SHORELINE MORPHOLOGY AND SEA LEVEL RISE; MODELLING AND VALIDATION.
QUALICUM BEACH, BRITISH COLUMBIA, CANADA.

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ABSTRACT

The waterfront and shoreline of the Town of Qualicum Beach, British Columbia, Canada is a key defining component of the town and surrounding area. In the past, development of the waterfront was unregulated, which resulted in most of the shoreline being armored. Demands to maintain commercial development are increasing awareness of the implications of future sea level rise (SLR).

A Waterfront Master Plan process was initiated by the Town to begin the process of planning for future development and adaptation to SLR. One objective of this plan was to define the coastal processes affecting the ongoing morphology of the Qualicum Beach shoreline, the effect of the existing seawalls and the potential influence of SLR on these processes.

To achieve this goal, a detailed sediment model of the Qualicum Beach shoreline was developed using the Coastal Modeling System (CMS) from the US Army Corps of Engineers (Demirbilek and Rosati, 2011). The process of this assessment, the validation of the modeling and the resulting implications are discussed. The results provide important information on the role of shoreline seawalls, revetments and bulkheads.

KEYWORDS: coastal processes, geomorphology, numerical modeling, validation, sea level rise.

1 INTRODUCTION

This paper summarizes an extensive investigation undertaken on behalf of the Town of Qualicum Beach to define the coastal process occurring historically, at present and potentially in the future, along the waterfront of the Town. The waterfront and shoreline of the Town of Qualicum Beach, British Columbia, Canada, Figure 1, is a key defining component of the town and surrounding area.

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A Waterfront Master Plan process was initiated by the Town to begin the process of planning for future development and adaptation to SLR. One objective of this plan was to define the coastal processes affecting the ongoing morphology of the Qualicum Beach shoreline, the effect of the existing seawalls and the potential influence of SLR on these processes.

The Town of Qualicum Beach is located in the central portion of the Strait of Georgia on the west coast of Canada, Figure 1. The shoreline is presently protected by a large variety of hard shoreline edge treatments, and by some less common softer treatments, interspersed among the many individual rock and concrete coastal structures (Figure 2).

The shoreline of the area is significantly influenced by the reworking of mainly fluvial and glacial deposited sediments, originating from the slow emergence of the shoreline after the last glaciation, subsequent submergence as pre-industrial sea levels outstripped the slowing isostatic rebound and the intermittent effects of tectonic plate movement. The pre-industrial net rate of coastal emergence of 1-2 mm/yr is now being out paced by the global and local rates of sea level rise of approximately 3 mm/yr and likely much higher in the near future.
Figure 1: Location of the Town of Qualicum Beach

Figure 2: Typical Qualicum Beach shorelines:
a) Seawall, b) Sloped Rock Revetment, c) Steep Gravel Beach, and d) Natural
The intertidal profile seaward of the shoreline edge typically consists of a steep prism of coarse material, generally consisting of coarse sand, pebbles, and cobbles over the high intertidal profile and a relatively flat, fine sand bench over the mid and low tide portions of the profile (Figure 2a).

2 METOCENARIO SETTING

The study area is exposed to frequent SE storms in the Strait of Georgia and to much less frequent but longer duration storm events from the NW, especially during winter outflow conditions. A detailed description of the last 20 years of storm exposure was developed for this assignment, including the influence of tide and storm driven water levels.

A summary of the storm characteristics of this area of the Strait of Georgia is provided in Figure 3. This figure shows patterns of severe storms (defined as storms resulting in Gale Force winds (> 34 knots) that have occurred in the last 20 years. There are significant differences over the years between the frequency and intensity of storms from the two primary directions of storms in the Strait of Georgia. In particular, there can be long intervals (3 or more winter seasons) when there are no storms from the NW (Unbalanced SE storm seasons) as well as years when only storms occur from the NW (Unbalanced NW storm seasons). There are also seasons when extensive clusters of SE storms occur. These storm characteristics make it difficult to assess both historical long term characteristics and future storm characteristics; however, for the purpose of this assessment, it has been assumed that the last 20 years of weather will be similar for storms in the past and for future patterns of storms.

