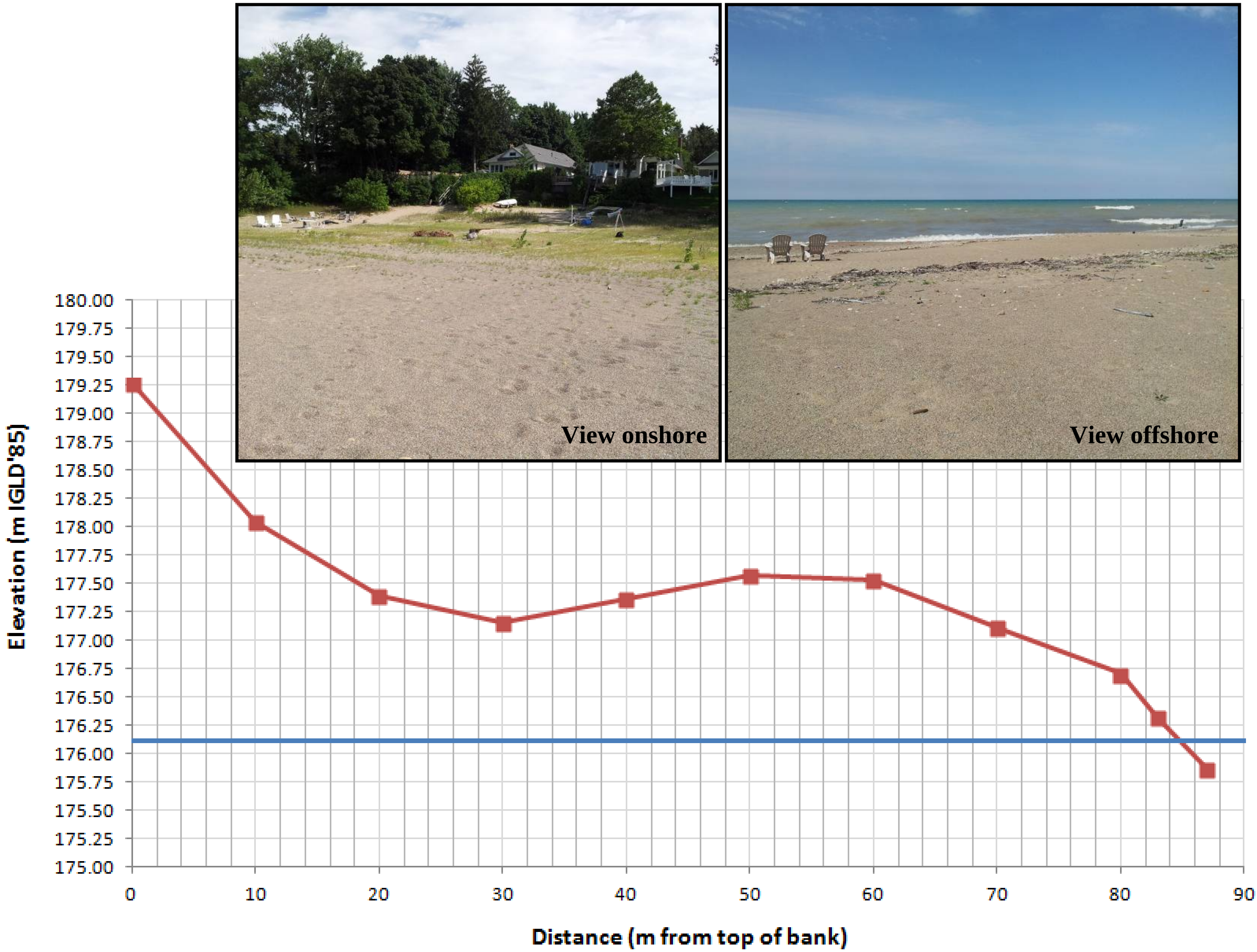

Figure A.7 Profile 7
(Note: Vertical Scale Exaggerated)

