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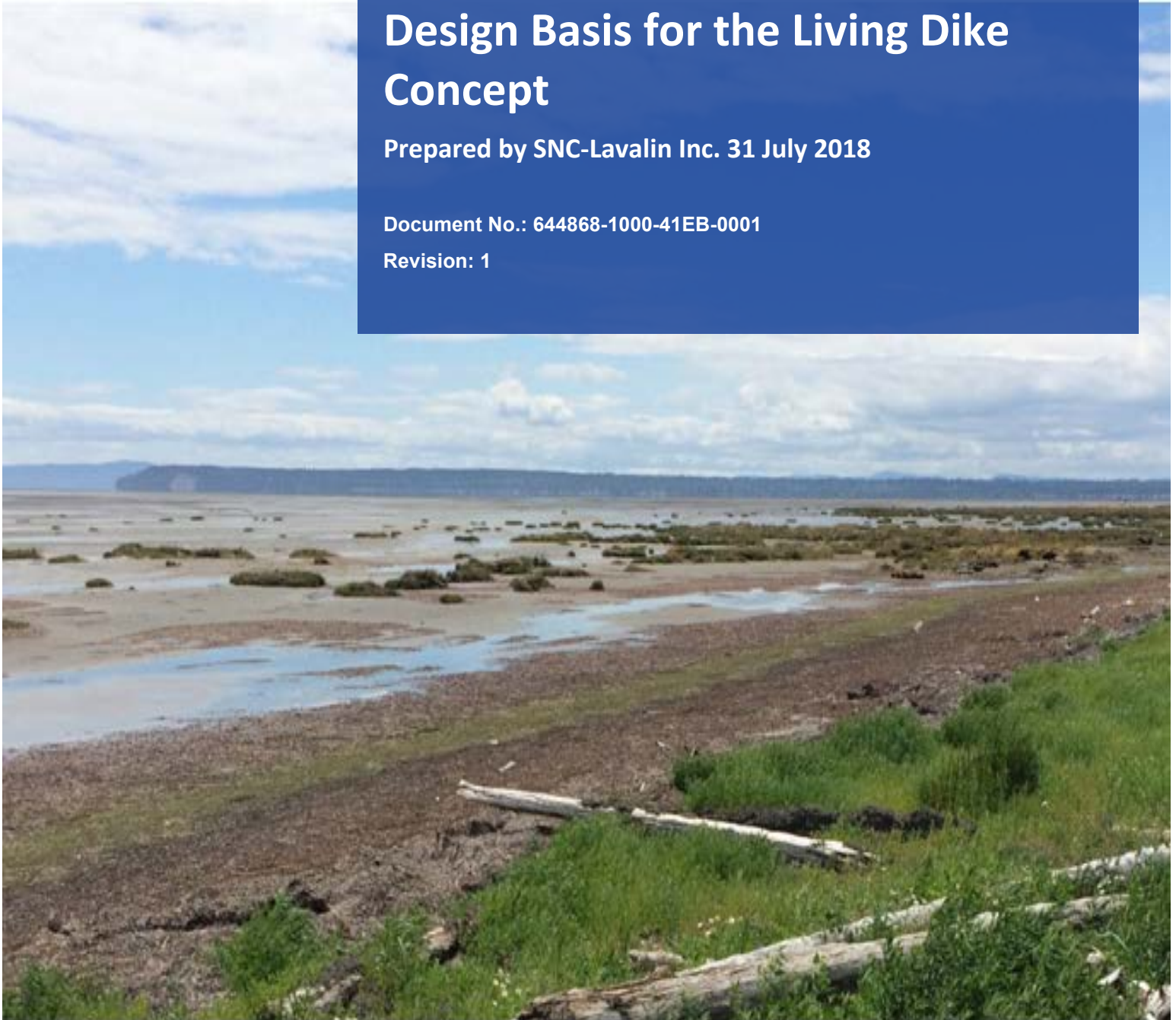
**West Coast Environmental Law**

# **Design Basis for the Living Dike Concept**

**Prepared by SNC-Lavalin Inc. 31 July 2018**

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**WEST COAST**  
Environmental Law

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## EXECUTIVE SUMMARY

### *Background*

West Coast Environmental Law (WCEL) is leading an initiative to explore the implementation of a coastal flood protection system that also protects and enhances existing and future coastal and aquatic ecosystems. The purpose of this document is to summarize available experience and provide an initial technical basis to define how this objective might be realized. This “Living Dike” concept is intended as a best practice measure to meet this balanced objective in response to rising sea levels in a changing climate.

It is well known that coastal wetlands and marshes provide considerable protection against storm surge and related wave effects when hurricanes or severe storms come ashore. Studies have also shown that salt marshes in front of coastal sea dikes can reduce the nearshore wave heights by as much as 40 percent. This reduction of the sea state in front of a dike reduces the required crest elevation and volumes of material in the dike, potentially lowering the total cost of a suitable dike by approximately 30 percent.

In most cases, existing investigations and studies consider the relative merits of wetlands and marshes for a more or less static sea level, which may include an allowance for future sea level rise. They generally do not consider the implications of the immediate loss of existing ecological services, when a standard dike is built in response to sea level rise, or the implications of long term depleted ecological services, while sea levels slowly rise to reach the design target elevation.

The intent of the Living Dike concept is to provide a means to minimize these ecological losses while still meeting relevant flood safety standards.

### *Approach and Methodology*

For this concept development study, we have estimated sea dike elevations required to provide flood protection along the exposed shoreline of Boundary Bay, based on the present updated British Columbia Provincial Climate Change Adaptation Guidelines for Sea Dikes and Coastal Flood Hazard Land Use, for

- a Living Dike concept with a seaward face that consists of a dynamically stable beach face that supports and sustains both high salt marsh vegetation and existing offshore eelgrass meadows, and
- a standard sea dike.

The representative study shoreline is part of the Boundary Bay Wildlife Management Area (WMA), and the WMA, which together with similar other areas in the Fraser River estuary and the adjacent agricultural areas, form an important stopover route on the extensive Pacific Flyway migration route. There are no comparable sites along the Pacific Coast between California and Alaska.

The report outlines a preliminary strategy for building the Living Dike by the provision of recurring lifts of fine beach material, coupled with recurring planting of salt marsh vegetation, as necessary, that will incrementally achieve the required sea dike elevation at a future date. The concept outlined in this study is designed for a net sea-level rise of 1 m.

It is not the intent of this definition of the Living Dike concept to address implications of sea level rise greater than 1 m; however, this is an important issue that involves many aspects of the implementation of a Living Dike concept and merits further evaluations.

### *Estimated Costs*

In this study, three methods for supplying the salt marsh material (assumed to be a fine sand mixture) to 14 kilometers of the Boundary Bay shoreline are outlined. These include:

- delivery of sand to the shallow sub-tidal waters of Boundary Bay, after which waves and currents are expected to transport the delivered material to the vicinity of the Living Dike footprint,
- delivery of sand to the lower inter-tidal areas of Boundary Bay, immediately in front of the Living Dike alignment, where waves and currents are also expected to complete the delivery to the final footprint area,
- delivery of sand by direct pumping from a delivery vessel into temporary stockpiles in the mid to high inter-tidal area of the foreshore, followed by staged transfer, as required, ashore to the Living Dike footprint.

The results of this study found that the estimated cost of the Living Dike concept, for a net sea level rise of 1 m along the northern shoreline of Boundary Bay, will be between \$175 million and \$250 million, depending on the method used for sand delivery. These costs include the cost of supplemental salt marsh planting over the estimated 25 to 30 year construction period during the supply and placement of successive 100 mm lifts of fresh sediments.

The most reliable method of sand delivery; direct pumping ashore, has an estimated capital cost of \$200 million, including supplemental salt marsh planting.

In 2012, a separate study [31] produced a preliminary concept for raising the Standard Dike that presently exists along the northern shoreline of Boundary Bay. We have reviewed and revised this preliminary design to reflect the more detailed engineering and recent tendered prices for supply of Standard Dike materials from two recent projects in 2015 and 2016. These updates to the 2012 study results suggest that a Standard Dike for 1 m of sea level rise in this area has an estimated capital cost of at least \$250 million dollars, in comparison to the Living Dike range of \$175 to \$250 million.

### *Information Gaps and Next Steps*

It is clear there are several gaps related to the Living Dike concept that need to be addressed:

- While salt marshes are generally acknowledged to thrive in areas of ongoing sedimentation, it is not known what maximum rates of sedimentation will allow an existing salt marsh to continue to exist or to expand as sea levels rise.
- The horizontal rate at which a salt marsh will expand and thus how much edge erosion, due to storm wave or currents, can be tolerated, is generally not known.
- The sensitivity of new or pioneer salt marsh vegetation to ongoing sedimentation is generally not known.
- Deposition and migration of dike materials (fine sand) over or through low tide or shallow subtidal areas will affect existing marine habitat areas and values. An upper limit rate of sedimentation in existing seagrass or mudflat areas is not clearly defined.
- There is very little information available on successful strategies for encouraging, aiding and sustaining salt marsh expansion in a scenario where sea levels are rising and successive lifts of dike material (fine sand) are deposited.

- The concept to date considers the use of mainly clean fine sand – likely dredged from the Fraser River – as the main “structural” component of the Living Dike. It is not known if fine sand alone would be a suitable medium for successful salt marsh colonization or expansion.

This high level assessment of the application of the Living Dike concept, specifically in Boundary Bay, has also identified several important gaps in the available information for this area, including:

- A detailed inventory of marine habitat and related ecological services in the area.
- A detailed description of either the historical or the present geomorphologic processes in the Boundary Bay area.
- Detailed descriptions of the coastal sediment processes; i.e.: rates of existing natural sediment supply to the area, sediment transport trends, rates, or sediment pathways.
- The intertidal portions of Boundary Bay have not been completely surveyed inshore of the 0 m (CD) contour. The absence of accurate bathymetric data will affect development of an understanding of coastal sediment transport processes, the geomorphologic setting and the merits of various sediment delivery methods and sites.
- There is a general lack of recorded metocean data in the area, including local wind data, measured wave or measured current data. Future steps in the evaluation of a Living Dike concept in this location should include:
  - Definition of the overwater wind field in the area
  - Definition of the shallow water wave climate across the Boundary Bay tidal flats
  - Definition of the tidal, wind, wave and river driven currents in the area.