A detailed description of the development of the wind and related wave climate is provided in the project documents, which are available on the Town of Qualicum Beach website.

Figure 3: Summary of Storms in the Strait of Georgia

3 COUPLED SEDIMENT TRANSPORT MODEL

A regional and a local coastal sediment transport model using two computational grids: a CMS-Flow grid, to compute hydrodynamics, sediment transport and geomorphology and a CMS-Wave grid to compute wave propagation, was assembled and extensively tested for this assignment.

Figure 4 shows the local CMS-grid with a spatially-varying cell size developed in the immediate vicinity of the Town of Qualicum Beach to investigate the detailed coastal processes along the Town waterfront. To ensure that the influence of the shoreline edge was properly captured, a cell size of 2 m by 2 m was used at the shoreline edge.

The domains of the CMS model and the supporting regional models are shown in Figure 5.

4 BOUNDARY CONDITIONS

The boundary conditions for the local area CMS Flow model was provided on the local model boundary from the results of a larger area CMS Flow tidal model, which in turn, was driven by recorded water levels from the Environment Canada water level recording station at Point Atkinson. Waves and related effects were also defined on the local area model boundary from the results of an independent SWAN based wind and wave model, which covered the entire water body of
the Strait of Georgia. The overwater wind fields in the SWAN model were derived from an SNC-Lavalin spatial model of the overwater windfield, which used modified winds from approximately 11 Environment onland and overwater recording stations. The wave conditions in the Strait during a severe SE storm are shown in Figure 6. Results from the regional tidal model in the vicinity of the Town are shown in Figure 7.
Similar results, which show an area of reduced sea state and weaker currents in the area offshore of the Town center were found for all phases of tide (spring and neap tides). The sea state during less common but typically longer duration NW storms was significantly more uniformly severe.

5 REPRESENTATION OF SHORELINE CONDITIONS

Development of the Town of Qualicum Beach started in approximately 1908 after the upland area immediately inshore of what is now the centre of the Town was cleared to establish a golf course and a destination hotel for the growing population of Vancouver Island. Historical photographs and anecdotal data indicate that at the time, the shoreline and the intertidal area was mostly sand with some gravel content. The construction of the hotel and golf course was quickly followed by the establishment of recreation oriented motels and campgrounds along the beach, followed by establishment of private residential and commercial properties. Historical records show that while the initial buildings were often located at or close to the visible high water mark along the shoreline and did not have seawalls, there was a slow build out of (typically) cedar post vertical seawall structures. In some cases, encroachment on to the high tide portion of the beach appeared to have occurred.

In the beginning, the early shoreline properties were accessed via a gravel road running close to the shoreline. The increasing use of the automobile and a growing population on Vancouver Island inevitably lead to upgrading of the gravel road to a more formal road, which eventually became the main highway serving this area of Vancouver Island. By the 1960s, a series of relatively severe storms led to the construction of the extensive concrete vertical seawall, including a
pedestrian oriented walkway, visible in Figure 2a. During the 1980’s and thereafter, most of the remaining shoreline of the Qualicum Beach area became valuable waterfront residential property and most properties eventually constructed hard shoreline protections structures, similar to those visible in Figure 2b and c.

During the study progress it became obvious that it was necessary to define the coastal processes along the shoreline for different scenarios and for different distributions or character of the intertidal sediments. Initially, based on historical photographs and available subtidal sediment mapping data from the 1960s, the model was run assuming fine sand and no seawall structures, everywhere. Eventually six different shoreline configurations and character were investigated as summarized in Table 1.

Table 1: Summary of Shoreline Configurations.