APPENDIX B

Particle Size Distribution

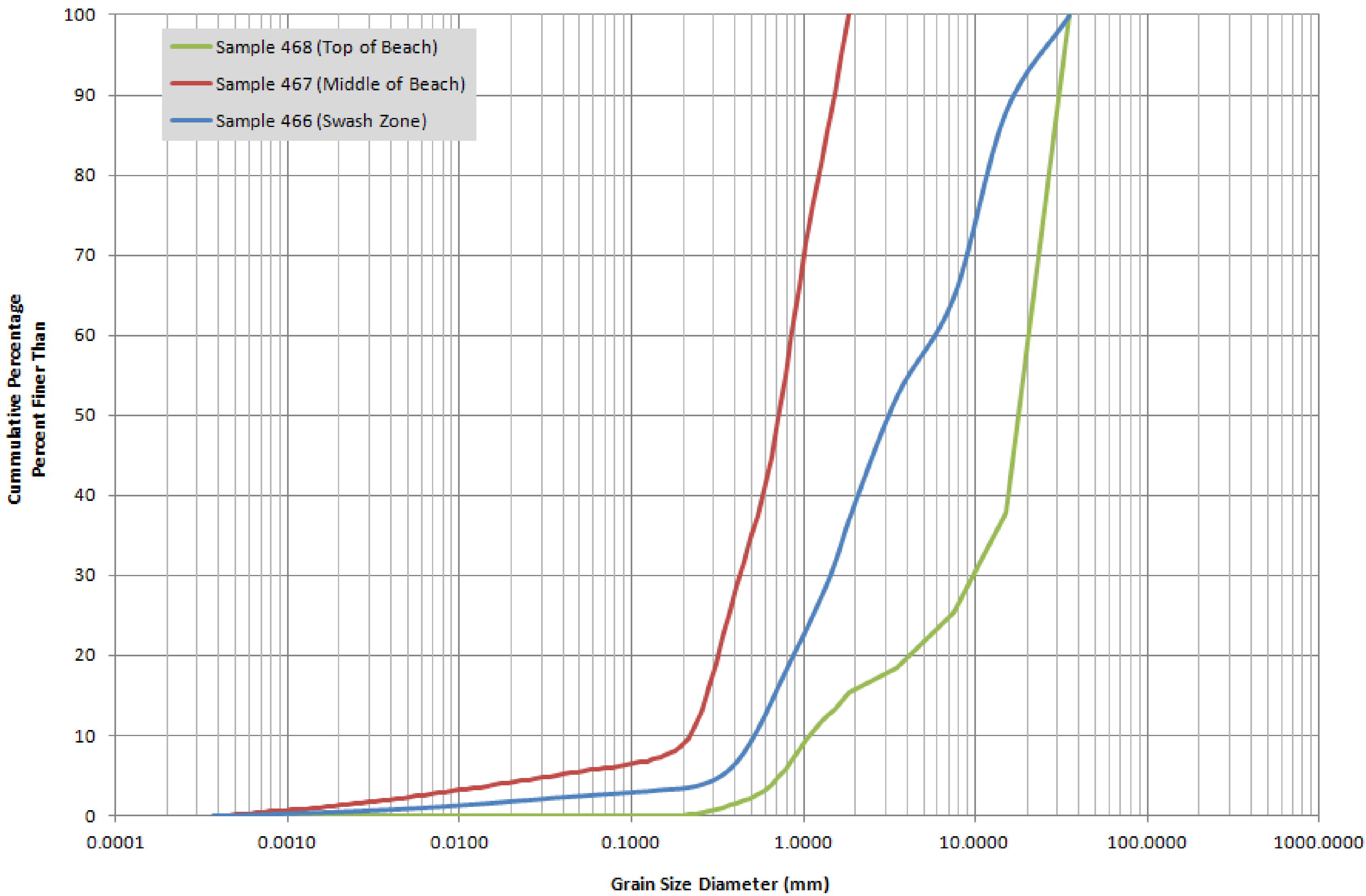

Figure 8.8 Profile 