These gaps limit the level of confidence and reliability that can be attributed to any assessments of the feasibility of dike concepts in Boundary Bay and a high priority should be given to completing a detailed evaluation of the metocean and sediment transport trends in this area.

### **End of Executive Summary**

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# 1. INTRODUCTION

## 1.1. Background

West Coast Environmental Law (WCEL) is leading an initiative to explore and support the implementation of coastal flood protection systems that also protect and potentially enhance coastal and aquatic ecosystems.

In early 2017, a workshop was organized in the Lower Mainland to introduce the Living Dike concept, the need for integrating coastal flood protection and ecosystem management and protection, and the current state of practice for these approaches. Attendees at the workshop included technical specialists from federal, provincial and local governments.

The coastal engineering group at SNC-Lavalin has been exploring and developing a technical basis for the Living Dike concept that could be implemented in inland coastal British Columbia waters, and potentially elsewhere, both in the Province and globally. This initiative arose as the result of experience and observations on several completed projects where coastal sediment materials (sand and gravel) and marine vegetation have shown beneficial interaction that can and have led to decreased wave effects at the shoreline and therefore can be expected to contribute to either improved or more economical flood or erosion protection.

There are similar initiatives in process elsewhere in the world. The prime objective of this report is to gather available experience and summarize a technical design basis for a Living Dike concept that can be moved forward as a best practice measure. The objective of the Living Dike concept is to support a flood protection strategy and enable a system that provides both the necessary flood protection and preserves the ecological services and values of the shoreline and nearshore areas while sea levels rise in response to climate change.

## 1.2. Scope

The scope of work for this document consists of the following:

- Summarize, and update from previous versions of this report, the basis for the Living Dike concept
- Outline the technical justifications (including both engineering and biological areas) for the concept
- Outline completed projects that support the concept
- Illustrate how a Living Dike concept might be implemented both technically and in a timeline compatible with known sea level rise trends.
- Develop an estimate of the installation cost of the concept and compare the cost to a similar level of estimate for an alternative Standard Dike solution.
- Identify the known information and technical gaps that still need to be addressed

This document summarizes the overall design basis and conceptual level cost estimate for the capital cost for the Living Dike concept

### 1.3. Acknowledgements

This study has benefitted from the contributions, review and comments of many individuals. In particular, the contributions of Mr. Dan Bowen and the experience of Project Watershed, and Mr. Rob Severinski of Fraser River Pile and Dredging (FRPD), who provided expertise and information on costing for the salt marsh planting and sand delivery costs, respectively, is acknowledged.



## 2. BASIS OF CONCEPT

### 2.1. Flood and Safety Basis

Ongoing climate change is leading to many environmental changes including increased air, land and ocean temperatures, which are in turn, are causing melting of land-based ice, thermal expansion of warming oceans and rising sea levels. Although the pace of these expected effects is uncertain, it is certain that sea levels are rising at a pace that at a minimum presents a clear and growing hazard to shorelines, to ecological services, to land values and to population health and safety around the low lying coastlines of the world, including British Columbia. The timeframe for this growing hazard is already relevant to the planning of maintenance of existing flood protection structures and for land use planning and infrastructure development.

There are four generally accepted options to react to the growing hazard:

- Protect
- Accommodate
- Retreat
- Avoid

The first option is generally the first planning choice for many obvious reasons. In most locations, a protection option implies the design and construction of relatively narrow protective coastal structures (dikes or seawalls), largely because of high land use values or functions on the landward side, and the negative environmental implications of encroachment of Protect solutions onto the adjacent intertidal lands. In reality; however, Protect solutions tend to encroach onto intertidal lands, in some cases because of a perception of the low economic value of intertidal lands but also because a seaward Protect option offers the possibility of less complicated private property or built infrastructure issues. Construction and maintenance access is also often a factor. Protection is not the only adaptation option, but it is likely to be widely applied, particularly in the medium term, while a greater understanding of the longer term impacts of climate change and sea level rise evolves.

Nevertheless, many conceptual level studies have identified the relative merits of using soft coastal structure solutions, including reinforcement, enhancement, restoration or even construction of new beaches, storm berms, salt marshes or engineered dune fields to provide the required protection against flooding and the associated defined level of safety to personnel and structures located adjacent to the Protect option. In most cases these conceptual level studies evaluate the relative merits for a more or less static sea level and do not consider the implications of the timing of the construction of the option to existing ecological services. This development of a Living Dike concept is intended to define a strategy for implementation that will provide the required protections against future flooding and will preserve intertidal ecological values throughout and after the installation process.

### 2.2. Environmental Basis

Coastal wetlands provide protection against storm surge and related wave effects in many places around the world, especially when hurricanes or tropical storms come ashore. In the US Gulf Coast area, barrier islands,

shoals, marshes, forested wetlands and other features of the coastal landscape provide a significant and potentially sustainable buffer from wind wave action and storm surge generated by tropical storms and hurricanes, Louisiana (2017), Reference [4]. The effectiveness of wetlands for coastal storm flood abatement will vary, depending on the size of the area, the type of vegetation, the condition of vegetation, the slope and orientation of the wetland in the flood path and the saturation of wetland soils before flooding.

## Ecological Services

Plants established on tidal marshes trap sediments and organic material that provide value to the marine environment. If the supply of sediment and organic material to tidal marshes is sufficient, tidal wetlands and marshes can persist and rise at the same rate as sea level (PWA and Faber 2004, Watson 2004). If sedimentation is slower than sea level rise, tidal marshes and tidal flats begin to erode and the area seaward of any shoreline protection structures converts to open water (PWA and Faber, 2004, Lowe and Williams 2008).

Because tidal marshes and tidal flats decrease wave heights or attenuate waves, the loss of tidal marsh seaward of protection structures further exacerbates potential flooding and erosion during storms by allowing larger waves to reach the structures.

Studies in the United Kingdom (Möller 2001, 2002, 2006) estimate that salt marshes in front of dikes reduce wave heights by as much as 40 percent. Reduction of the sea state in front of a dike reduces the required crest elevation and the volumes of material, lowering the total cost by 30 percent (Turner and Dagley 1993).

Marine ecological services provided by tidal marshes include:

- Improvement and maintenance of water quality
- Filtration of pollutants from the water
- Shade and microclimate benefits
- Detritus and nutrient delivery and retention
- Reduction of the potential for adjacent area erosion issues
- Slope stability
- Upland and intertidal connectivity
- Promotion of a higher abundance and diversity of organisms
- Provision of critical spawning and foraging areas for fish and wildlife.
- Carbon capture and sequestration

## Additional benefits of marshes

Recent science has found that marshlands provide an important and extremely effective sink for the storage of carbon. It remains to be defined if increased creation of new marshlands provides a significant offset to the increased levels of carbon dioxide contributing to the GHG effect and the associated expected rise in sea levels. The potential benefits of the Living Dike concept for future carbon capture and sequestration are not considered in this study.

## Eelgrass considerations

Establishment and protection of eelgrass (*Zostera marina*) in low intertidal and shallow subtidal areas is also an important ecological services consideration because of their valuable multi-faceted ecosystem role. Eelgrass provides well-known physical functions of wave attenuation and the building of subtidal substrate (through settlement of sediments transported in the area of eelgrass meadows by waves and currents) in addition to the important ecological services.

Eelgrass typically avoids high intertidal areas where desiccation becomes an issue; the upper intertidal area of Boundary Bay is a good example.

Maximum seaward depth of an eelgrass meadow is determined by light availability, which is heavily influenced by turbidity, and by seabed sediment type, stability and supply.

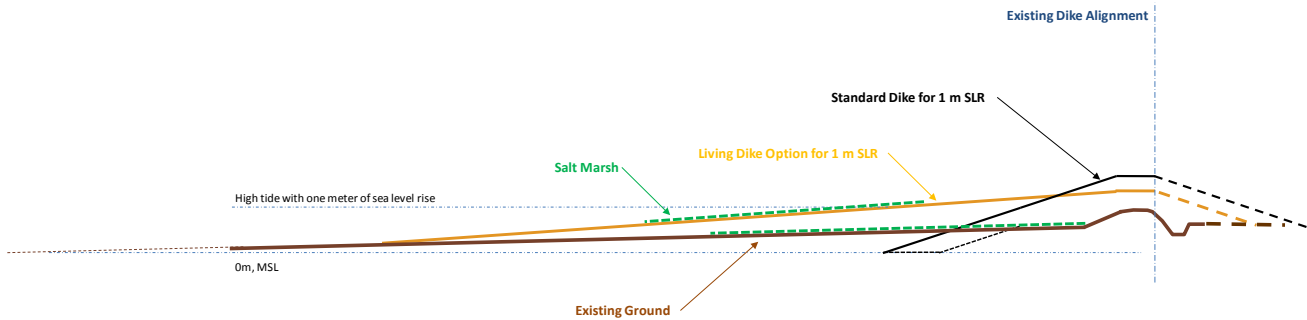
It should be noted that a substrate that slowly grades upwards towards the high intertidal portion of a shoreline should provide spatial opportunity for the natural landward migration of eelgrass, as sea levels rise. If the existing substrate is essentially flat over large areas it is unlikely that existing eelgrass meadows will naturally migrate onshore. Natural migration will depend on the rate of sea level rise. The migration “ability” of the eelgrass by rhizome horizontal elongation is approximately 0.5 to 1.0 m per year. It is likely that the natural migration shoreward could be supplemented with deliberate eelgrass transplanting. For the purpose of this study it is assumed that existing eelgrass/seagrass meadows in Boundary Bay will remain approximately in their present locations.