<table>
<thead>
<tr>
<th>Era</th>
<th>Shoreline Status</th>
<th>Upper Intertidal Sediments</th>
<th>Lower Intertidal Sediments</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1908</td>
<td>Natural beach foreshore</td>
<td>Fine sand</td>
<td>Fine sand bar</td>
<td>Represents natural undeveloped shoreline.</td>
</tr>
<tr>
<td>1930s - present</td>
<td>Build out of seawalls on natural beach</td>
<td>Fine sand</td>
<td>Fine sand bar</td>
<td>Represents the slow build out of hard shoreline structures.</td>
</tr>
<tr>
<td>Present (2013)</td>
<td>Existing seawalls with gravel/cobble beach</td>
<td>Gravel/cobble</td>
<td>Fine sand bar</td>
<td>Represents the existing condition.</td>
</tr>
<tr>
<td>Future scenario 1</td>
<td>All structures remain as-is</td>
<td>Gravel/cobble</td>
<td>Fine sand bar</td>
<td>Represents the as-found shoreline with 1 m of sea level rise.</td>
</tr>
<tr>
<td>Future scenario 2</td>
<td>All structures raised to provide flood protection</td>
<td>Gravel/cobble</td>
<td>Fine sand bar</td>
<td>Represents potential raising of all shoreline structures to accomodate 1 m of sea level rise.</td>
</tr>
<tr>
<td>Future scenario 3</td>
<td>All structures replaced with soft sediment shoreline protection options</td>
<td>Gravel beach fill concept</td>
<td>Fine sand bar</td>
<td>Represents potential replacement of all hard shoreline structures with a gravel upper-intertidal beach.</td>
</tr>
</tbody>
</table>

6 MODEL CALIBRATION AND VALIDATION

A numerical model that covers a large area such as this one and which, also includes as many physical processes and sediment conditions as exist in the area, requires extensive field data to ensure that the results are both representative and reliable. The need to also address conditions that span nearly 200 years of experience, from the early 1900s to possibly as late as 2100 introduces further complications and requirements for calibration and validation.

Coastal process models contain many empirical science based factors that must be defined during model setup, ideally with the benefit of site field based programs or with time series of field measurements defining the expected coastal process responses, such as beach profile change time series or sediment deposition/erosion measurements. These types of data, spanning the period 1900 through to the present, simply do not exist in this area. To ensure that the model results could be taken to be as reliable and representative as practically possible, the following approaches and tests were made during model setup:

- The overwater windfield was validated against years of measurements at an Environment Canada wind and wave recorder (Halibut Bank) located in the area.
- The deepwater wave climate was validated against storm specific measurements from the same wave recorder.
- Tidal model results were validated against official (CHS) tidal predictions for Northwest Bay, located approximately 12 km east of the Qualicum Beach area.
- Tidal model current predictions were validated against the general current magnitudes and directions provided in the Current Atlas for the Strait of Georgia.
- Nearshore sea state conditions during storms similar to those considered during the study were subjectively evaluated with the assistance of several real time web-camera systems operated by independent organizations along the coast.
- In most cases CMS default settings were adopted for sediment properties.
The initial model results indicated coastal process trends that on examination were not consistent with the nearly uniform trend of waterfront properties building shoreline defences. Detailed review and examination of the CMS model found that various inconsistencies occurred within the standard setup and interface features of the CMS modules. After benchmark testing and review and modification of the various algorithms and the interface aspects of the model ensemble, it was realized that very a high definition of the shoreline (a 2 m x 2 m grid resolution) and structure specific definition of shoreline reflection properties were required. It was also important to match the expected effects of the mainly gravel and cobble lag deposits on the upper intertidal portion of the profile on the initiation of motion, the transport and the deposition of the fine sand materials that was the main substrate of interest. Extensive sensitivity model runs were made and the details are available to interested readers in the main report and appendices available on the Town of Qualicum Beach website.

7 MODEL RESULTS

The CMS model ensemble results provide extensive detailed definition of seabed elevation changes and net volume changes for the main local areas of interest shown in Figure 6 (red polygons). Detailed numerical results for the upper and lower intertidal areas and the sub-tidal areas are also available. In the interests of space, only high level summary results and the overall trends are summarized below.

