

Greening Shorelines to Enhance Resilience:

An Evaluation of Approaches for Adaptation to Sea Level Rise

June 2014





This report was written by Grant Lamont, John Readshaw, Clifford Robinson and Philippe St-Germain of the SNC-Lavalin Coastal Engineering Group and produced for the Stewardship Centre for British Columbia, 2014. Report available at www.GreenShores.ca.

Suggested Citation:

Lamont, G., Readshaw, J., Robinson, C., St-Germain, P. (2014): Greening Shorelines to Enhance Resilience, An Evaluation of Approaches for Adaptation to Sea Level Rise; guide prepared by SNC-Lavalin Inc. for the Stewardship Centre for B.C. and submitted to Climate Change Impacts and Adaptation Division, Natural Resources Canada (AP040), 46p.

Acknowledgements

Funding was provided for this study by Natural Resources Canada with in-kind support by the organizations represented in the project Advisory Committee. The committee provided assistance with quality assurance, relevancy, consistency with other shoreline guidance and initiatives, collaboration, and outreach to key audiences. Thanks are extended to the following organizations for their contribution to the project: Flood Protection Program, Emergency Management BC; Town of Qualicum Beach; West Vancouver Shoreline Preservation Society; Climate Change Adaptation Secretariat, BC Ministry of Environment; District of West Vancouver; the Green Shores Technical Advisory Committee, and Washington Sea Grant, Seattle, WA.

This document does not necessarily represent the views of individual members of the Advisory Committee, or the official positions of the organizations with which the individual committee members are associated.

With support from Natural Resources Canada through the Adaptation Platform



Natural Resources Canada
Ressources naturelles Canada

The Stewardship Centre for BC

The Stewardship Centre for BC (SCBC) was created to assist governments, businesses, conservation and environmental organizations, and citizens carry out stewardship activities in the most efficient, effective, and rewarding ways. A leader in promoting stewardship values as the foundation for sustainability, the SCBC wants to help make “shared stewardship” – the voluntary adoption of environmentally sustainable practices by all sectors of society – a reality in British Columbia. As good stewardship relies on good decision-making, we work closely with our partners to develop innovative technical, educational, and capacity building resources. Green Shores™ is a program of SCBC. For further information contact SCBC by email info@stewardshipcentrebc.ca, toll-free 1-866-456-7222, or go to www.StewardshipCentreBC.ca.

Cover Photos

Main cover, bottom left and right: Harriet Rueggeberg, Little Qualicum River Delta, BC. *Photos taken during similar conditions at high-tide with a wind speed of approximately 32 knots.*

Bottom middle: John Readshaw, Cox Bay, BC.




Disclaimer The Stewardship Centre for BC provides the information in this report found on the Green Shores website for educational purposes only. Material contained within it carries no guarantee of any kind, express or implied. SCBC does not endorse, recommend or control linked websites and accepts no responsibility whatsoever for their contents or views. The Stewardship Centre for BC accepts no liability for damages to any person or business entity because of using this website, its information or any website linked to it.



ENGINEERING REPORT


GREENING SHORELINES TO ENHANCE RESILIENCE

AN EVALUATION OF APPROACHES FOR ADAPTATION TO SEA LEVEL RISE

| | | |
|------------------------------|--|---|
| Contributors: | Clifford Robinson/Grant Lamont/ Phillipe St-Germain/John Readshaw |  |
| Reviewed and Approved by: | John Readshaw |  |
| Approved by SCBC: | DG Blair |  |
| | <i>Name</i> | <i>Signature</i> |

| | | | |
|--------------|-----------------------|---------|---|
| Document No. | 614443-1000-41ER-0001 | Rev No. | 0 |
|--------------|-----------------------|---------|---|

| | |
|--|------------|
| © 2014 SNC-LAVALIN INC. This document is licensed to the Stewardship Centre for British Columbia and may be used and distributed for educational purposes, subject to the Notice to Readers set out herein. | 2014/06/30 |
|--|------------|


| | | |
|--|--|------------------|
|  | GREENING SHORELINES TO ENHANCE RESILIENCE | PAGE: 2 of 44 |
| | | DATE: 2014/06/30 |
| | AN EVALUATION OF APPROACHES FOR ADAPTATION TO SEA LEVEL RISE | REVISION NO.: 0 |

NOTICE TO READERS

This document contains the expression of the professional opinion of SNC-Lavalin Inc. (“SLI”) as to the matters set out herein, using its professional judgment and reasonable care. It is to be read in the context of the Agreement, and the methodology, procedures and techniques used, SLI’s assumptions, and the circumstances and constraints under which its mandate was performed. This document is written solely for the purpose stated in the Agreement, and for the sole and exclusive benefit of the Client, whose remedies are limited to those set out in the Agreement. This document is meant to be read as a whole, and sections or parts thereof should thus not be read or relied upon out of context.

SLI has, in preparing any cost estimates, followed methodology and procedures, and exercised due care consistent with the intended level of accuracy, using its professional judgment and reasonable care, and is thus of the opinion that there is a high probability that actual costs will fall within the specified error margin. However, no warranty should be implied as to the accuracy of any estimates contained herein. Unless expressly stated otherwise, assumptions, data and information supplied by, or gathered from other sources (including the Client, other consultants, testing laboratories and equipment suppliers, etc.) upon which SLI’s opinion as set out herein is based has not been verified by SLI; SLI makes no representation as to its accuracy and disclaims all liability with respect thereto.

SLI disclaims any liability to the Client and to third parties in respect of the publication, reference, quoting, or distribution of this report or any of its contents to and reliance thereon by any third party.

| | | |
|--|--|------------------|
|  | GREENING SHORELINES TO ENHANCE RESILIENCE | PAGE: 3 of 44 |
| | | DATE: 2014/06/30 |
| | AN EVALUATION OF APPROACHES FOR ADAPTATION TO SEA LEVEL RISE | REVISION NO.: 0 |

SUMMARY

This report describes the results of an initial study to advance policies and practices in British Columbia, and elsewhere, with regard to the use of “soft” shore armoring alternatives¹ within the context of climate change, sea level rise (SLR) practices and guidelines and flood protection. The study was initiated by the Stewardship Centre for British Columbia (SCBC), with the support of Natural Resources Canada (NRCan).

The intent of this study was to test several approaches, for specific case examples, and evaluate the effectiveness of the soft shore armoring alternatives, compared to an equally appropriate hard alternative², based on the following criteria:

- Adaptability to climate change related sea level rise.
- Their effectiveness in protecting the shoreline against flooding.
- Their effectiveness in providing ecological resilience.
- Their relative cost, considering initial capital cost, maintenance cost and long term replacement cost.

For the purpose of this evaluation, 3 soft shore alternatives were selected for evaluation:

- Use of a mainly beach nourishment or shore replenishment alternative, consisting of supply and placement of typical beach intertidal materials – ranging from sand to a gravel/cobble mixture.
- Use of nearshore – mainly inter-tidal - rock features, including boulder clusters and inter-tidal and sub tidal rock habitat reefs.
- Use of a typical headland – beach system to maintain a conventional beach intertidal substrate in an area exposed to incident waves from more than one primary direction.

In the first two alternatives, the soft shore alternative is applied to the adaptation of an existing community scale hard shoreline. In the alternative, the soft shoreline alternative was already in place. In this particular example, the soft shore alternative is compared to a conventional sea dike alternative to provide additional insight.

In all cases, the hard and soft alternatives provided appropriate levels of flood protection for the scenario considered in this study.

The results of this assessment of alternate approaches to providing flood protection to coastal shoreline developments indicates that in all cases, the soft alternative provides a significant cost advantage over the hard alternative. The margin of cost saving varies, ranging from approximately 35 per cent of the cost of the hard alternative for Case 1 to 75 per cent of the cost of the hard alternative for Case 2.