## Shoreline protection considerations

Coastal structures, including dikes, seawalls and revetments, have been constructed on tidal marshes and tidal flats in many locations worldwide. This practice restricts the landward migration of the intertidal ecosystem as sea levels rise in a process commonly referred to as “coastal squeeze”. In contrast, on a natural unprotected shoreline, tidal marshes can move landward as sea levels rise and the increased wave energy resulting from deeper water over the existing tidal flats mobilizes and transports sediments inshore. The presence of coastal structures at the high water shoreline can also further negatively affect marsh survivability and renewal processes by reflecting wave energy onto the adjacent seaward areas resulting in scouring and loss of existing marsh vegetation.

The intent of the Living Dike concept is to emulate the natural unprotected shoreline rebuilding process, while still maintaining a more or less stationary shoreline position. Although the present concept implies a steepening of the intertidal area, the overall intent of the steepening is considered to be relatively benign and consistent with the overall objective of balancing the provision of flood protection while maintaining ecological services.

A schematic illustration of the Living Dike concept and an equivalent Standard coastal sea dike is provided in Figure 1.



**Figure 1: Schematic Illustration of a potential Living Dike Option and a Standard Coastal Sea Dike for 1 m of SLR**

*Based on existing coastal sea dike in Boundary Bay (shown as part of the Original Ground)*

*Standard Dike location selected to minimize intrusion on existing land-use.*

The two sections in Figure 1 are scaled to an existing coastal sea dike, shown as part of the Original Ground, and are located with the respective crests (approximately 5 m wide) superimposed at the same location as the existing dike alignment. The Standard Dike includes excavation of a toe to protect against scour on the foreshore seaward of the Standard Dike. Both dikes include a rear section that is intended to ensure that any expected wave overtopping during a severe storm will not compromise the dike stability. The indicated locations do not represent any specific evaluation of land use or ownership in the lee of the dike or implications of environmental issues.

### 3. DESIGN BASIS

The primary objective of this section of the Design Brief is to summarize the physical parameters considered in this definition of the concept.

#### 3.1. Water Levels, Bathymetry and Sea Level Rise

##### Present Water Levels

A summary of the relevant water levels used for the concept development is provided in Table 1. These water levels are approximately valid for the Boundary Bay area; however it should be noted that they are based on some judgement and interpolation of published values in Reference [13]. These water levels should be validated by field measurement prior to a site specific application.

The elevations are provided relative to both the terrestrial datum (CGVD28) and the local chart datum (CD). The terrestrial datum is approximately equal to mean sea level and is the datum presently used to define the required elevation of existing dike structures in Boundary Bay. The existing dikes have a crest elevation of approximately +3.5 m (CGVD28).

Table 1

**Vertical Datum and Related Water Levels  
Present Day – Boundary Bay**

	Terrestrial Datum CGVD28	Chart Datum
Design Total Water Level (DFL)	+3.5 m	+ 6.25 m CD
High Water Spring Tide (HHWLT)	+1.8 m	+ 4.55 m CD
Mean High Water (HHWMT)	+1.35 m	+ 4.1 m CD
Mean Sea Level (MSL)	+0.15 m	+ 2.9 m CD
Terrestrial Datum (CGVD28)	0 m	+ 2.75 m CD
Mean Low Water (LLWMT)	-1.55 m	+ 1.2 m CD
Low Water Spring Tide (LLWLT)	-2.60 m	+ 0.15 m CD
Chart Datum	-2.75 m	+ 0 m CD

## Bathymetry

For the purpose of this concept development, we have used the current charted definition of the offshore and intertidal bathymetry, as indicated on the latest edition of CHS Chart 3463, supplemented by recent survey information in the vicinity of ongoing dike upgrades in the approximate centre of Boundary Bay. The charted bathymetric data is shown in Figure 2. According to the records of CHS<sup>1</sup>, the intertidal portion of Boundary Bay has never been surveyed inshore of the 0 m (CD) contour, except in the vicinity of the point soundings on Chart 3463, where a small tidal channel existed up to the locations of the point soundings in 1932.

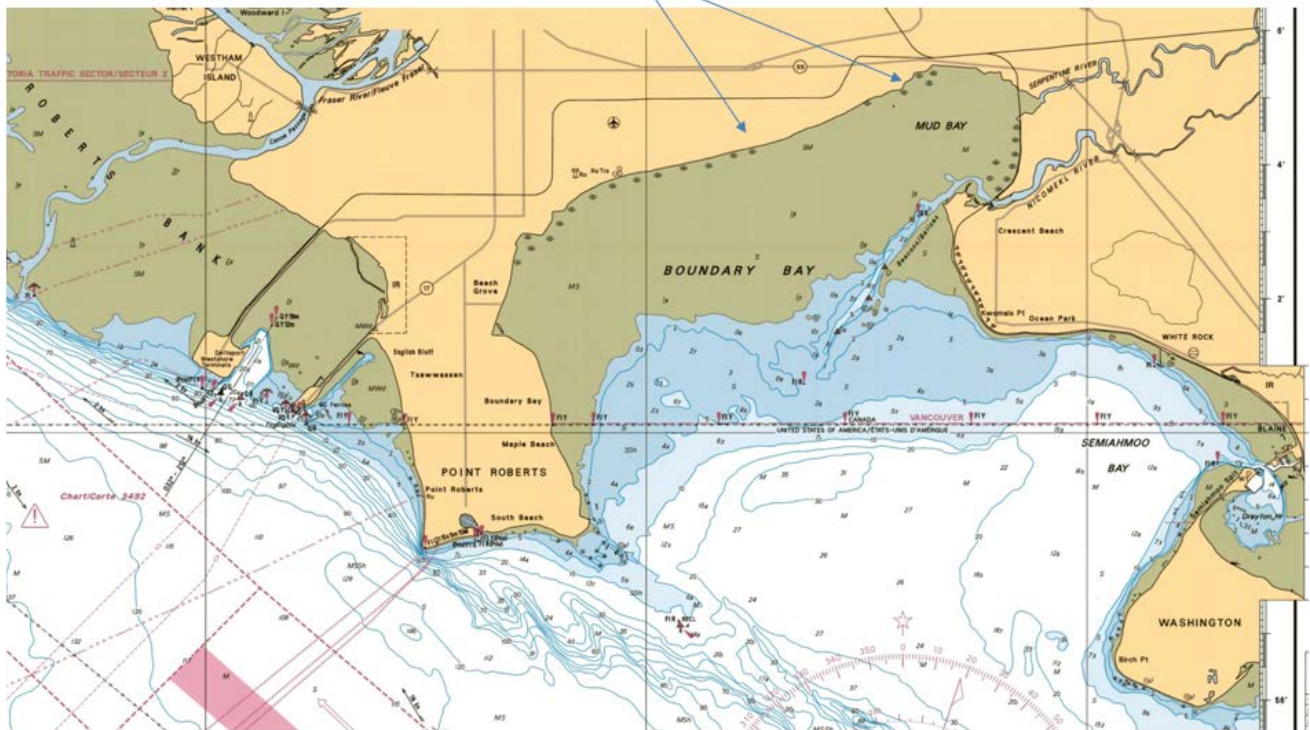
The recent available survey data from dike upgrade projects in 2015 -2017 shows that the typical slope in the upper intertidal area, near the existing dike, is approximately 1:30 (vertical:horizontal) for a distance of approximately 25 m from the existing dike. The average slope over the remainder of the intertidal area, extending out to the 0 m CD contour in Figure 2 is approximately 1:800, indicating how relatively flat this area is.

For the purpose of estimating quantities of material required to build a Living Dike, we have assumed the upper intertidal area slowly transitions from a 1:30 to a 1:50 slope over the footprint of the Living Dike as shown in Figure 8.

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<sup>1</sup> Email from CHS dated 19 April 2017

Approximate location of Oyster Farming areas (1900s–1950s)



**Figure 2: Boundary Bay Study Area**  
source: CHS Chart 3463 – not for navigation

## Sea Level Rise

The intent of the Living Dike concept is to provide flood protection during a Designated Storm as defined in the updated Provincial Guidelines for the management of coastal flood lands and the design of coastal sea dikes; References [1], [2] and [3], and at the same time, maintain ecological services and values of existing foreshore, intertidal and nearshore areas. For the purpose of the concept definition we have considered a net local relative sea level rise of 1 m above present mean sea level.

In the area of Boundary Bay, a net rise of local sea level of 1 m includes the ongoing subsidence of the Fraser River Delta, occurring at approximately 2 mm/yr and the global and regional influences on the rate of absolute sea level rise. The mean global sea level has been rising, on average between 1993 and 2017, at approximately 3.4 mm/yr. This global sea level rate of rise is expected to accelerate in the future.

Recent analysis of regional sea level rise rate, Reference [15], suggests, based on extensive analysis of satellite measured water level data, that Pacific Northwest sea levels are rising, since approximately 2012, at a rate of approximately 6 to 15 mm/yr. Although this new information suggests a significant increase in local sea level rise rates, it is too early to determine if this increase represents a sustained increase in the local rate of sea level rise. Nevertheless we have considered annual rates of this magnitude, as defined further below.



## Tide

For the purpose of this assignment, no change to existing tide ranges or characteristics is considered to occur as sea levels rise.

## 3.2. Wind, Wave and Current Regime

### Storm Types and Wind Field

The Boundary Bay area is directly exposed to strong winds and related waves (sea state) generated by mainly NE – E winds blowing down the Fraser River valley and by SE – S winds blowing across Boundary Bay. W and NW winds may affect the area; however, these are mainly expected to be blowing off the shoreline and will not govern the local wave climate. W or NW winds in the Strait of Georgia may be deflected into Boundary Bay by thermal effects, especially in the summer months; however, there is a general lack of recorded data in the Boundary Bay area to reliably define this, likely, secondary influence.