![CMS Model Results showing Typical Erosion and Deposition Trends after a severe SE Storm.](image)

The results of the modeling process revealed several defining aspects of the coastal processes in the Town of Qualicum Beach area. In particular:

1. The results indicated that prior to development, the area was in a state of dynamic equilibrium, as the result of several features:
   - Steep submerged and likely non-erosive glacial till subtidal bluffs in the French Creek, Eaglecrest and Little Qualicum River (LQR) area, Figure 8, control a large portion of the sediment transport in the area. Volumes of material either eroded or deposited in these areas tend to consistently move back and forth depending on the direction of the storms (SE or NW).
   - The net transport outside of the boundary of the modeled area is consistent with the estimated supply of sediments from several rivers and creeks in the study area and with the volumes of sediment introduced into the active sediment transport substrate area by the net geological processes (crustal uplift of 1-2mm/yr on average due to tectonic plate effects on the east coast of Vancouver Island).
   - The area in front of the Town Waterfront, Figure 8 is relatively sheltered during the predominate SE storms but much more exposed during less common but generally longer NW storms. There was net deposition in the Town Waterfront area during SE storms that more than offset the erosion during NW storms.

2. Once seawalls started to be constructed, the model results showed:
   - Erosion of fine sand in the upper intertidal portion of the Town Waterfront area nearly doubled during NW storms and the rate of erosion of the lower intertidal fine sand bench increased in both SE and NW storms.
   - Although the proportion of fine sand on the undeveloped upper intertidal portion of the beach is unknown, due to the lack of samples from this area during the development years, it is clear from historical photographs that overtime the beach became coarser.

3. Once the seawalls were built out and the upper intertidal beach became coarser, the rate of erosion of fine sand nearly doubled again during both SE and NW storms on the lower intertidal beach. The model results
still suggest that deposition of fine sand should still be ongoing during SE storms; however, the deposition rates are substantially diminished.

4. Extensive CMS model runs for the various combinations of storm classes, as summarized in Figure 3, showed that regardless of the state of tide when a storm occurred, the overall effects on the coastal processes, especially rates of erosion or deposition in the local areas, was approximately linear with the total number of severe storms (greater than gale force) in a storm sequence.

8 FIELD VALIDATION

As essentially no historical measured data on beach behavior is available from the past, an extensive investigation of historical information going back to 1908, involving careful re-occupation of historical photography sites was undertaken. The extensive series of recreated photographs are provided in the main report and supporting appendices on the Town of Qualicum Beach website. One example is shown in Figure 9.

The overall results clearly show that the volume of the upper intertidal beach has shrunk and the lower intertidal fine sand berm has decreased in elevation and extent. Based on the decreased elevation of the top of beach in front of the seawall at the Shady Rest restaurant, originally built in 1927, the beach has lowered approximately 0.7 m between 1927 and 2015. This is consistent with the linear superposition of storm sequence responses of the intertidal profile since 1927.

![Figure 9: Re-Occupation of Historical Photograph from approximately 1927](image_url)
THE EXPECTED EFFECT OF 1 m OF SEA LEVEL RISE

The CMS model suite was re-run for the primary SE and NW storms described above, after increasing the recorded total water levels used to drive the model, by an additional 1 m, to reflect the sea level rise (SLR) expected due to climate change effects by sometime between 2050 and 2100. During these SLR model runs, three potential shoreline responses were considered as summarized in Table 1. Metrics for the Qualicum Beach shoreline area are summarized in Table 2. Metrics for the Town Waterfront local area are summarized in Table 3.