In all cases, based on the evaluation framework for ecological services developed for this study, the soft alternatives proved better or neutral opportunities for ecological resilience of the shoreline. It should be noted that the framework evaluation was based on limited information at each site; however, in Case 2, the framework clearly indicated that even a hard alternative, when combined with supporting ecological based efforts, could provide a net positive or better opportunity for ecological resilience. This outcome suggests that the evaluation framework could provide a useful methodology for the evaluation of the ecological attributes of future flood protection projects.

¹ “soft” shore armoring techniques include, in general terms: beach nourishment, restoration or construction, dune and wetland construction, shore vegetation preservation or restoration and construction of (nearshore) reefs and berms and similar, generally rocky features as part of the system. A detailed summary of soft shore armoring techniques can be found in Reference [1].

² “hard” armoring approaches include, in general terms: seawalls and revetments, including vertical concrete seawalls, steel sheet pile seawalls, bulkhead systems, gabion, and rock armour revetments, and conventional sea defense diking systems. A detailed summary of hard shore armoring techniques can be found in Reference [1].


| | | |
|--|--|------------------|
|  | GREENING SHORELINES TO ENHANCE RESILIENCE | PAGE: 4 of 44 |
| | AN EVALUATION OF APPROACHES FOR ADAPTATION TO SEA LEVEL RISE | DATE: 2014/06/30 |
| | | REVISION NO.: 0 |

TABLE OF CONTENTS

INTRODUCTION..... 5

1.1 BACKGROUND5

1.2 TERMS OF REFERENCE AND SCOPE.....6

1.3 ACKNOWLEDGEMENT7

2.0 DESIGN BASIS 8

3.0 FRAMEWORK MODELS 9

3.1 EVALUATION OF ECOLOGICAL RESILIENCE.....9

3.2 EVALUATION OF COST EFFECTIVENESS 13

4.0 CASE EXAMPLES..... 14

4.1 CASE EXAMPLE 1 15

4.1.1 *Background* 15

4.1.2 *Existing Shoreline* 16

4.1.3 *Hard Alternative*..... 16

4.1.4 *Soft Alternative* 17

4.2 CASE EXAMPLE 2 18

4.2.1 *Background* 18

4.2.2 *Existing Shoreline* 19

4.2.3 *Hard Alternative*..... 19

4.2.4 *Soft Alternative* 20

4.3 CASE EXAMPLE 3 21

4.3.1 *Background* 21

4.3.2 *Existing Shoreline* 22

4.3.3 *Hard Alternative*..... 22

4.3.4 *Soft Alternative* 24

5.0 ASSESSMENT OF CASE EXAMPLE ALTERNATIVES 25

5.1 ECOLOGICAL ASSESSMENT OF CASE EXAMPLE ALTERNATIVES 25

5.1.1 *Case Example 1* 25

5.1.2 *Case Example 2* 26

5.1.3 *Case Example 3* 27

5.1.4 *Summary of Ecological Services Assessment*..... 29

5.2 CAPITAL COST 29


6.0 SUMMARY AND RECOMMENDATIONS..... 31

6.1 SUMMARY 31

6.2 RECOMMENDATIONS 31

7.0 REFERENCES 33

APPENDIX A 34

| | | |
|--|--|------------------|
|  | GREENING SHORELINES TO ENHANCE RESILIENCE | PAGE: 5 of 44 |
| | AN EVALUATION OF APPROACHES FOR ADAPTATION TO SEA LEVEL RISE | DATE: 2014/06/30 |
| | | REVISION NO.: 0 |

INTRODUCTION

1.1 Background

This report describes the results of an initial study to advance policies and practices in British Columbia, and elsewhere, with regard to the use of “soft” shore armouring alternatives¹ within the context of climate change, sea level rise (SLR) practices and guidelines and flood protection. The study was initiated by the Stewardship Centre for British Columbia (SCBC), with the support of Natural Resources Canada (NRCan) and was awarded to SNC-Lavalin Inc in response to a proposal responding to a call for proposals dated 27 March 2013.

The purpose of the project was to conduct an evaluation of approaches to providing shoreline protection, that were consistent with Green Shores³ approaches, comparing them to traditional “hard” armouring approaches², within the context of expected future climate change and sea level rise scenarios.

As the global climate changes, with various associated impacts, including an increasing rate of sea level rise, it is expected that both existing and new developments will require protection from flooding, both as the result of flooding of low lying lands or as the result of geomorphologic changes, themselves potentially influenced by the impacts of global climate change.

In British Columbia, over half of the province’s 29 Regional Districts are bounded by tidal waters and exposed to the risks presented by climate change related sea level rise. Approximately 30 per cent of the municipal governments in the province and approximately two-thirds of the province’s population are also exposed the future expected consequences of climate change related sea level rise.


The intent of this study was to evaluate the effectiveness of soft shore armouring alternatives, compared to an equally appropriate hard alternative, using specific case examples, based on the following criteria:

- Adaptability to climate change related sea level rise.
- Their effectiveness in protecting the shoreline against flooding.
- Their effectiveness in providing ecological resilience.
- Their relative cost, considering initial capital cost, maintenance cost and long term replacement cost.

Adaptation of existing shoreline developments, such as the case examples in this study, to expected effects of climate change, and in particular, to sea level rise, can take several forms, including Protect, Accommodate or Retreat. For the purpose of this study, it has been assumed that a decision to Protect the existing shoreline development has been made. On this basis, the conceptual design for both hard and soft alternatives is based on providing a consistent level of protection that meets the provincial standards established for flood protection works.

It is recognized that there are many possible outcomes of a process that would typically unfold in any community when a decision to Protect is made. The alternatives in this study are only one example and their development is based only on the two dimensional (cross-shore) aspects of the site. The conceptual solutions represent only one outcome of several that might be initially considered in each specific case.

³ *The Green Shores program was initiated by SCBC in 2005 with multiple funding partners and with the assistance of the Green Shores Technical Advisory Team. Details of the Green Shores program can be found at the Green Shores website: www.greenshores.ca or at www.stewardshipcentrebc.ca.*

| | | |
|--|--|------------------|
|  | GREENING SHORELINES TO ENHANCE RESILIENCE | PAGE: 6 of 44 |
| | AN EVALUATION OF APPROACHES FOR ADAPTATION TO SEA LEVEL RISE | DATE: 2014/06/30 |
| | | REVISION NO.: 0 |

A comprehensive multi-stakeholder process, which considers all aspects, in all respects, of the complex and interrelated concerns and interests of a community, would likely identify other approaches for consideration. The conceptual designs presented in this report are the sole responsibility of the project, for the purpose of illustration only, and for only one scenario of expected climate change related sea level rise (CCSLR).

As the understanding of future climate change and the associated effects to the coastal regions of both the world and of the British Columbia coast become clearer, the need to upgrade existing coastal flood protection and to provide future flood protection becomes more apparent with time. As this understanding evolves, there is an increasing appreciation of the potential value provided by alternatives to conventional sea dike systems, that (for instance) are outlined in the Provincial Dike Design and Construction Guide, Reference [1] and [3]. Conventional systems typically involve the construction of hard armoured revetments or armoured dike structures along the shoreline.

An evolving body of literature; References [4] and [5], and experience, is indicating that human created, more natural, shoreline structures can also provide the same degree of protection, while at the same time preserving the ecological services of the existing shoreline. In many situations, they may be more economical than the conventional alternates, Reference [8]⁴.

1.2 Terms of Reference and Scope


The terms of reference for this study are provided in the proposal submitted to the SCBC by SNC Lavalin Inc (SLI) dated 26 April 2013 and can be summarized as follows:

1. Develop a framework to evaluate the adaptability of “soft” shore armouring alternatives to climate change related sea level rise (CCSLR), their ecological resilience and their cost effectiveness. The framework will form the basis for the evaluation of the specific case examples.
2. Complete an initial design and evaluation for three case examples that include examples of:
 - a. A community shoreline with a pre-existing hard alternative system protection system that would require enhancement to meet the expected CCSLR.
 - b. A community shoreline, with no pre-existing shoreline system, which might require enhancement to meet expected CCSLR.
 - c. An example of a private residential shoreline that requires enhancement to meet expected CCSLR.
3. Review and provide recommendations to the British Columbia Flood Protection Program (FPP) to enable funding of “soft” shore armouring alternatives for flood protection.