On site experience during ongoing dike upgrade projects in 2015 and 2016-2017 for the Corporation of Delta suggest that during SE – S events, local winds in Boundary Bay are not as strong as they are offshore in the Strait of Georgia where the recorded wind data is available. A spatial gradient in overwater wind field will result in less severe sea states close to shore, as shown in Figure 3, which was taken in a recent severe SE storm.

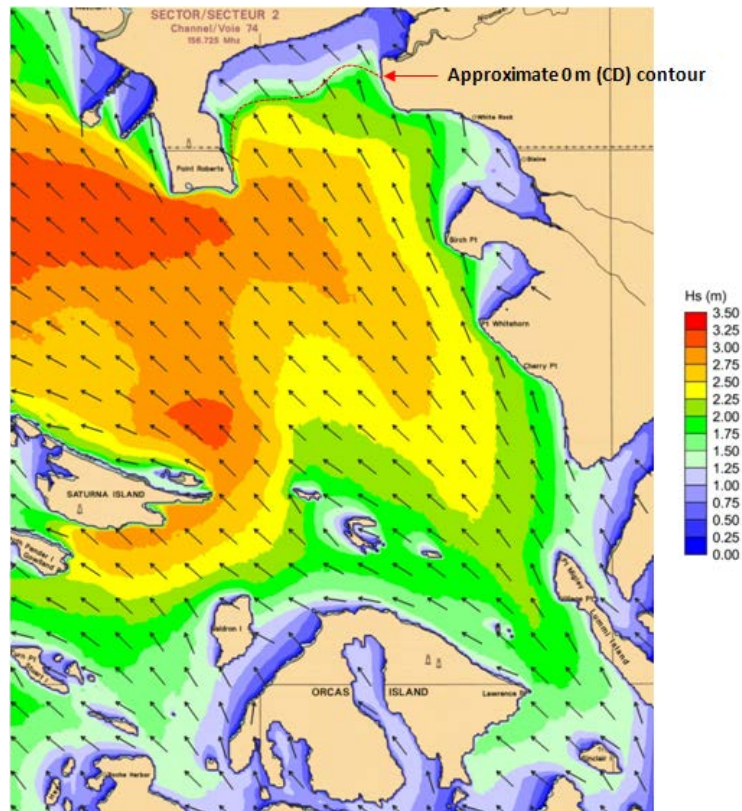
For the purpose of this assignment, we have considered the governing storm will be a mid-latitude extra tropical winter storm or frontal system, crossing the southern British Columbia coast and generating SE to SSW winds at 47 knots in the southern portion of the Strait of Georgia. No adjustment is made for any micro climate influences that might characterize the overwater wind field, the wave climate or the current regime across the extent of Boundary Bay.

An example of the expected variation in the wave climate across Boundary Bay is indicated in Figure 4, which shows how the sea state varies considerably across the intertidal area and how the wave direction close to shore (indicated by the black arrows) turns to the west along the east portion of the intertidal area. The higher sea state on the west side of Boundary Bay and the change in wave direction towards the west on the east side of Boundary Bay has the capability of tending to result in sedimentation in the centre of the bay.

Detailed assessment and quantification of the combined wave and current driven coastal processes will be required in later stages of a Living Dike evaluation.



**Figure 3: Observed Sea state during Storm of 7 April 2017 at 96th Street**  
 photo taken at high tide ( $\approx 1.5$  m CGVD, wind speed  $\approx 38$  knots in Strait of Georgia)



**Figure 4: Expected Wave Climate during a Severe SE Storm**  
 source: SNC R&D Project CE1- (water level = +3.1 m CGVD)

## Definition of the Designated Storm

The definition of the Designated Storm for this concept definition of the Living Dike concept is based on the updated Provincial Guidelines for Sea Dikes [3]. The key features of the Designated Storm are:

- Estimated joint, or combined probability, for total tide and storm surge water level during the design event; 1/10,000, based on the increasing value of land use in the low lying lands behind the existing dike, i.e:
  - Increasing warehouse parks in the vicinity of Boundary Bay airport
  - Increasing numbers of greenhouse farms
  - Increasing value of existing agricultural land, including their residential components
  - Important transportation links including road, rail and air (Boundary Bay airport and Delta Heritage Airport).
- Annual exceedence probability (AEP) for the Designated Storm: 1:500
- Peak incident storm surge: 1.3 m
- Local wind set-up in Boundary Bay: 0.4 m
- Peak wind speed and direction during the Designated Storm: 47 knots (24.2 m/s) from 160 deg T

The wave conditions expected at the toe of the dike during the Designated Storm are:

- Maximum breaking wave at toe of structure: 2 m
- Associated wave period: 7 seconds

## Dike Geometry and Wave Effects

For the purpose of this assessment, an average slope for the surface of the Living Dike of 1:15 (V:H) was used, based on the expectation that fine sand would be the primary structural component of the dike system. The average slope of 1:15 is based on Reference [16] for a fine sand material less than 0.3 mm diameter (mean grain size) and a relatively mild wave environment on the dike face. This slope represents a reasonable average dynamically stable slope for the Boundary Bay environment.

It is likely that the actual slope on the Living Dike face will vary depending on the strategy eventually taken to promote and assist vegetation in colonizing the dike and the strategies adopted to minimize local dike slope displacement during severe storms that should be expected during winter months.

The expected target elevation of the crest of the Living Dike, for a net sea level rise of 1 m, was defined based on wave runup and overtopping guidance for mild slope structures outlined in Reference [17]. A reduction factor of 0.8 was used to define the beneficial effect of the sub-aqueous existing eelgrass meadows during the design event. A further reduction factor of 0.75 was used to define the influence of the 1:15 dike slope and any salt marsh vegetation present over the upper intertidal portion of the dike.

More detailed procedures are available to define crest elevations and should be considered in later stages. The elevations defined at this stage are likely upper bound elevations for 1 m of net sea level rise.

### 3.3. Coastal Sediment Processes

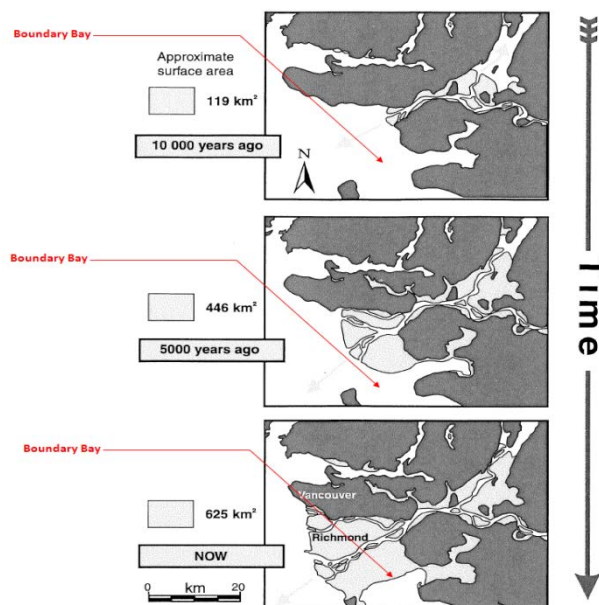
The Living Dike concept assumes that either the dike is located in a reasonably stable or depositional area and not subject to significant alongshore coastal sediment transport processes, or that appropriate control structures, such as a classical headland-beach systems, or similar approaches, are incorporated into the overall system design.

Coastal sediment processes are discussed in more detail below in the example application for this concept.

## 4. EXAMPLE APPLICATION

### 4.1. Selected Site

#### Physical Characteristics



**Figure 5: Historical Growth of the Fraser River Delta and Boundary Bay Area.**

source: GSC Bulletin 567, modified from Clague, (1994)

Although a Living Dike concept has the potential to be applied in many locations, including river and creek estuaries, small embayment beach locations, or as suggested above, on open coastlines with appropriate stabilization measures, a generic location within Boundary Bay was selected as an illustrative application basis for this assessment.

The shoreline configuration of Boundary Bay was formed over the last 5000 years, mainly by fluvial processes related to the Fraser River, the Serpentine River and the Nicomekl River, before the intervention of anthropogenic actions such as river training, dredging, agricultural related diking and the construction of the sea dams on the Serpentine and Nicomekl Rivers in the recent era (post mid to late 1800s). The geological growth of the Boundary Bay area is illustrated in Figure 5. As the Boundary Bay shoreline evolved it would also have been subject to coastal marine processes as the area interacted with historical pre-industrial age sea levels.

A preliminary review of the literature shows that very little documented information is available on the coastal processes or the wind and wave climate of Boundary Bay. A detailed assessment of the Beach Grove area, Page et al (1998), suggests that the western area of Boundary Bay, in the vicinity of Beach Grove, was historically supplied by coastal sediments from the cliffs along the Point Roberts headland area. Studies of the coastal processes on the east side of Boundary Bay, Warren et al (1978), including a shore processes assessment by Wolf Bauer for the Greater Vancouver Regional District (now Metro Vancouver Regional District) in 1977, suggests that prior to the armoring of the

Burlington Northern Railroad (now Burlington Northern Santa Fe Railway) right of way, the coastal bluffs between Kwomais Point and Crescent Beach supplied coastal sediments transported towards Crescent Beach and Blackie Spit at the entrance to the Nicomekl River. It is quite likely that some sediment was transported towards the middle portion of Boundary Bay by the residual tide or wind, wave, river outflow and tidal driven currents within Boundary Bay. Prior to the agricultural diking and construction of the sea dams on the Nicomekl and Serpentine Rivers, these rivers also likely supplied sediment to the Boundary Bay coastal system. It is also possible that prior to the diking of the main arm of the Fraser River between 1912 and 1935, [Atkins et al (2016)], and the construction of the Tsawwassen and Roberts Banks causeway structures in the 1960s and the Point Roberts marina jetties and breakwater in the 1980s, some sediments from the Fraser River may have found their way south around Point Roberts and into the Boundary Bay coastal system.