1 Particle Size Distribution

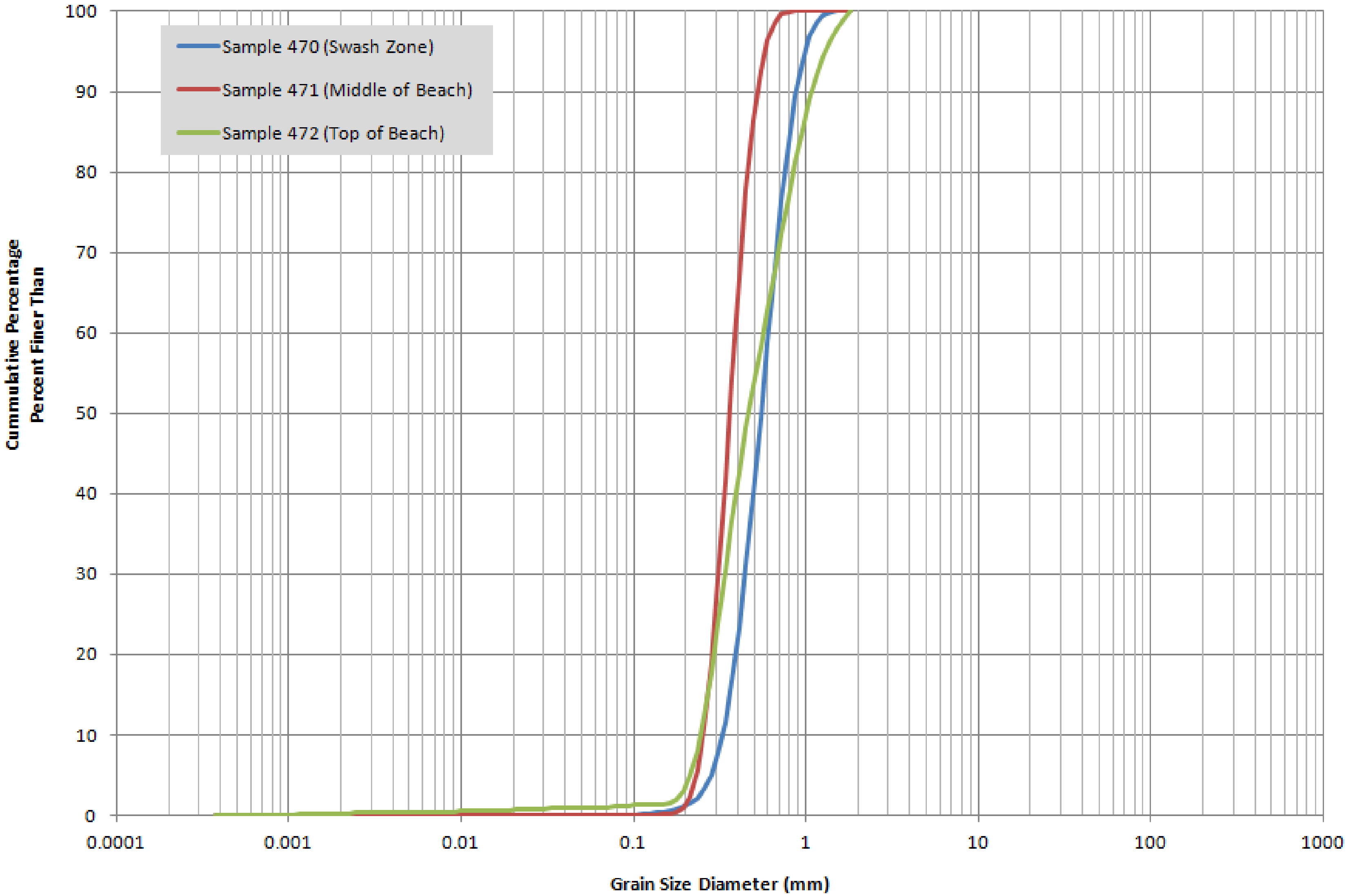

Figure 8.9 Profile 2 