During the course of this study it became clear that development of a framework to evaluate the adaptability of “soft” shore alternatives to CCSLR could be undertaken with the guidelines presented in two existing provincial government guideline documents:

1. **“Guidelines for Management of Coastal Flood Hazard Land Use** – Climate Change Adaptation Guidelines for Sea Dikes and Coastal Flood Hazard Land Use”, BC Ministry of Environment, 27 January 2011.
2. **“Sea Dike Guidelines** – Climate Change Adaptation Guidelines for Sea Dikes and Coastal Flood Hazard Land Use”, BC Ministry of Environment, 27 January 2011.

⁴ This issue (cost benefit of alternate concepts for shorelines) is the subject of this evaluation exercise.


| | | |
|--|--|------------------|
|  | GREENING SHORELINES TO ENHANCE RESILIENCE | PAGE: 7 of 44 |
| | | DATE: 2014/06/30 |
| | AN EVALUATION OF APPROACHES FOR ADAPTATION TO SEA LEVEL RISE | REVISION NO.: 0 |

These documents provide rational based procedures to estimate the required elevations of either Flood Construction Levels (FCL) or the crest elevation of a sea dike necessary to provide safety against flooding or security of personnel at the top of a sea dike. For the purpose of this study, the procedures of the “**Sea Dike Guidelines**” and in particular, the thresholds for acceptable quantities of overtopping of the crest of hard or soft alternative, as appropriate, were used. This procedure ensured that in each Case Example, both the hard or soft alternatives were equally as effective in meeting the primary design objective of providing safety or security against flooding expected due to CCSR for the considered scenario.

1.3 Acknowledgement

Preparation and publication of this document was made possible by funding support from Natural Resources Canada through the Adaptation Platform (Project NRCan-CCAID: AP040) and administrative support from the Stewardship Centre for British Columbia. The participation and contributions of the Project Advisory Committee from many organizations and municipalities in British Columbia and Washington State also provided valuable input into the project.

The contributions of the organizations and individuals at each of the Case Example sites are also gratefully acknowledged. It should be noted that the conceptual development of the existing Case Examples to accommodate a 1 m rise in local sea level is the sole responsibility of this project, the level of engineering in each case is consistent with a conceptual design and intended only for the purpose of this project.


| | | |
|--|--|------------------|
|  | GREENING SHORELINES TO ENHANCE RESILIENCE | PAGE: 8 of 44 |
| | AN EVALUATION OF APPROACHES FOR ADAPTATION TO SEA LEVEL RISE | DATE: 2014/06/30 |
| | | REVISION NO.: 0 |

2.0 DESIGN BASIS

The design basis used for this assessment was as follows;

- Case Examples were selected from existing communities along the British Columbia shoreline where either existing shorelines were largely of a natural character or where works were already in place that were consistent with the objectives of the Green Shores™ program.
- The Case Examples were located in areas where future flooding, due to the expected effects of sea level rise due to climate change, is anticipated.
- The Case Examples were scaled up, in a manner consistent with the present works, to accommodate a one (1) meter rise in local sea level.
- As all of the Case Examples are in areas where future flooding is expected, the general arrangements of the scaled up concepts must provide a level of safety against flooding, or to personnel or adjacent structures, that is consistent with the Provincial Guideline documents and specifically the acceptable tolerances for average rates of overtopping (which could lead to flooding) during a severe storm.
- For the purpose of this assessment, the severe storm was defined to be consistent with an annual average recurrence interval (ARI) of 500 years.
- The total water level during the severe storm was taken to be:

HHWLT + 1 m of SLR + expected storm surge during storm
- The expected wave interaction at each Case Example was taken to be consistent with expected incident conditions during the severe storm, as modified by the local bathymetry at the Case Example site. Where site specific information was available the site specific information was used.
- Only the functional requirements of the upgraded examples were defined. It is taken as given that stability of the components would be ensured as the result of detailed design, which was not in the scope of the present assessment.
- For the examples of soft shoreline alternatives, the concept design for the upgraded structures was developed with sufficient allowance in the cost estimates for provision of control structures (headlands, offshore reefs or sills and groynes) that would be required to prevent or minimize maintenance requirements over an approximate 25 year service life.
- In all cases, further consultation with stakeholders and more detailed engineering and environmental design, would need to be undertaken.

| | | |
|--|--|------------------|
|  | GREENING SHORELINES TO ENHANCE RESILIENCE | PAGE: 9 of 44 |
| | AN EVALUATION OF APPROACHES FOR ADAPTATION TO SEA LEVEL RISE | DATE: 2014/06/30 |
| | | REVISION NO.: 0 |

3.0 FRAMEWORK MODELS

Climate change is expected to manifest itself in coastal areas through increased freshwater run-off, increased storm (wave and surge) intensity, and higher sea levels. These processes act to directly increase flood risk to coastal developments, and they may also increase shoreline erosion, which in some situations, may lead to increased flooding. Climate change is also expected to have direct influences on the ocean environment including changes in ocean temperatures, salinity and acidity. All of these factors will lead to stress, disturbance or change in the ecological services available at the shoreline where flood control systems (structures) will likely be built to reduce or minimize the risk of future flooding.

3.1 Evaluation of Ecological Resilience

Ecological resilience can be defined as the capacity of a shoreline; which includes the adjacent upland zone, the inter-tidal zone and adjacent sub-tidal areas, to respond to disturbance, or to recover quickly from disturbance, without losing or depleting its ecological functions and services.

“Soft” shore protection alternatives are generally considered to provide preferred and robust alternatives to hard engineering approaches for the preservation or recovery of ecological services along a shoreline. The Green Shores (GS) program⁵ has specifically evolved since 2005 with the objective of providing guidance in achieving these objectives. The GS guiding principles are:

1. Preserve the integrity or connectivity of coastal processes,
2. Maintain or enhance habitat diversity and function,
3. Minimize or reduce pollutants to the marine environment, and
4. Reduce cumulative impacts to the coastal environment.

The objective of preserving, protecting or enhancing the ecological values of a shoreline are presently captured in the Green Shores⁵ program in the Coastal Development Rating System (CDRS), Reference [6], which covers many aspects of the planning and implementation of the concept. Although consideration of climate change effects is considered within the CDRS (Optional Credit 4), it does not specifically address the interaction between climate change and the ecological services of the shoreline.

For the purpose of defining an evaluation framework for ecological resilience, seven key coastal or ecological services were selected to evaluate and compare soft and hard alternatives at any given site. A summary of the 7 services and their relationship to the GS prerequisite considerations in the CDRS is provided below in Table 1. A detailed description of the design of this evaluation framework is provided in Appendix A.

⁵ *The Green Shores program is not the only formalized program promoting the consideration and use of soft shoreline protection measures. The Metropolitan Waterfront Alliance (www.waterfrontalliance.org) in New York State promotes the consideration of waterfront access, resilience and ecological benefits into an integrated design. Living Shorelines projects and groups are emerging throughout North America and typically promote the use of plants, soft sediments (sand) and the limited use of rock to provide shoreline protection and to maintain valuable habitat. In general terms all of these programs are concerned primarily about maintaining, restoring or protecting marine habitat rather than providing flood protection per se.*


| | | |
|--|--|------------------|
|  | GREENING SHORELINES TO ENHANCE RESILIENCE | PAGE: 10 of 44 |
| | | DATE: 2014/06/30 |
| | AN EVALUATION OF APPROACHES FOR ADAPTATION TO SEA LEVEL RISE | REVISION NO.: 0 |

Table 1: Summary of Ecological Services and Roles

| Ecological Service | Ecosystem role | Link to CDRS |
|---|--|---------------------|
| ES 1: Alongshore transport processes | Conservation of coastal sediment processes | Prerequisite 4 |
| ES 2: Upland-foreshore linkages | Connectivity processes | Prerequisite 2 |
| ES 3: Marine riparian vegetation | Ecosystem structure and function | Prerequisite 3 |
| ES 4: Emergent and submerged aquatic vegetation | Ecosystem structure and function | Prerequisite 3 |
| ES 5: Foreshore habitat supply | Ecosystem structure and function | Prerequisite 2 |
| ES 6: Foreshore habitat diversity | Ecosystem structure and function | Prerequisite 2 |
| ES 7: Foreshore-offshore linkages | Connectivity processes | Prerequisite 2 |

Guidance for evaluating the alternatives for each Ecological Service is provided below. In these tables, EA refers to the Engineering Alternative, which could be either a hard or a soft alternative.