Prior to approximately the late 1950s, the shoreline of Boundary Bay was used extensively and productively for oyster farming. The approximate location of known oyster farming areas is shown on Figure 2. Oyster shell and larvae were laid along the shoreline, which suggests the area was exposed to relatively benign coastal forcing.

## Ecological Characteristics

The northern coastal portions of Boundary Bay, which include extensive high tide salt marsh, intertidal mud flats and low intertidal and shallow subtidal seagrass meadows, are extensively documented in Groulx et al (2004), Reference [22]. Within Reference [22], Harrison and Dunn (2004) summarize the extent of seagrass meadows from a 1992-1993 survey. Native eelgrass dominated 28% of the intertidal area of Boundary Bay (not including Semiahmoo Bay) while dwarf eelgrass (*Zostera Japonica*) dominated a further 8% of the area. Salt marsh dominated approximately 2% of the intertidal area. The results of more recent surveys undertaken by The Friends of Semiahmoo Bay Society and Ducks Unlimited were not specifically reviewed for this concept development.

These Boundary Bay areas, together with similar other areas in the Fraser River estuary and the adjacent agricultural areas, form a stopover route on the extensive Pacific Flyway migration route. There are no comparable sites along the Pacific Coast between California and Alaska, Harrison and Dunn (2004), Reference [22].

Views of the three main Boundary Bay areas are provided in Figure 6 and Figure 7.



**Figure 6: View of the mid intertidal mudflats and low intertidal limit of seagrass meadows in Boundary Bay – looking south from Beach Grove area**





*Figure 7: View of the mid intertidal mudflat and high intertidal salt marsh areas*

It is clear that the intertidal areas of Boundary Bay provide valuable ecological services, including forage fish habitat and important biofilm resources over the mud flats. It is also clear that both the subtidal and low intertidal seagrass meadows and the upper intertidal salt marsh areas provide valuable physical coastal engineering services that are well described in a number of reference materials. It is not the intent of this document to summarize the technical literature on the coastal engineering services provided by these areas; however, an outline of the known services are available in Reference [23], [24] and [25], among many.

## 4.2. General Configuration

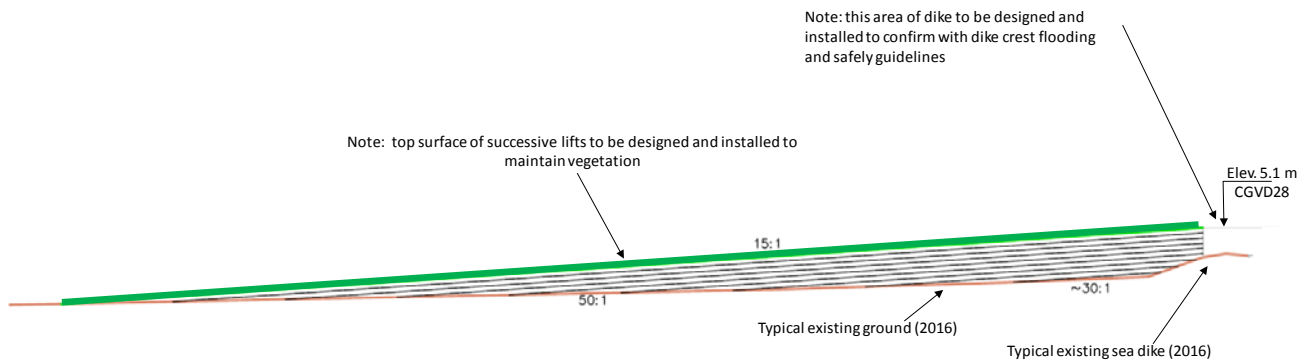
For the purpose of this concept development we have considered a prism of appropriate material, assumed to be fine sand, extending offshore from the existing coastal sea dike, at a uniform average slope, as described above, until it intersects the existing seabed in Boundary Bay. The working scenario is that the prism will be installed in successive lifts at a rate that needs to be compatible with acceptable sedimentation rates on an existing salt marsh, to be compatible with the time required for the marsh to respond and expand over the new sediment and to be compatible with the rate of rise of local sea level.

It is well recognized in the literature that natural salt marshes thrive in areas where there is ongoing sedimentation; however, guidance on acceptable rates of natural sedimentation is limited and varies widely. Page et al (1998), [18] state that the existing salt marsh at Beach Grove expanded with sedimentation rates of 2 mm/yr. Van Loon-Steensma and Vellinga (2013), [25] state that salt marshes have expanded in areas where more than 20 mm/yr sedimentation has occurred. Further assessment of the acceptable and compatible rates of sedimentation is required; however, for this assignment we have used a constant annual rate of sediment placement of 100mm/yr as an upper limit estimate. This rate would ensure, assuming it was compatible with biological processes, that the Living Dike would be at the required elevation to accommodate 1 m of sea level rise in the current most aggressive estimate of the future rate of sea level rise.

A schematic of the successive raising of the Living Dike prism is provided in Figure 8. It is fully expected that the actual surface of the Living Dike will vary from the indicated average slope as a result of:

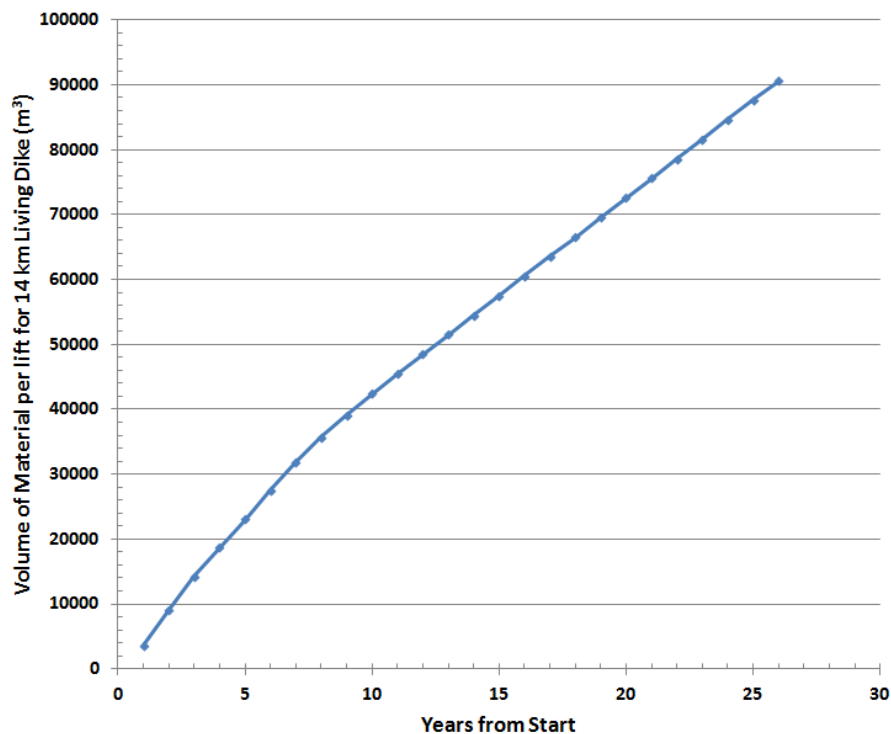
- Strategies to maximize the efficiency and effectiveness of salt marsh expansion after each lift

- Changes in the average slope due to either seasonal or episodic adjustment to metocean forcing.



**Figure 8: Schematic of Successive Lifts for Structural Component of Living Dike**  
(thickness of lifts exaggerated for clarity)

The volume required in each lift over a 14 km long Living Dike is summarized in Figure 9 based on the assumption that one 100 mm thick lift is applied every year. The total volume of new material required to achieve a Living Dike that provides the expected protection against flooding for 1 m of net sea level rise is 1.3 million m<sup>3</sup> of material spread over approximately 25 years.



**Figure 9: Volume of Material Required for Successive 100 mm Lifts**



As noted above, recent investigations, Reference [15], suggests that mean sea levels along the Pacific Northwest coast appear to be rising in recent years at a rate of 6 to 15 mm/year. Other studies, notably Hansen et al (2016), suggest that before 2100, sea levels may rise as fast as 50 mm/yr. These potential rates suggest that planting of lifts of 100 mm thickness would eventually have a recurring interim service life of 2 to 6 years before being submerged. A schematic illustrating this succession process is provided in Figure 10.