Particle Size Distribution

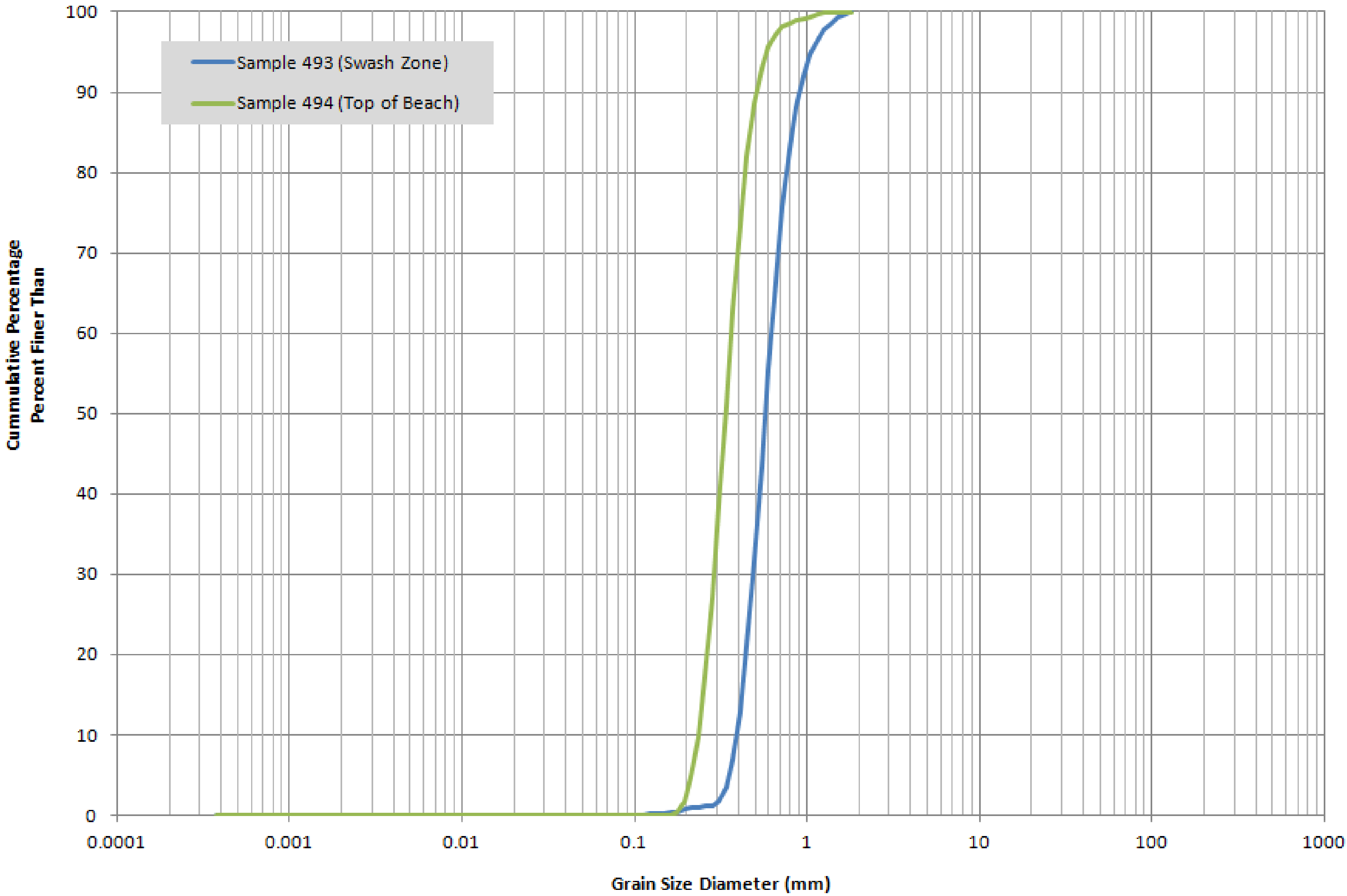

Figure 8.10 Profile 3 Particle