The application of this Ecological Services Framework is summarized for each Case Example in this study in Section 5.0.


| | | |
|--|--|------------------|
|  | GREENING SHORELINES TO ENHANCE RESILIENCE | PAGE: 11 of 44 |
| | | DATE: 2014/06/30 |
| | AN EVALUATION OF APPROACHES FOR ADAPTATION TO SEA LEVEL RISE | REVISION NO.: 0 |

Table 2: Summary of Guidance for Evaluation of Ecological Services

Note: in the Tables below, EA refers to the Engineering Alternative, which can be a hard or a soft alternative.

| ES 1: Alongshore transport processes | |
|---|--|
| Score | Guidance |
| + 2 | EA results in > 50% of a shoreline with no hard structures such as seawalls and riprap, or results in the placement of subtidal structures parallel to the shoreline outside of the foreshore zone and poses no significant influence on alongshore transport processes (e.g., nearshore berm). |
| + 1 | EA results in < 50% of a shoreline with no hard structures such as seawalls and riprap, or the EA results in the placement of subtidal structures parallel to the shoreline outside of the foreshore zone and poses no significant influence on alongshore transport processes (e.g., nearshore berm). |
| 0 (neutral) | In light of the site's history, the EA does not modify alongshore transport processes. |
| - 1 | EA results in placement of hard structures such as seawalls or riprap parallel to and along <50% of the shoreline that act to reflect wave energy. |
| - 2 | EA results in placement of hard structures running perpendicular to the shoreline (e.g., groins). The structures can trap sand that is probably flowing to a neighboring beach. |

| ES 2: Upland-foreshore linkages | |
|--|--|
| Score | Guidance |
| + 2 | EA provides natural access along 100% of the shoreline for movement of organic and inorganic materials between the upland and foreshore (e.g., by way of intertidal marsh, marine riparian vegetation, beach dunes). |
| + 1 | EA provides natural access to at least 50% of shoreline for movement of organic and inorganic materials between upland and foreshore (e.g., by way of intertidal marsh, marine riparian vegetation, beach dunes). |
| 0 (neutral) | In light of the site's history, the EA poses no significant barrier or enhancement to across shore movement of organic and inorganic materials between the upland and foreshore. |
| - 1 | EA uses hard vertical structures (e.g., seawalls or bulkheads) on <50% of shoreline that prohibit movement of organic and inorganic materials between upland and foreshore. |
| - 2 | EA uses hard vertical structures (e.g., seawalls or bulkheads) on >50% of shoreline that prohibit movement of organic and inorganic materials between upland and foreshore. |

| ES 3: Marine riparian vegetation (MRV) | |
|---|---|
| Score | Guidance |
| + 2 | EA involves restoring or enhancing > 50% of the shoreline with endemic MRV within a minimum 5m zone adjacent to the HWM. |
| + 1 | EA involves restoring or enhancing < 50% of the shoreline with endemic MRV within a minimum 5m zone adjacent to the HWM. |
| 0 (neutral) | In light of the site's history, the EA does not destroy or enhance shoreline MRV. |
| - 1 | EA results in removal of up to 50% of the endemic MRV, and/or reduces the MRV zone to < 5m wide adjacent to the HWM, and/or replaces endemic MRV with grass or hardened surfaces (e.g., asphalt). |
| - 2 | EA results in removal of > 50% of the endemic MRV, and/or reduces the MRV zone to < 5m wide adjacent to the HWM, and/or replaces endemic MRV with grass or hardened surfaces (e.g., asphalt). |


| | | |
|--|--|------------------|
|  | GREENING SHORELINES TO ENHANCE RESILIENCE | PAGE: 12 of 44 |
| | AN EVALUATION OF APPROACHES FOR ADAPTATION TO SEA LEVEL RISE | DATE: 2014/06/30 |
| | | REVISION NO.: 0 |

Table 2 continued: Summary of Guidance for Evaluation of Ecological Services

Note: in the Tables below, EA refers to the Engineering Alternative, which can be a hard or a soft alternative.

| ES 4: Emergent and submerged aquatic vegetation | |
|--|--|
| Score | Guidance |
| + 2 | EA plants or enhances the density of emergent or submerged aquatic vegetation along > 50% of the shoreline. |
| + 1 | EA plants or enhances the density of emergent or submerged aquatic vegetation along at least 50% of the shoreline. |
| 0 (neutral) | In light of the site's history, the EA does not enhance or reduce the existing emergent or submerged aquatic vegetation. |
| - 1 | EA results in a reduction in emergent or submerged aquatic vegetations along < 50% of the shoreline. |
| - 2 | EA removes all existing emergent or submerged aquatic vegetations along > 50% of the shoreline. |

| ES 5: Foreshore habitat supply | |
|---------------------------------------|---|
| Score | Guidance |
| + 2 | EA restores or enhances > 50% of the amount (m ²) of a naturally occurring foreshore habitat. |
| + 1 | EA restores or enhances < 50% of the amount (m ²) of a naturally occurring foreshore habitat. |
| 0 (neutral) | In light of the site's history, the EA does not reduce or enhance naturally occurring benthic habitats. |
| - 1 | EA reduces up to 50% of a naturally occurring foreshore habitat (m ²). |
| - 2 | EA reduces more than 50% of a naturally occurring foreshore habitat (m ²). |

| ES 6: Foreshore habitat diversity | |
|--|--|
| Score | Guidance |
| + 2 | EA increases foreshore habitat diversity by at least 2 benthic habitat types along the shoreline. |
| + 1 | EA increases foreshore habitat diversity by at least 1 benthic habitat type along the shoreline (e.g., habitat benches on rip rap revetments). |
| 0 (neutral) | In light of the site's history, the EA does not destroy or enhance foreshore or subtidal habitat heterogeneity. |
| - 1 | EA results in direct burial, removal or destruction of < 50% of existing foreshore habitats. |
| - 2 | EA results in direct burial, removal or destruction of > 50% of existing foreshore habitats. |


| | | |
|--|--|------------------|
|  | GREENING SHORELINES TO ENHANCE RESILIENCE | PAGE: 13 of 44 |
| | | DATE: 2014/06/30 |
| | AN EVALUATION OF APPROACHES FOR ADAPTATION TO SEA LEVEL RISE | REVISION NO.: 0 |

Table 2 continued: Summary of Guidance for Evaluation of Ecological Services

Note: in the Tables below, EA refers to the Engineering Alternative, which can be a hard or a soft alternative.

| ES 7: Foreshore-offshore linkages | |
|-----------------------------------|---|
| Score | Guidance |
| + 2 | EA introduces a natural biogenic breakwater structure (e.g., oyster reef) perpendicular to the dominant wave exposure, in either the lower foreshore or subtidal, that does not modify coastal currents. |
| + 1 | EA introduces a non biogenic breakwater structure (e.g., boulders) perpendicular to the dominant wave exposure, in either the lower foreshore or subtidal, that does not modify coastal currents. |
| 0 (neutral) | In light of the site's history, the EA does not modify the intertidal or subtidal with a breakwater structure |
| - 1 | EA introduces one continuous man-made or biogenic breakwater structure parallel to < 50% of shore. This design will lead to modification of alongshore currents and change sedimentation patterns in the foreshore. |
| - 2 | EA introduces one continuous man-made or biogenic breakwater structure parallel to > 50% of shore. This design will lead to modification of alongshore currents and change sedimentation patterns in the foreshore. |


In general terms, both hard and soft alternatives at any site can be evaluated with respect how each alternative affects the ecological services and can be assigned a score of +2, +1, 0, -1 or -2 depending on the specific interaction. Alternatives that generate high positive scores can be expected to provide the greatest opportunities for ecological resilience.