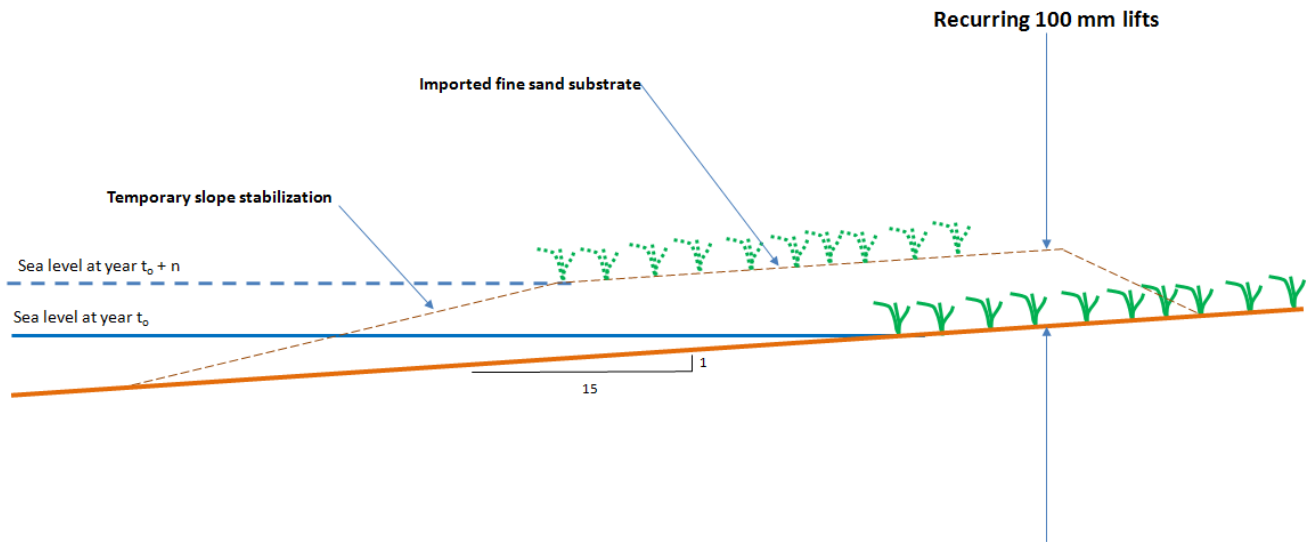
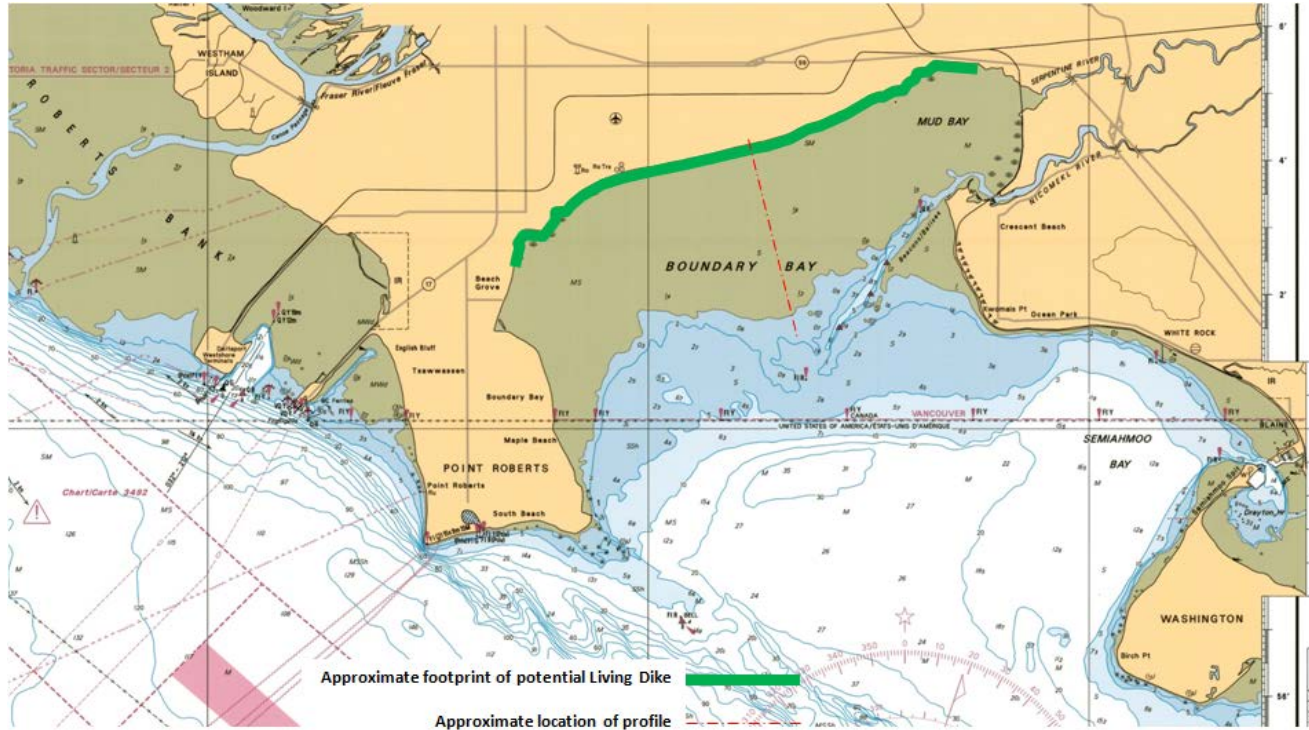


Figure 10: Schematic illustrating the potential succession cycle of recurring sediment lifts and supporting planting

## 5. IMPLEMENTATION AND CONSTRUCTION ISSUES

The general location of a Living Dike in Boundary Bay, as indicated in Figure 11, will mean that the supply of the required dike material (fine sand) to the area will be a significant implementation and construction challenge. The distance between the dike footprint and the 0 m (CD) contour is approximately 4 km and the distance to the 5 m (CD) contour is approximately 6 km. A depth of 5 m, which would be available at a high spring tide at the 0 m (CD) contour, at frequent intervals, is likely the minimum depth that would allow the supply of required dike material by tug and barge. The 5 m (CD) contour would likely be the point of closest approach for a fully loaded trailing suction hopper dredge carrying dredged fine sand material from (say) the Fraser River at high tide.

It should also be noted that the 5 m (CD) contour is located in and around the International Boundary between Canada and the United States. Supply of dike materials by sea will likely require international cooperation unless the material can be transferred at appropriate tides into the area between the International Boundary and the 0 m (CD) contour.



**Figure 11: General Location of a Living Dike Concept in Boundary Bay**

*source: CHS Chart 3463 – not for navigation*

An alternative means of supply for the necessary dike materials to the Boundary Bay area would be by land, most likely by truck, from a suitable source location, or by pumping in a dedicated slurry pipeline from a suitable source or transfer location.

For the purpose of this study, the preferred and most likely source for dike material is from the maintenance dredging program in the Fraser River. This program is currently undertaken on an annual cycle to maintain the navigation channel. The total volume of dike material required is approximately equal to one half to one year of the present (2017) maintenance dredging cycle and it is assumed for the purpose of this study that the total quantity will be supplied over many years. The expected supply rate is indicated in Figure 9, based on providing a 1 m sea level rise dike configuration.

Once the required material is transported to the general area, especially if by sea, there are several strategies that could be considered for moving material into the dike area. These can be loosely subdivided into natural and mechanical means. Natural means would include disposal in the shallow subtidal area (between approximately the 0 m and 5 m (CD) contours, where wave and current processes would be relied upon to move the material in a net landward direction over time. The initial disposal would most likely be by controlled bottom dumping, or by reversing the flow through the trailing suction hopper dredge dragheads, or by rainbowing techniques from a dredge.

Natural transport onshore would likely be feasible in the early years of dike implementation; when only small quantities are required in the initial lifts. However, evaluation of the maximum ecologically sustainable annual

rate of deposition into the sea, giving consideration to the effect on existing seagrass meadows and expected metocean conditions, still needs examination and definition.

A basis for the expectation that natural processes could be used to build the Living Dike structure over time is outlined in Takeda and Sunamura (1986), Nishimura and Sunamura (1986) and Mimura et al (1986). An alternative strategy would be to consider the concept of the “Sand Engine” technique, similar to that described in Stive et al (2013), where an appropriate volume of dike material could deliberately be placed at a suitable location on the shallow subtidal or intertidal shoreline of Boundary Bay.

Mechanical means would include placement of sand along the Boundary Bay shoreline by direct pumping from a hopper dredge located in at least 8 m water seaward of the intertidal area. This technique would require a floating or bottom founded supply line, or land based delivery to a storage area onshore.. As the distance from sufficiently deep water offshore of Boundary Bay is considerable (4 to 6 km), mechanical delivery onshore would likely involve additional pumping booster stations partway across the intertidal portions of Boundary Bay. Mechanical methods almost certainly ensure that most delivered material ends up in the target location.

## 6. ESTIMATE OF COST

Section 6 was prepared for Revision 1 of this document with the assistance of Project Watershed and Fraser River Pile and Dredging who provided implementation expertise and information on costing. The final cost estimates were prepared by SNC Lavalin Inc.

### 6.1. Costing Basis

For the purpose of defining an order of magnitude estimate of the cost of the Living Dike Concept we have built up a cost basis using the following scenario:

- The approximate location of the final Living Dike is shown in Figure 12.
- Sand material is sourced from the maintenance dredging program in the Fraser River and transported by hopper dredge to Boundary Bay for off-loading.
- Each hopper dredge load will consist of approximately 3500 m<sup>3</sup> of fine sand, based on draft limits for dredging in the Fraser River (freshwater).
- Three methods for delivery of the fine sand material to the shoreline are considered. For all three methods it is assumed that the delivery method and procedures will meet the project physical and environment requirements; however, further coastal process and supporting environmental (and permitting) evaluation studies are both required and anticipated for each method.
- The three delivery methods considered for this cost estimate are:
  - A. Delivery of material into deep (> 2 m chart depth) sub-tidal portions of Boundary Bay where the natural wave and current processes are expected to transfer the material to the shoreline. The offshore delivery area is shown in Figure 13 as Location A.

For the purpose of this estimate, it is assumed that only 1/3 rd of the delivered material will reach the Living Dike target area. The remaining 2/3rds are assumed to either remain in-place (without negative effect to existing ecological services) or will be transported by waves and currents to the

shoreline in other locations in Boundary Bay. The potential benefit the increasing the adjacent shoreline resilience to sea level rise is not considered in this cost estimate.

- B. Placement of material into shallow subtidal or low intertidal areas along the low tide portion of the intertidal area on the west and north sides Boundary Bay. Approximate delivery areas are shown in Figure 14 as Location B.

It is assumed this delivery method will also meet the project physical requirements; however, further coastal process and supporting environmental (and permitting) evaluation studies are both required and anticipated. For the purpose of this estimate, it is assumed that 1/2 of the supplied material will reach the target area. The remaining half of the material is assumed to either remain in-place (without negative effect to existing ecological services) or be will be transported naturally ashore and likely deposited along the shoreline between Boundary Village and the west end of the Living Dike. The benefit to increasing the Boundary Village – Beach Grove shoreline resilience to sea level rise is not considered in this cost estimate.

- C. Pump Ashore from three potential locations in the deep areas (approximately 8 m water depth including tidal assist) of Boundary Bay, in Canadian waters, to stockpile areas located along the landward edge of existing sea grass meadows. The assumed transfer areas are shown in Figure 15 as Location C. Delivered sand is transferred annually, as needed, using a small pontoon based dredge, floating line and spreading system.