Size Distribution

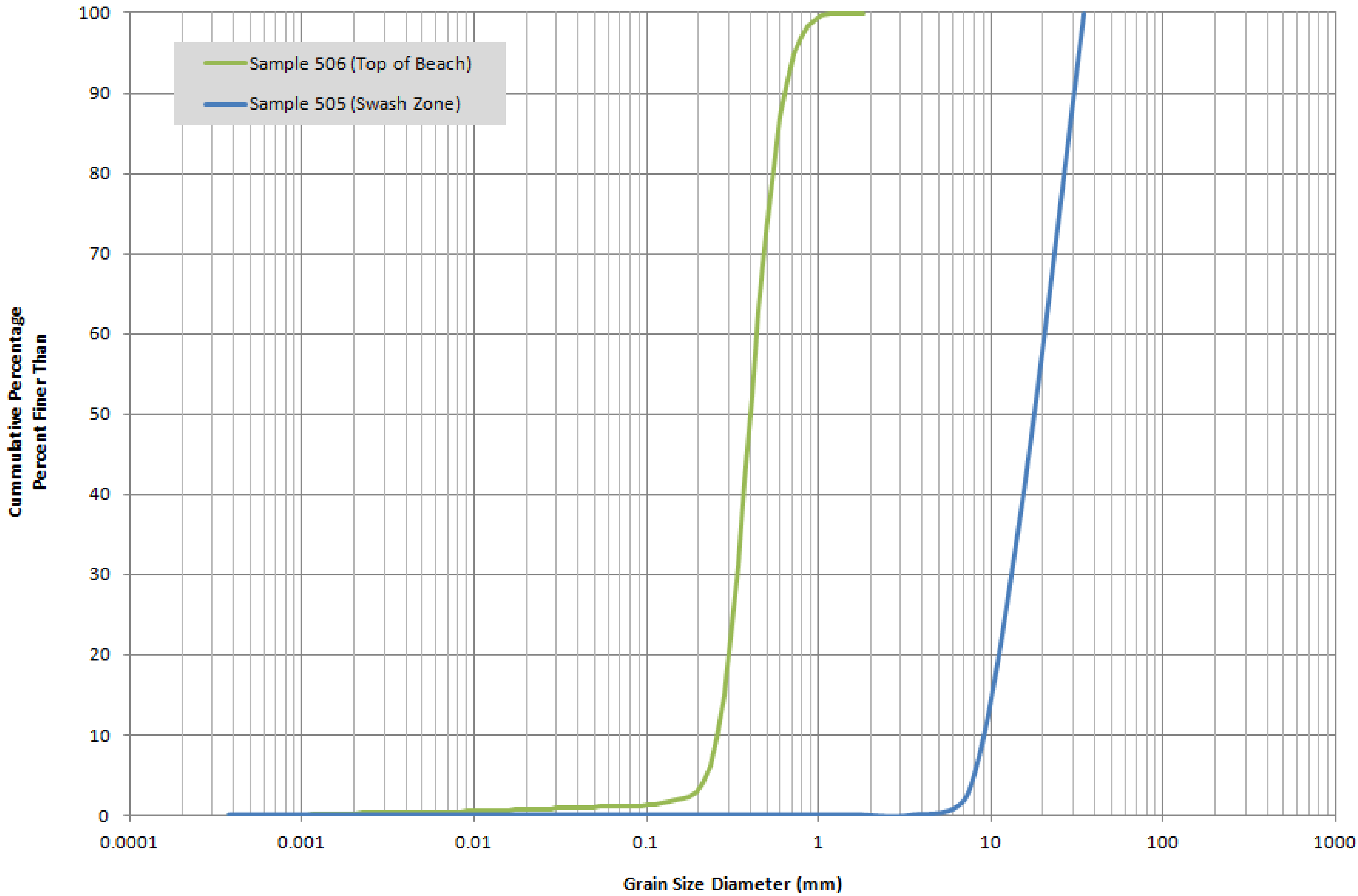

Figure 8.11 Profile 4 Particle