3.2 Evaluation of Cost Effectiveness

The evaluation of cost effectiveness of both hard and soft alternatives ideally involves full consideration of the life cycle costs of each alternative over the expected service life of the project. Life cycle cost typically includes the initial capital cost, any planned short term maintenance costs and longer term, and generally less likely, repair or replacement costs; usually as the result of extreme conditions beyond the stated design basis. The expected service life of a project is generally tied to an economic factor such as the replacement cycle of the landside development or the duration of the underlying need. The renewal cost, to upgrade or enhance an existing system, is generally not considered as part of the life cycle cost.

In the case of designs intended to accommodate a future expected level of sea level rise, the total service life should include a period of time between the decision to build the protection and a reasonable duration of time anticipated before ongoing sea level rise overtakes the concept design basis. Life cycle costs of both hard and soft alternatives are therefore complex because climate change related sea level rise is expected to continue at increasingly faster rates for durations that exceed the usual life span of coastal projects. As sea level continues to rise, the design basis (a one meter local rise in sea level) will no longer be valid. Both hard and soft alternatives may need to be upgraded or enhanced at some time in the future if a decision is made to continue the Protect alternative for adaptation to climate change related sea level rise. For the purpose of this assessment, this renewal cost is also not included.

Each concept in this study has been designed (at the conceptual level of engineering design) to withstand the expected design storm conditions that were calculated to occur when local sea level has risen by one meter. As all concepts are essentially designed for wave conditions that are depth-limited and therefore the design conditions are unlikely to occur until local sea level rise approaches one meter, it can also be assumed that both soft and hard alternatives will have the same but likely minimal, need for repair or maintenance during the years prior to the arrival of one meter of local sea level rise. It is expected that monitoring of any alternative will be required throughout its life cycle.

| | | |
|--|--|------------------|
|  | GREENING SHORELINES TO ENHANCE RESILIENCE | PAGE: 14 of 44 |
| | | DATE: 2014/06/30 |
| | AN EVALUATION OF APPROACHES FOR ADAPTATION TO SEA LEVEL RISE | REVISION NO.: 0 |

Monitoring will be required for both hard and soft alternatives. It can reasonably be expected that hard alternatives will be accompanied by scouring or erosion of the foreshore in front of the alternative. Scouring or erosion can create a threat to the stability of the hard alternative, possibly leading to catastrophic failure. In general terms, soft alternatives are often assumed to require periodic replacement of the soft sediment (sands, gravels, pebbles or cobbles) and possibly of marine or riparian vegetation that may form part of the system.

Although the designs shown below for each Case Example are two dimensional in character (cross-shore) the capital costs presented for the basis of evaluation include provision for control structures, as understood from existing practice, that are required to maintain soft sediments in place for each case. Experience in several British Columbia cases has shown that the types of conceptual designs presented have performed without maintenance for almost 25 years. This might not be the case on long exposed ocean shorelines where beach nourishment alone, for example, is considered. For the purpose of this assessment, it is estimated that the costs for monitoring and maintenance will be the same for both hard and soft alternatives.

Properly designed and constructed hard alternatives, similar to those considered for the Case Examples have been in-place for intervals of 40 to 80 years prior to replacement; however, this experience has been acquired during a time of relatively slow sea level rise (a global mean SLR of 2 to 3 mm/yr). It is generally recognized that future sea level rise will be significantly faster (an average annual rise of approximately 10 mm/yr is required for a SLR of 1 m in 100 years).

For the purpose of this assessment it has been assumed that both the hard and the soft alternatives have the same probability of providing useful service for the same duration of time once the design basis (one meter of local sea level rise) has appeared. It is likely that both types of alternatives will need to be renewed, at similar intervals, if the decision to Protect the related shoreline development was maintained.


The evaluation of the alternatives in each Case Example in this study is therefore based solely on the initial capital costs, with the provisions described above. It is also assumed that either alternative would be constructed in one stage and the decisions would be made at the same relative time. Costs associated with phased implementation or escalation due to other economic factors is not considered.

4.0 CASE EXAMPLES

For the purpose of this evaluation, three case examples of soft shore alternatives were selected for evaluation:

- Use of a mainly beach nourishment or shore replenishment alternative, consisting of supply and placement of typical beach intertidal materials – ranging from sand to a gravel – cobble mixture.
- Use of nearshore – mainly inter-tidal rock features, including boulder clusters and inter-tidal and subtidal rock habitat reefs.
- Use of a typical headland – beach system to maintain a conventional beach intertidal substrate in an area exposed to incident waves from more than one primary direction.

In the first two case examples, the soft shore alternative is compared to modification of the existing community scale hard shoreline for evaluation. In the third case example, the soft shoreline alternative was already in place as the result of alternative recent replacement of a vertical cedar log piled seawall that reached the end of its useful life. In this particular example, the soft shore alternative is compared to a conventional sea dike alternative to provide additional insight.

| | | |
|--|--|------------------|
|  | GREENING SHORELINES TO ENHANCE RESILIENCE | PAGE: 15 of 44 |
| | | DATE: 2014/06/30 |
| | AN EVALUATION OF APPROACHES FOR ADAPTATION TO SEA LEVEL RISE | REVISION NO.: 0 |

4.1 Case Example 1

4.1.1 Background


In this case example, the shoreline along the central waterfront of the community of Qualicum Beach, British Columbia was selected because the area is characterized by the historical presence of an extensive sandy – gravel beach, which formed the focus for the waterfront activities of the community for nearly 100 years, is recognized as the single most important unique aspect of the community character and will need to be preserved or adapted in the future to maintain this characteristic aspect of the community.

An overall view of the central waterfront is provided in Figure 1. The site is exposed to waves generated by winds blowing both up the Strait of Georgia from the ESE or blowing down the Strait from the WNW and NW. At normal high tides, a narrow strip of mainly gravel and pebble beach material is present at the foot of the existing seawall, originally built in the 1960's.

Land-use along this shoreline consists of a mix of public park and private residential and commercial properties, along a relatively narrow waterfront strip on the seaward edge of the low coastal plain immediately in front of higher coastal bluffs. An important community arterial roadway exists between the waterfront property strip and the toe of the coastal bluff. A collector sewer line is also located along the shoreline, seaward of the existing seawall, and buried approximately 3 m below the beach, as indicated in Figure 2.



Figure 1: Qualicum Beach Waterfront – Jubilee Park
source: R. Guthrie, SNC Lavalin

| | | |
|--|--|------------------|
|  | GREENING SHORELINES TO ENHANCE RESILIENCE | PAGE: 16 of 44 |
| | AN EVALUATION OF APPROACHES FOR ADAPTATION TO SEA LEVEL RISE | DATE: 2014/06/30 |
| | | REVISION NO.: 0 |

4.1.2 Existing Shoreline

The existing cross shore profile in the area shown in Figure 1 is illustrated in Figure 2, based on a combination of recent (2009) LiDAR data, extending into the intertidal profile and CHS sounding data, beginning at the low tide contour.