For the purpose of this estimate it is assumed that 90 per cent of the delivered material will end up in the required location along the target area. The cost estimate for this supply method includes the cost of plant and operations required onshore to spread the material as required, as part of the salt marsh planting program.

Additional details of each method are summarized in Section 6.2.

For the purpose of this cost estimate the following unit rates have been used:

- Delivery of fine sand sediments to stockpiles in Boundary Bay: \$38/m<sup>3</sup> – source FRPD.
- Delivery of sediments to Boundary Bay ( Method A or B): \$35/m<sup>3</sup> source FRPD.
- Transfer of delivered sediment to shoreline areas: \$21/m<sup>3</sup> – source FRPD.
- Nursery cost for salt marsh plants: \$2/plant: - source PW.
- Planting labour: \$14/hr:- based on current minimum wage plus benefits.
- Core material for revised upgraded Standard Dike: \$66/m<sup>3</sup> – tendered prices 2015/2017.
- Armour material for revised upgraded Standard Dike: \$73/m<sup>3</sup> – tendered prices 2015/2017.
- Indirect cost allowance (all methods): 10 to 15 % of direct costs as noted below.
- Contingency allowance (all methods): generally 15 % of direct costs as noted below.
- Mob/demob costs include acquisition, assembly and storage of project specific dredge plant and pipelines as required.
- Suction Hopper dredge costs assume use of BC located dredge.





**Figure 12: Approximate Location of seaward toe of final Living Dike**  
 (note: Canada - US border is at bottom of image)  
 (contours shown are from CHS chart 3463)



**Figure 13: Sand Delivery Area for Method A**



Figure 14: Sand Delivery Areas for Method B



Figure 15: Sand Delivery System for Method C



## 6.2. Supply and Placement of Sand Material

### Method A

The costing basis for Method A includes:

- Sand material is sourced in the Fraser River and is transported and placed in the area indicated in Figure 13 at the required amounts, as indicated in Figure 9, every year.
- Placement occurs during high tides at any hour and without weather restrictions.
- The rate of vessel sailing or of pumping during placement is assumed to conform to any turbidity requirements and is yet to be defined.

### Method B

The costing basis for Method B includes:

- Sand material is sourced in the Fraser River and is transported and placed in the area indicated in Figure 14 at the required amounts, as indicated in Figure 9.
- Selection of the delivery location and of the amount may vary from year to year depending on monitoring results of the sand migration along the shoreline.
- Not all potential locations are expected to be used every year.

### Method C

The costing basis for Method C includes:

- Sand material is sourced in the Fraser River and is transported and pumped to the stockpile areas shown in Figure 15 at approximately 10 year intervals.
- For the purpose of this study it is assumed that approximately 1/3 of the total required volume of sand is pumped to the three stockpile areas at each 10 year interval.
- The stockpiles are not protected by coastal structures (i.e. submerged rock reefs or breakwaters) and some natural migration of sand ashore is expected.
- The final locations of the stockpile areas are assumed to be landward of existing seagrass meadows and no offsets are required.
- Compaction of the seabed under the stockpiles is expected over time; however, no offsets or limits on recovery of delivered sand volumes are imposed.
- The floating pipeline routes for sand delivery to the stockpile areas will be aligned along the natural channels that exist, as visible in Figure 11. The pipeline routes in Figure 15 are indicative only.
- Recovery of sand from the stockpile areas will be undertaken on an annual basis to supply the volumes along the shoreline at the rates indicated in Figure 9.
- Recovery and placement of sand on the annual basis will be undertaken using a small pontoon based suction dredge, operating at high tide, in the shoreline proximity areas shown in Figure 15.
- The landward end of the pontoon dredge related floating pipeline will be equipped with a second pontoon equipped with a mounted baffle system or spray nozzles to control the placement and velocity of sand directed onto existing salt marsh.



- Examples of the expected pipe end pontoon based systems can be viewed at the USACE “Thin Layer Placement” technology website at:

<https://tlp.el.erdc.dren.mil/what-is-tlp/>

### 6.3. Installation of Salt Marsh

The costing basis for the installation of the salt marsh component is based on the following scenario, which is based on the methodology employed by Project Watershed in the ongoing salt marsh restoration projects in the Comox River estuary. The salt marsh installation and succession approach can be summarized as follows:

- It is assumed that the sand sediment foundation for each salt marsh succession increment is already in place and rough graded as described in Section 6.2.
- Detailed grading of the in place material to create the inter salt marsh island channels and marsh area elevation grading is included in the salt marsh construction costs.
- Access to the marsh areas for equipment, supplies and personnel is from the existing dike.
- Restoration of the access right of ways over any existing marsh or dike is included in the salt marsh costs.
- Marsh islands will be protected on the seaward side during the 3 year cycle by sacrificial sand berms.
- Marsh creation will likely occur over a 3 year cycle as follows:
  - Year 0 (spring – summer): nearshore delivery and grading of sand marsh islands and channels
  - Year 1 (spring – summer): planting of required marsh plants to aid natural recruitment
  - Year 2 (spring – summer): augmentation planting of marsh plants to aid marsh establishment
  - Year 3 (spring – summer): minor augmentation to offset any observed damage
  - Year 4 (spring – summer) placement of successive sand lifts as defined by Living Dike implementation plan.
- New marsh islands will be created each year in a stepwise leapfrogging manner.
- The costs are based on multiple 10 person planting crews, with supervision and monitoring for every 5 crews.
- The costing is based on an average thickness of sediment to be supplied every year of 100 mm. This thickness assumes that existing salt marsh will grow through the overlay and only needs to be supplemented with new plant stock.
- Each salt marsh island is monitored and maintained for a period of 3 years, after which it is assumed it may be absorbed into a successive lift of Living Dike as indicated in Figure 8 and Figure 10.
- The cost estimate includes the cost of the 3 years of monitoring and of augmentation, each year, of the marsh plants.

## 6.4. Order of Magnitude Cost Estimates

Table 2: Comparison of Living Dike Alternatives

	Delivery Method			Comment
	A Placement in subtidal waters	B Placement in intertidal water (Sand Engine concept)	C Pumping ashore	
<b>Direct Costs</b>				
<b>Delivery of Sand</b>	\$171,000,000	\$114,000,000	\$135,000,000	Methods A and B assume some loss of sand to adjacent areas of Boundary Bay
<b>Salt Marsh Planting</b>	\$23,000,000	\$23,000,000	\$23,000,000	Assumes planting at a rate of one plant every 0.5 m with supplemental planting in years 2 and 3 of the lift cycle.
<b>Total Direct Costs</b>	<b>\$194,000,000</b>	<b>\$137,000,000</b>	<b>\$158,000,000</b>	
<b>Indirect Costs</b>				
<b>Supporting Investigations and design</b>	\$19,400,000	\$13,700,000	\$15,800,000	Includes front end science and engineering and pilot projects
<b>Contingency</b>	\$31,900,000	\$22,600,000	\$26,000,000	
<b>Total Costs</b>	<b>\$245,000,000</b>	<b>\$173,000,000</b>	<b>\$200,000,000</b>	

**Notes:**

- a. All cost components rounded up
- b. Applicable taxes not included

It should be noted that the Living Dike concepts costs include several assumptions that still need to be validated with appropriate pilot projects or studies:

- Method A assumes that only 1/3 of the sand material delivered into the subtidal waters of Boundary Bay actually ends up at the shoreline along the existing dike alignment. It is assumed that full salt marsh planting will still be required although it is possible that natural recruitment of the existing marsh will occur as the sand migrates onshore at a natural rate.
- Method B assumes that only 1/2 of the sand delivered onto the intertidal portions of Boundary Bay actually ends up at the shoreline along the existing dike alignment. It is assumed that full salt marsh planting will still be required although it is possible that natural recruitment of the existing marsh will occur as the sand migrates alongshore at a natural rate.

- All methods assume that the entire surface of the Living Dike will need to be planted to aid salt marsh development, even though the chosen thickness of successive lifts (100 mm) is understood at this time to allow full recovery of the underlying existing salt marsh after 2 to 3 years, without planting.
- The potential benefits along adjacent shorelines of some of the sand which does not get naturally transported to the target area is not included as a benefit of the Living Dike Concept,

## 6.5. Life Cycle Costing

The Living Dike concept is intended to be installed over a 25 to 30 year period of time. During that time period costs are likely to change due to various factors. For the purpose of this study all costing is based on 2017-2018 costs without any further adjustment.

As noted below, material costs for the Standard Dike alternative were updated to reflect tendered costs from 2017. No adjustment was made for costs of non sand material cost related items, including utility relocation, lift station improvements, flood box upgrades, or agricultural land acquisition. These cost components of the Standard Dike alternative are 2012 prices.

No estimate is included in this study for the likely timing of construction of the Standard Dike alternative. It is assumed that the Living Dike would start installation of the first lift of sediment sometime in the next 2 to 5 years. No adjustment is made for the installation date of the Standard Dike alternative.

Neither the Living Dike concepts or the Standard Dike alternative contain any allowance for beyond design criteria storm or other damage over the comparison time basis, which is assumed to be approximately the next 30 years.

## 6.6. Comparison with Alternatives

For the purpose of this development and assessment of the estimated order of magnitude of cost of the Living Dike, we have compared the estimate of cost for the Living Dike with the estimate of a Standard Dike as outlined for the Boundary Bay portion of the overall study described in MFLNRO (2012), [31].

Our review of the 2012 dike section in this area (Shoreline #21 in [31]) indicated that the suggested cross section did not fully account for ongoing upgrades to the existing dike in this area (which are not yet fully implemented along the entire 14 km of the dike) nor did the 2012 design fully reflect the more detailed engineering included in the ongoing upgrades. We have adjusted the cost estimate in [31] as follows:

- the unit (per meter of dike) volumes indicated in [31] were modified to conform with recent upgrades to the Boundary Bay dikes.
- the unit rates in [31] for supply and placement of materials were updated to reflect recent tendered costs for work in this area of the Lower Mainland
- No adjustments were made for related costs including: utilities relocation, pump stations, flood box improvements.
- Agricultural land acquisition areas were adjusted to reflect the slightly wider upgraded Standard dike footprints which reflect the reviews and requirement in 2016 and 2017 of the Inspector of Dikes and the South Coast Wildlife Management Area.