Size Distribution

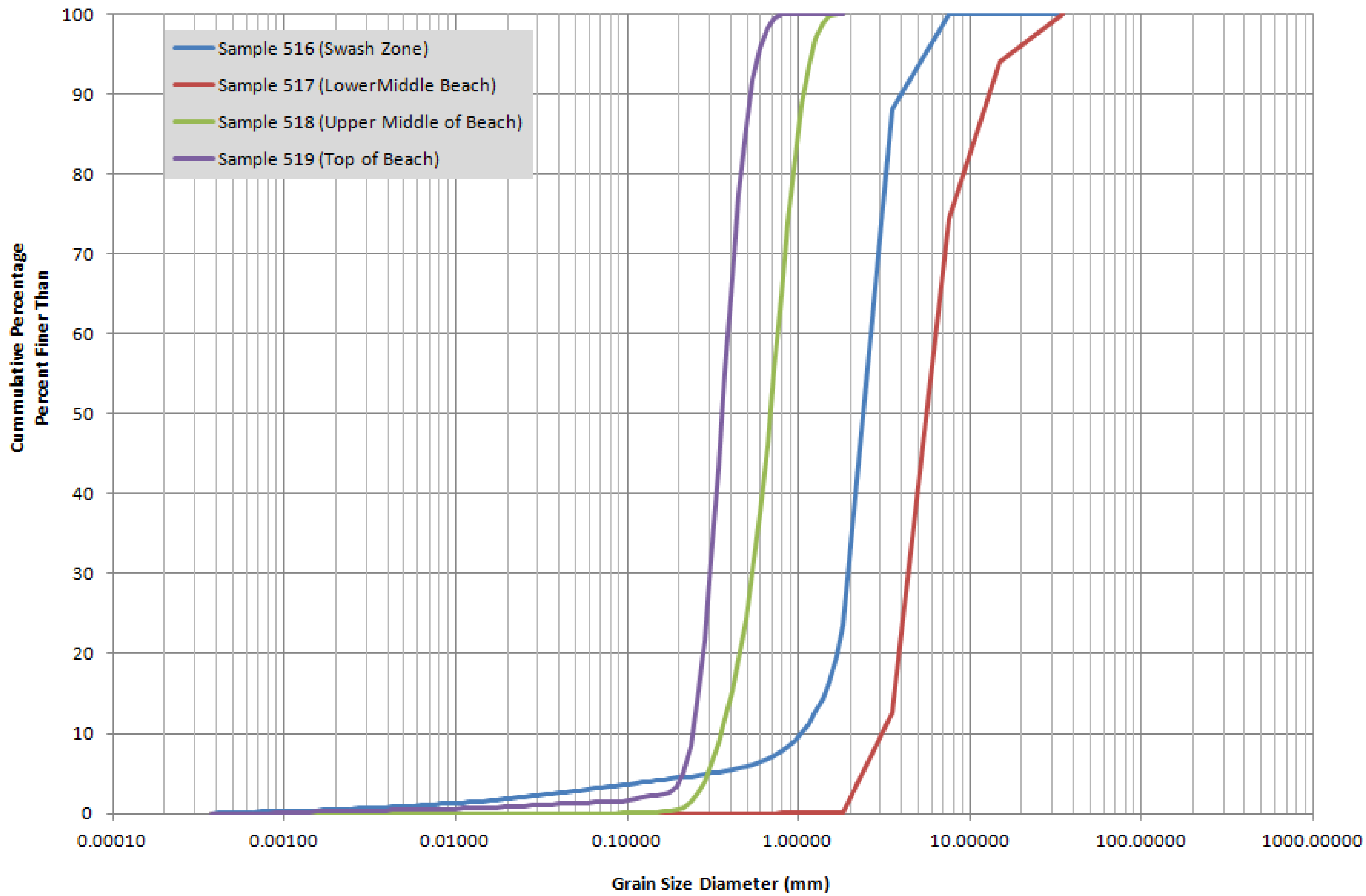

Figure 8.12 Profile 5 Particle Size Distribution