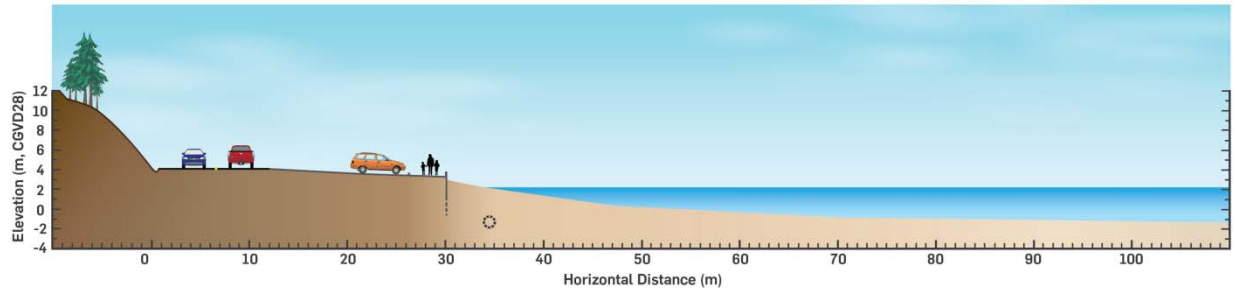


Figure 2: Existing Shoreline Condition at Present High Tide (HHWLT)
(waves not shown)

A 1 m rise in local sea level will result in flooding of the existing shoreline during a severe storm as indicated in Figure 3.

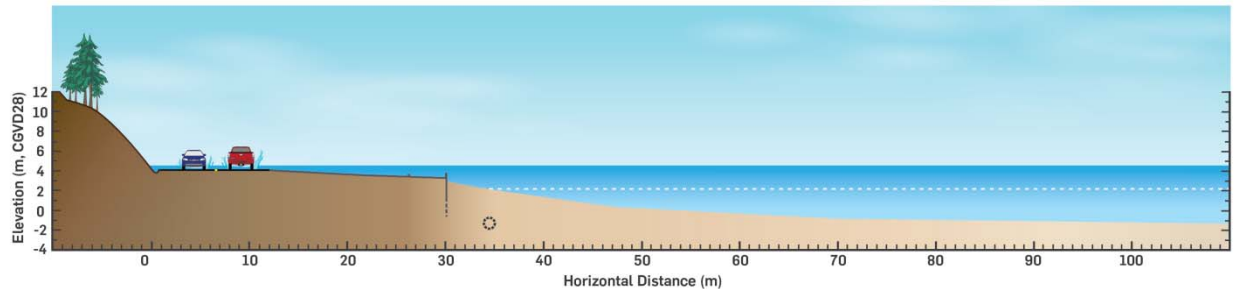


Figure 3: Expected Condition with 1 m SLR and Storm Surge
(waves not shown)

4.1.3 Hard Alternative

For the purpose of this evaluation, it was assumed that the conventional hard approach would be to raise the existing seawall in a similar fashion to the concept shown in Figure 4, with the following main assumptions regarding the functional aspects of the alternative for this case example:

- The height of the seawall would be sufficient to prevent erosion of the land surface behind the seawall during the severe storm.
- The elevation of the coastal plain behind the seawall would not be raised to preserve the existing land uses and roadway.
- A raised walkway would be provided along the public portions of the seawall to maintain the present views available to pedestrians along this portion of the waterfront.

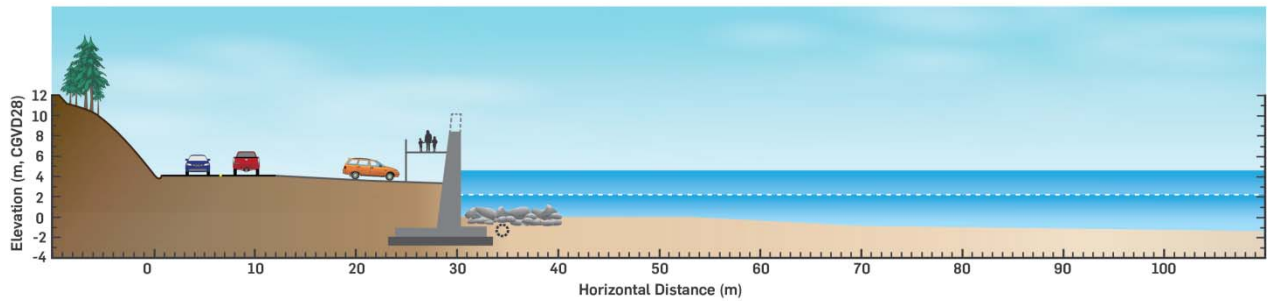


Figure 4: Hard Alternative with 1 m SLR and Storm Surge
(waves not shown)

4.1.4 Soft Alternative

The soft shore alternative is shown in Figure 5 and Figure 6, which illustrate both the height of the beach fill which must be provided to serve the same functional requirements as the hard alternative; safety against flooding, preservation of land use – by positioning the alternatives mainly over the intertidal profile - and access for the public. Figure 5 shows the footprint if the imported beach material consists of a mainly gravel and pebble mixture. Figure 6 shows the footprint if the imported beach material consists of mainly medium to coarse sand material. Both versions of the soft alternative include a conceptual section intended to act as an impervious dyke to prevent flooding through internal seepage.

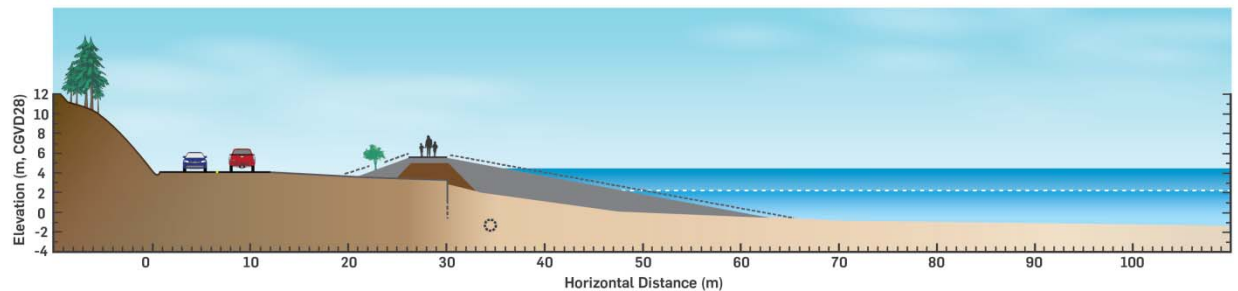


Figure 5: Soft Alternative – Gravel/Pebble/Cobble Beach with 1 m SLR and Storm Surge
(waves not shown)

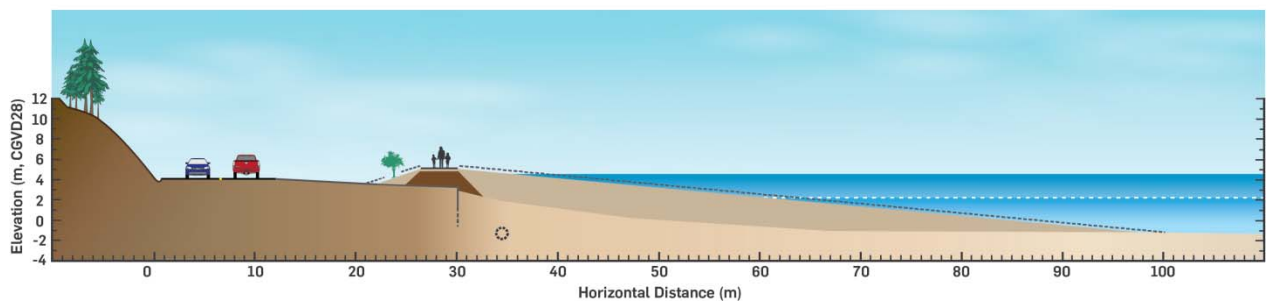



Figure 6: Soft Alternative – Mainly Sandy Beach with 1 m SLR and Storm Surge
(waves not shown)

| | | |
|--|--|------------------|
|  | GREENING SHORELINES TO ENHANCE RESILIENCE | PAGE: 18 of 44 |
| | | DATE: 2014/06/30 |
| | AN EVALUATION OF APPROACHES FOR ADAPTATION TO SEA LEVEL RISE | REVISION NO.: 0 |

4.2 Case Example 2

4.2.1 Background

In this case example, a section of the District of West Vancouver shoreline in the vicinity of Marr Creek was selected to highlight an example where both high urban development and an existing shoreline enhancement program exist. The Marr Creek area is in the process of being improved as part of the District of West Vancouver Shoreline Protection Plan (SPP). The SPP is described in more detail on the West Vancouver SPP website⁶. The primary intention of the SPP is to enhance and protect the waterfront of the District of West Vancouver by re-creating and fostering natural processes to sustain a naturally resilient and healthy shoreline.