Table 2: Summary of CMS Model Runs for Qualicum Beach Shoreline

<table>
<thead>
<tr>
<th>Storm</th>
<th>Profile zone</th>
<th>Undeveloped Shoreline (Pre – 1930)</th>
<th>Existing Shoreline (2014)</th>
<th>Future Shoreline Scenarios After 1 m of SLR</th>
<th>units</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Option 1</td>
<td>Option 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SE</td>
<td>Full Profile (subtidal and intertidal)</td>
<td>-18,000</td>
<td>-13,100</td>
<td>-9,100</td>
<td>-10,200</td>
</tr>
<tr>
<td>NW</td>
<td>Intertidal Portion of Profile</td>
<td>+2,700</td>
<td>+2,700</td>
<td>+2,700</td>
<td>+2,900</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>m³/storm</td>
<td></td>
</tr>
</tbody>
</table>

Table 3: Summary of CMS Model Runs for 1 m of Sea Level Rise

<table>
<thead>
<tr>
<th>Storm</th>
<th>Profile zone</th>
<th>2015 Shoreline</th>
<th>Future Shoreline</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Option 1 Option 2 Option 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2015 Shoreline</td>
<td>Existing No Change Raise Structures Gravel Beach System</td>
</tr>
<tr>
<td>SE</td>
<td>Full Profile (subtidal and intertidal)</td>
<td>+1,700</td>
<td>+400</td>
</tr>
<tr>
<td></td>
<td>Lower Intertidal</td>
<td>-0.8</td>
<td>-1.6</td>
</tr>
<tr>
<td></td>
<td>Upper Intertidal</td>
<td>+2.2</td>
<td>+0.7</td>
</tr>
<tr>
<td>NW</td>
<td>Full Profile (subtidal and intertidal)</td>
<td>-5000</td>
<td>-5700</td>
</tr>
<tr>
<td></td>
<td>Lower Intertidal</td>
<td>-27.9</td>
<td>-42</td>
</tr>
<tr>
<td></td>
<td>Upper Intertidal</td>
<td>-1.8</td>
<td>+10</td>
</tr>
</tbody>
</table>

These results indicate that over the entire Qualicum Beach area, the magnitude of shoreline response, Table 2, is expected to decrease, especially during the predominant SE storms. Local area responses, Table 3, are more nuanced; however, it appears that results are not significantly affected regardless of the future choices made regarding the fate of the existing shoreline coastal structures.

10 CONCLUSIONS

These results were surprising and suggest considerable flexibility is available to the Town for the planning of adaptation measures in the future. Detailed examination of the CMS model results indicated that the main reason why coastal processes will tend to decrease in the future is because the rate of energy dissipation across the inter-tidal profile will decrease in the future as the depth of water increases. While this increase in water depth has a potentially beneficial effect on the coastal processes, conservation of energy means that the future risk to the Qualicum Beach shoreline and the land-
uses along the shoreline, will largely be associated with wave impact, potential shoreline structure damage and increased frequency and intensity of coastal flooding.

ACKNOWLEDGEMENT

The investigations and findings described in this paper were made possible by funding provided to the Town of Qualicum Beach from the Federal Gas Tax Fund. The authors of the paper would also like to acknowledge the input and contributions made by many individuals and organizations that provided information, observations, review and research that was invaluable to this investigation, including, in particular:

- The Qualicum Beach Historical and Museum Society
- The BC Archives Collection of the Royal BC Museum
- Dr. John Clague, P Geo., Simon Fraser University
- Members of the U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, the original developers of the CMS model ensemble used for this study, who conducted numerous reviews and re-examined elements of the CMS model to verify the trends indicated by the project specific results.
- Numerous residents of the Town of Qualicum Beach who provided photographs, video and observations of many aspects of the waterfront and who provided access to their properties for the re-construction of the historical photographs found at the Historical Museum and the Public Archives.
- Mr. Patrick Krohn of Krohn-Photos.com, who re-examined family archives to confirm dates of historical photographs taken by a family member who was a professional travel photographer visiting the Qualicum Beach area in the late 1920’s and 1930s.

This investigation would not have been possible without their voluntary contributions.

REFERENCES