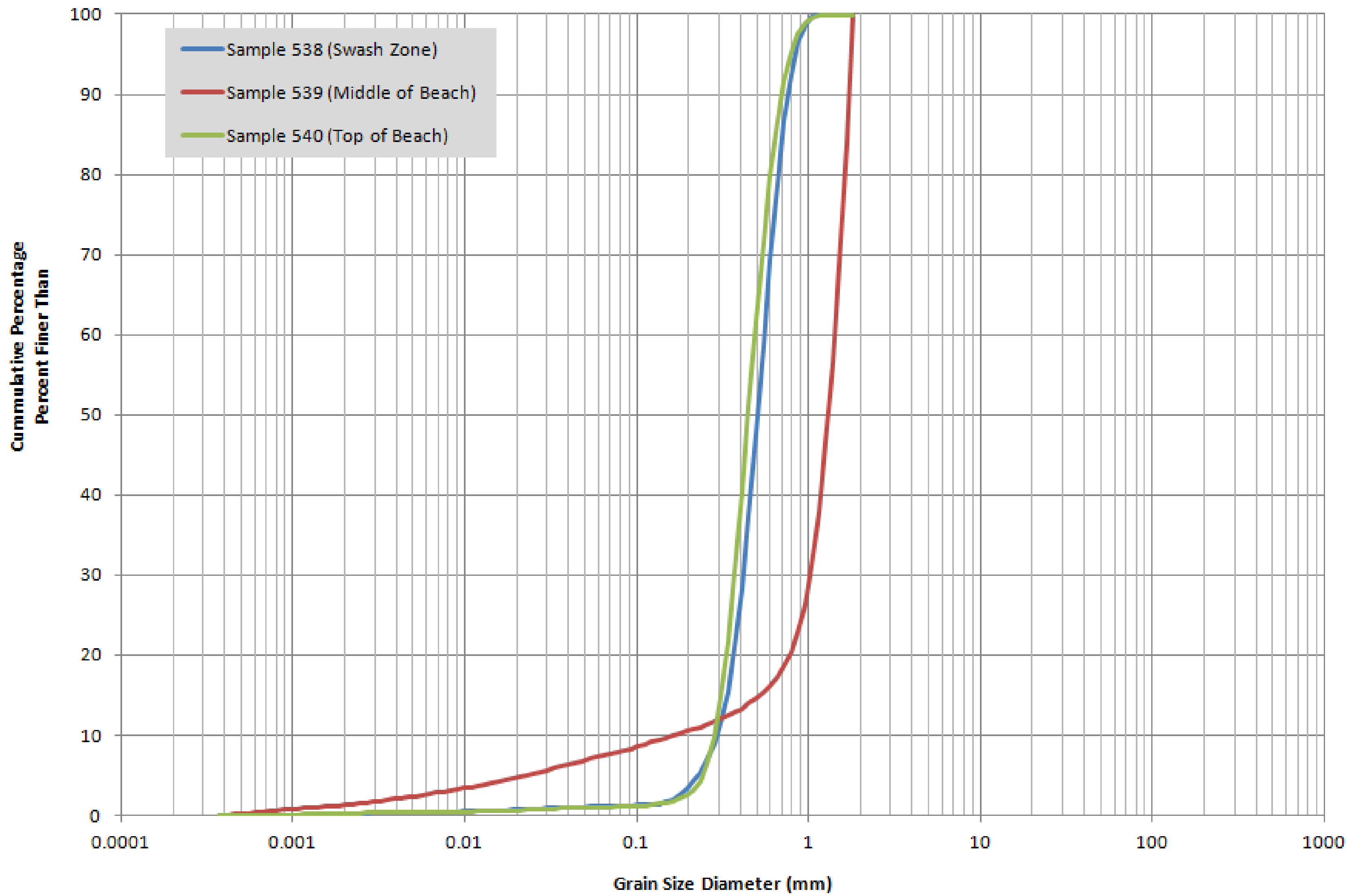

Figure 8.13 Profile 6 Particle Size Distribution