An overall view of the Marr Creek area during strong winds on 26 September 2009, at high tide, is shown in Figure 7. The site is exposed to waves generated in the Strait of Georgia from the S, SW and WNW and at low tide; the existing substrate consists mainly of vegetated cobble and some gravel in the interstitial spaces.



Figure 7: Marr Creek Area – District of West Vancouver

source: "Wester Van – Google Earth"

Land use along this part of the District shoreline consists primarily of the public walkway and private residential properties landward of the walkway.

The Marr Creek SPP project is in an early stage of implementation and is being undertaken by the District of West Vancouver as means and opportunities become available. In March 2014, the Marr Creek work is still in progress and some rock clusters and some large boulders have been placed in the upper inter-tidal area. The overall objective of the project is to promote the retention of sediments provided by natural processes, mainly from Marr Creek, which presently discharges on to the foreshore by way of a small culvert through the existing lock-block seawall visible in Figure 7.

⁶ <http://westvancouver.ca/sites/default/files/shoreline-protection-plan.2012-2015.pdf>

4.2.2 Existing Shoreline

A typical cross shore profile for the existing general area is illustrated in Figure 8, based on a combination of terrestrial contour data from aerial photogrammetry and sounding data seaward of the existing seawall. The intent of the present SPP plan for the Marr Creek area is shown schematically (to scale). As sediment accumulates naturally, the plan calls for the rock features to be lifted up, to avoid burial, and to continue to assist in accumulating sediments. It should be noted that the present plan includes a sub tidal rock habitat reef (not shown) that will eventually be constructed approximately 500 m seaward of the seawall.

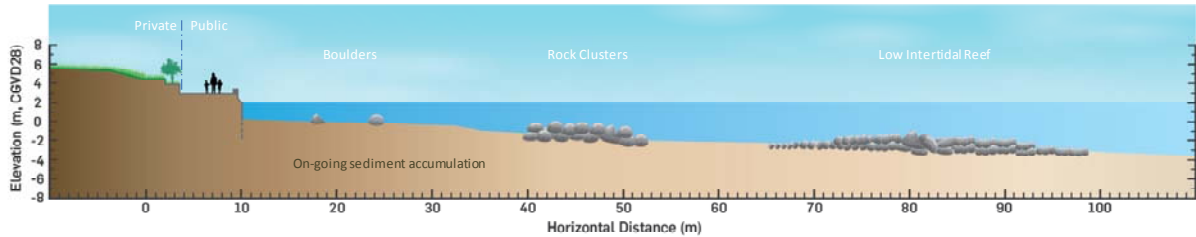


Figure 8: Existing Shoreline Condition at High Tide
(waves not shown)

In the future, a 1 m rise in local sea level will result in flooding of the existing public walkway and of some private lands landward of the walkway, both at high tide and during a severe storm, as indicated in Figure 9. For the purpose of this assessment, it has been assumed that at sometime in the future, the public walkway will be raised, as a separate project, to preserve the present high tide (calm weather) dry access for the public, regardless of which alternative might eventually be implemented.

It is also assumed that in either case, the flood protection components of either alternative will likely be undertaken on a different schedule from the ongoing SPP, as appropriate, to ensure active management of the flood risk. The flood protection concept will need to reflect on-going pace of the SPP portion of the works. Analysis for this case example suggested that the rock components and especially the rock clusters and the low intertidal reef (Figure 9) might need to be raised in advance of the natural accumulation of sediments⁷.

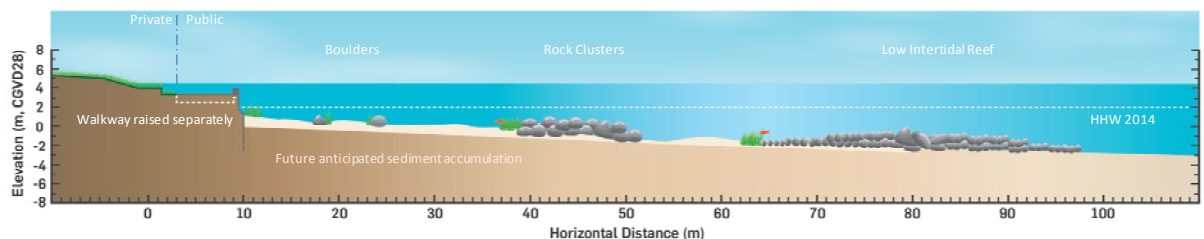


Figure 9 – Existing Shoreline with 1 m SLR, High Tide and Storm Surge
(waves not shown)

4.2.3 Hard Alternative

For the purpose of defining the hard alternative for this evaluation, it was further assumed that the conventional hard alternative approach will only involve raising the parapet section of the seawall, as indicated in Figure 10, with the following main assumptions regarding the functional aspects of the alternative for this case example:

⁷ Preliminary analysis indicated that more than 2 m of sediment would need to accumulate on the seaward side of the rock structures before the seabed significantly influenced the seastate at the structures during the reference storm.

- The height of the seawall will be sufficient to prevent erosion of the private lands present on the landward side of the public walkway. This should minimize the chance of undermining the public walkway and seawall structure.
- The elevation of private lands behind the walkway will not be raised.
- Access to the public walkway will be restricted during forecast storms to minimize the risk to pedestrians.
- As naturally supplied sediments are retained by the ongoing SPP project, the various rock structures (but not the sub tidal reef) will be periodically raised to preserve the relative crest elevation of the rock structures, with respect to the intertidal seabed.
- The offshore rock habitat reef, located 500 m seaward of the walkway would be in-place.

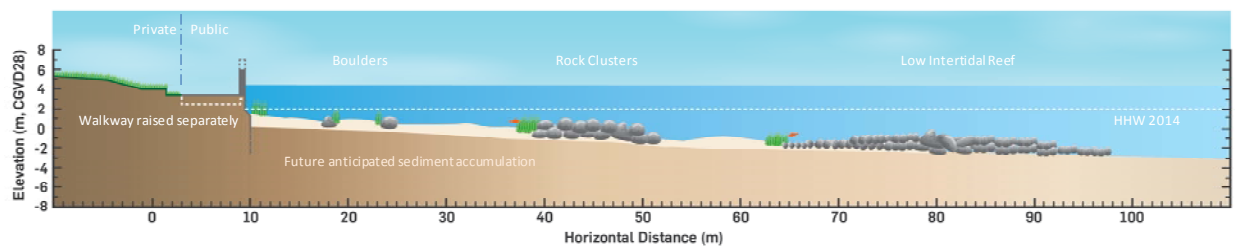


Figure 10 – Hard Alternative with 1 m SLR and Storm Surge
(waves not shown)

4.2.4 Soft Alternative

The soft alternative is shown in Figure 11, where the crest height of the rock clusters and of the inter-tidal reef has been raised to ensure that the wave energy and the volumes of overtopping at the high water shoreline (now on private land) is either below the threshold required to prevent erosion of the surface of the private lands, or is below the threshold consistent with preventing structural damage to the building envelope that occurs (on average) at the left hand side of Figure 11. The sub-tidal rock habitat reef 500 m seaward of the seawall is included in this scenario.

It is possible that changes to the private lands could also be incorporated into this alternative, for instance by raising the elevation of the private lands or by setting buildings even further back; however, for this study, these site specific responses have not been considered.