- No adjustment was made for the agricultural land acquisition cost assumed in 2012.
- The 50 per cent contingency in the 2012 report was reduced to 25 per cent to reflect the more detailed engineering reflected in the work done for dike upgrades in 2016 and 2017.

The cost estimate for the revised upgraded Standard Dike in Boundary Bay (Shoreline #21 in [31]) is summarized below in Table 3.

*Table 3: Estimated Costs for a Standard Dike Alternative in Boundary Bay*

	2012 estimate \$	Upgraded (2018) estimate \$	Comment
<b>Direct Costs</b>			
<b>Dike Structure</b>	82,858,200	178,175,662	
<b>Environmental Offsets</b>	0	1,428,947	Only includes planting at the top of the dike. No allowance for any potential scouring seaward of the dike.
<b>Utilities</b>	4,137,000	4,137,000	2012 pricing
<b>Pump Station</b>	2,500,000	2,500,000	2012 pricing
<b>Flood Box</b>	2,000,000	2,000,000	2012 pricing
<b>Land Acquisition</b>	8,129,990	9,670,727	2012 pricing
<b>Indirect Cost</b>	14,943,779	19,791,234	As defined in [31]
<b>Contingency</b>	57,284,484	32,655,535	Reduced to 25% for upgraded estimate
<b>Total Cost</b>	<b>\$171,854,000</b>	<b>\$250,360,000</b>	

## 6.7. Summary of Cost Evaluation

The results of this assessment of the likely order of magnitude cost for the Living Dike suggests:

- The total installed cost of the Living Dike concept, for a 1 m net sea level rise, varies between \$173 million and \$254 million dollars depending on how the sand required for the dike structure is delivered to the shoreline.
- The most reliable sand delivery method – Method C – has a total installed cost of \$200 million dollars.
- A Standard Dike in Boundary Bay) has an estimated (upgraded) total cost of \$250 million for a 1 m net sea level rise scenario; however, some components of this estimate may not reflect 2017 prices for utility relocation, Pump Station upgrades or relocation, Flood box improvements or Land Acquisition. The estimated \$250 million estimate for the Standard Dike alternative may be a low estimate for this alternative,
- It is assumed that utility relocation, Pump Station upgrades or relocation, Flood box improvements or Land Acquisition are not required for the Living Dike because the Living Dike is seaward of the existing dike and has no significant effect on structures or lands behind the dike.
- Offsets are not required during the implementation of the Living Dike concept.

## 7. INFORMATION AND TECHNICAL GAPS

The purpose of this document is to summarize the Design Basis for a Living Dike concept and to outline gaps in the available information to both refine the feasibility of the Living Dike concept and to apply the concept in the Boundary Bay area. The identified gaps and next steps are organized in the remainder of this section according to two general topics; gaps for the Living Dike Concept and gaps in information in Boundary Bay.

### 7.1. Information Gaps for the Living Dike Concept

It is clear that there are several gaps related to the Living Dike concept that need to be addressed to confirm the feasibility of the concept:

- While salt marshes are generally acknowledged to thrive in areas where sedimentation is ongoing, it is not known what maximum rates of ongoing sedimentation (mm of deposition per year) will allow an existing salt marsh to continue to exist in place or to naturally expand as the result of supply of new sediment.
- The general annual average horizontal rate at which a salt marsh will expand and thus how much edge erosion due to storm wave or currents can be tolerated is generally not known.
- The sensitivity of new or pioneer salt marsh vegetation, compared to established vegetation, to ongoing sedimentation, or to burial to some depth (e.g. 100 mm lifts) is generally not known.
- As outlined above, deposition and migration of dike materials (fine sand) over or through low tide or shallow subtidal areas will affect existing marine habitat areas and values. It is generally not known what rates of sedimentation can be tolerated in existing seagrass or mudflat areas.
- There is very little information available on successful strategies for encouraging, aiding and sustaining salt marsh expansion in a scenario where sea levels are rising and successive lifts of dike material (fine sand) are being deposited.
- The concept to date considers the use of mainly fine sand – likely dredged from the Fraser River – as the main “structural” component of the Living Dike. It is not known if fine sand alone would be a suitable medium for successful salt marsh colonization or expansion. Finer sediments (silt or clay) or organic material (beach wrack) may be required to provide necessary nutrients for successful plant survival. Fine sediment content may also provide an important source for sustaining the ecological services provided by the biofilm found in mudflat areas seaward of the existing salt marshes.

### 7.2. Information and Technical Gaps for Implementation at Boundary Bay

This high level assessment of the feasibility of a Living Dike concept in Boundary Bay has identified several important gaps in the available information in this area, including:

- The existing state and status of marine habitat and related ecological services in the area. It is known that eelgrass mapping is ongoing in the area; however, the scope of this study did not permit further evaluation or quantification of the recent mapping.
- A detailed description of either the historical or the present geomorphologic processes throughout Boundary Bay, other than some limited descriptive information from the 1970s, is not available. It is not known if the area is generally accreting or slowly degrading as the result of various developments: diking, sea dams, river training and breakwater and causeway construction.

- A detailed description of the coastal sediment processes; i.e. rates of sediment supply to the area, sediment transport trends and rates or sediment pathways and rates of transport is not available.
- The intertidal portions of Boundary Bay have never been surveyed inland of the 0 m (CD) contour. The absence of accurate bathymetric data will influence the understanding of coastal sediment transport processes and of the geomorphologic setting.
- There is a general lack of recorded metocean data in the area, including local wind data or measured wave or current data. The absence of recorded data of this type limits the level of confidence that can be stated for numerical modeling results of coastal processes in Boundary Bay. Next steps should include:
  - Definition of the overwater wind field in the area, which will affect the confidence in the shallow water wave climate for design purposes.
  - Definition of the shallow water wave climate, which will affect understanding of the relative stability of any dike structure during both storms and over longer (inter-annual and inter-decadal) intervals.
  - Definition of the tidal, wind, wave and river driven currents in the area, which will have similar influences on dike (and plant) stability.
- The absence of reliable metocean data will also limit the level of confidence and reliability that can be attributed to any assessments of the feasibility of natural, or other means of moving sediments from shallow subtidal or intertidal areas into the higher intertidal areas of Boundary Bay.

## 8. GLOSSARY AND ABBREVIATIONS

Definitions and abbreviations of terms used in this report are listed below.

	2011 Provincial Guidelines	Guidelines posted by BC Ministry of Environment, BCMoE (2011a,b,c), and available online at: <a href="http://www.env.gov.bc.ca/wsd/public_safety/flood/fhm-2012/draw_report.html#3">http://www.env.gov.bc.ca/wsd/public_safety/flood/fhm-2012/draw_report.html#3</a>
AEP	Annual Exceedance Probability	The current probability of a specific event occurring (or being exceeded) in any given year.
CD	Chart Datum	At Boundary Bay, CD is 2.75m below Geodetic Datum (CGVD28).
DFL	Designated Flood Level	A water surface elevation which includes appropriate allowances for future SLR, land crustal movement, tide, and storm surge during the Designated Storm. The effects of wave action are not included in the DFL.
DS	Designated Storm	A storm, which includes concurrent winds, storm surge and waves, and which has a specific AEP.
	Fetch	The horizontal distance over open water (in the direction of the wind) over which wind generates waves.
FCL	Flood Construction Level	Defined as the underside elevation of a wooden floor system for habitable buildings, or the top elevation of a concrete slab for habitable buildings [2].
	Freeboard	A vertical allowance added to the DFL and the Wave Effect allowance to establish the FCL. This allowance is included to cover any uncertainties in defining the FCL.
HHWLT	Higher High Water Large Tide	The average of the annual highest tides over the 18.6 year tidal cycle.
H <sub>s</sub>	Significant Wave Height	The mean height of the highest 1/3 of waves recorded in a given sea state and approximately equal to the wave height estimated at sea by experienced observers.
	Overtopping	The passage of water over the seaward edge of the shoreline as a result of wave run-up.
	Residual Water Level	The component of the measured water level that is not attributed to tidal effects. The residual water level is generally assumed to be approximately equal to the storm surge. Calculated as the measured total water level minus the predicted tides at a given location.



	Run-Up	The vertical distance travelled by waves that up the shoreline or the seaward face of a shoreline structure.
SLR	Sea Level Rise	The rise in sea level including: global sea level rise driven by global warming and local sea level rise driven by regional tectonic or isostatic (glacial) subsidence or uplift.
	Storm Surge	The non-tidal rise/fall in a body of water due to atmospheric effects.
	Sea state	Used to summarize, in a general way, all of the parameters and characteristics necessary to define waves at a given time and location. For engineering purposes, the sea state is often characterized by the significant wave height $H_s$ .
SWAN	<b>Simulating WAves Nearshore</b>	Wave modelling software, which can simulate waves generation and offshore wave transformation to the nearshore.
°T	Degrees, True North	Direction in degrees, with respect to True North.

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## 11. REVISION INDEX AND SIGNATURES

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Issue Code	Rev. No	Date (yyyy-mm-dd)	Description of Changes	Initials
RR	PA	2017-04-13	Released for Review and Comment	JSR
RR	PB	2017-04-13	Released for Client Review and Comment	JSR
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<b>RC</b>	Released for Construction
<b>RD</b>	Released for Design
<b>RF</b>	Released for Fabrication
<b>RI</b>	Released for Information
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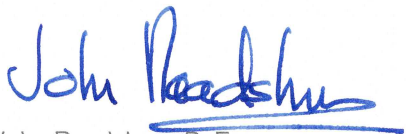
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