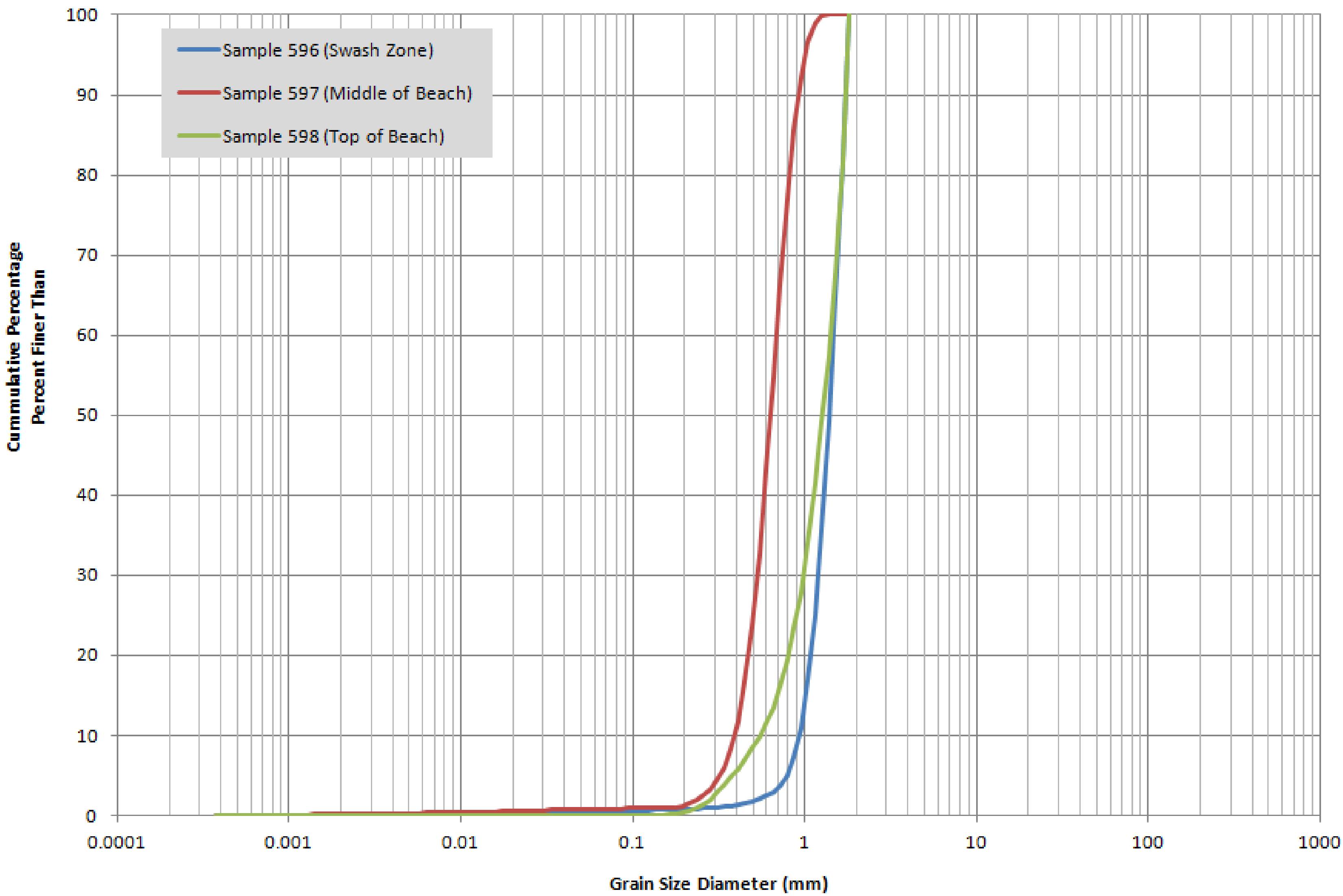

Figure 8.14 Profile 7 Particle Size Distribution