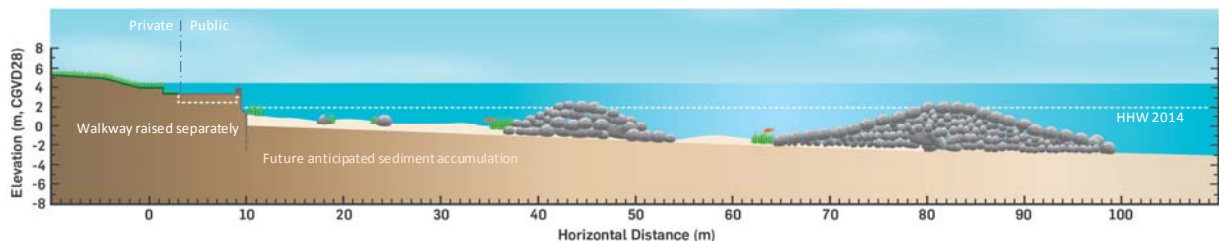



Figure 11: Soft Alternative – Augmentation of Inter-tidal Rock Components
(with 1 m SLR and storm surge – waves not shown)

| | | |
|--|--|------------------|
|  | GREENING SHORELINES TO ENHANCE RESILIENCE | PAGE: 21 of 44 |
| | AN EVALUATION OF APPROACHES FOR ADAPTATION TO SEA LEVEL RISE | DATE: 2014/06/30 |
| | | REVISION NO.: 0 |

4.3 Case Example 3

4.3.1 Background

In this case example, a completed project installed at a private property on the east coast of Vancouver Island in 2007 was selected as it provides a useful case study of the implications of adapting a headland controlled beach system to accommodate expected sea level rise due to climate change.

A view of the present completed project is shown in Figure 12 which shows three of the 6 headland structures and the associated imported beach fill material placed between the headland structures. The headland structures and beach fill were installed to replace a vertical untreated cedar pile seawall and groyne system, originally installed in the late 1960's, which, by 2006, had come to the end of its useful life.

The site is exposed to waves generated in the Strait of Georgia as the result of ESE winds blowing up the Strait and from WNW and NW winds blowing down the Strait.

The project is located in front of a single private property with approximately 250 m of waterfront frontage. A restrictive covenant on the property precludes moving the house which is located just inshore of the beach crest. A community force main is buried below the beach in a right of way located between the beach crest and the inshore end of the headlands.



Figure 12 – Private Residence – Vancouver Island

source: R. Guthrie, SNC Lavalin

4.3.2 Existing Shoreline

The as-built plan view of the existing headland – beach system shown in Figure 12 is illustrated in Figure 13, which shows the relative location of the headland structures, the force main right of way and the backshore, where the original cedar log seawall structure was located at the seaward property line. The upland property immediately behind the property line is presently located at an elevation of approximately + 3.2 m (CGVD28), based on LiDAR survey in 2009 and has no history of flooding during storms.

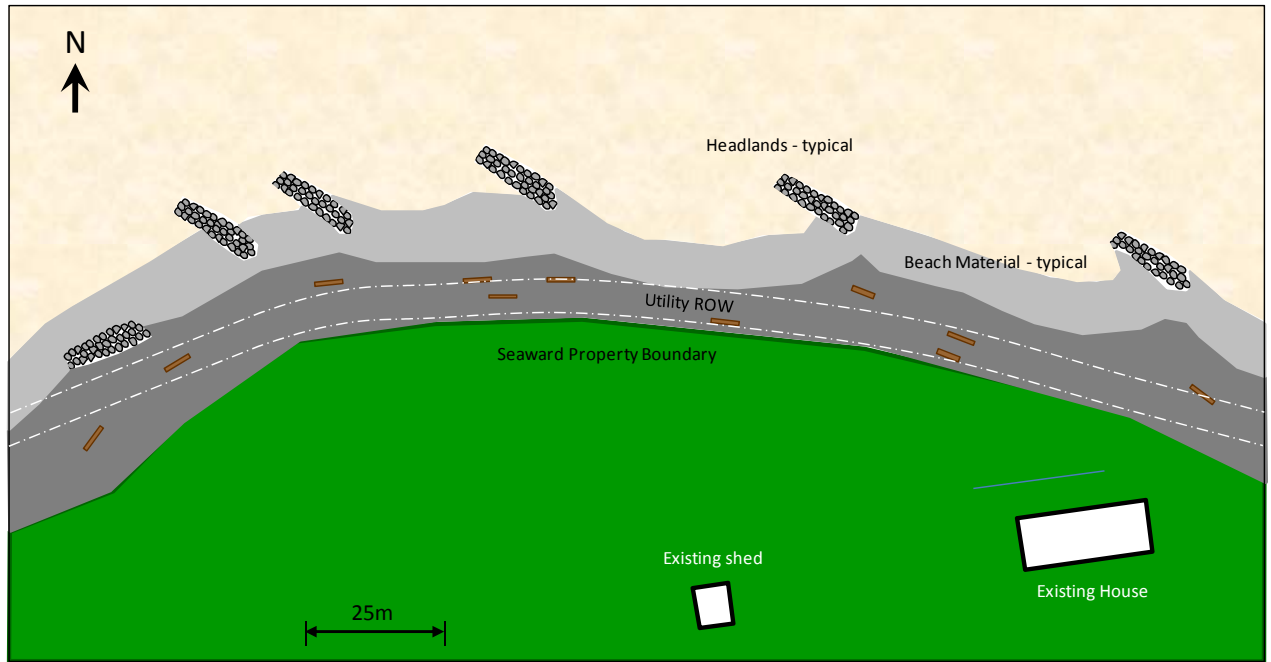


Figure 13: General Arrangement of Existing Headland System

A 1 m rise in local sea level will result in flooding of the upland property and the house, during severe storms, as indicated in Figure 14.

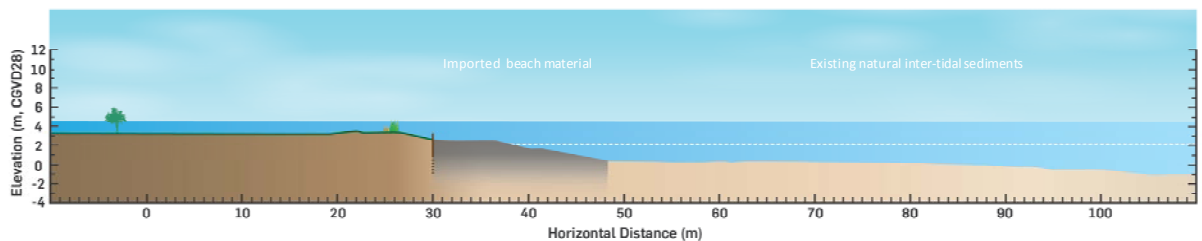


Figure 14: Existing Profile with 1 m SLR and Storm Surge
(waves not shown)

For the purpose of this assessment, it has been assumed that no additional grading of the property, or improvements or raising of the existing house foundations or floor slab will be undertaken.

4.3.3 Hard Alternative

For the purpose of defining the hard alternative for this case example it was assumed that the hard alternative would be to construct a conventional sea dyke, consistent with standard sea dykes elsewhere in the province of British Columbia, along the property boundary. The following assumptions were made regarding the functional aspects of the hard alternative for this case example:

- The height of the sea dike was set to be sufficient to prevent damage to the house immediately behind the sea dyke, to prevent erosion of the grass-covered land behind the sea dyke and because this property is an occupied residential property, to limit danger to the occupants. A typical cross section for the sea dike is shown in Figure 15.
- The length of the sea dyke was set to be the same as the water frontage of the property; however, this is an arbitrary assumption, made only to evaluate the hard and soft alternatives in a consistent fashion.
- Provision for a vertical reinforced concrete retaining wall surrounding the existing house was also included in the hard alternative, as indicated in Figure 16.
- It was further assumed that the sea dykes would extend inland far enough at the edges of the property to prevent outflanking of the sea dyke. No coordination with neighbouring properties was considered.

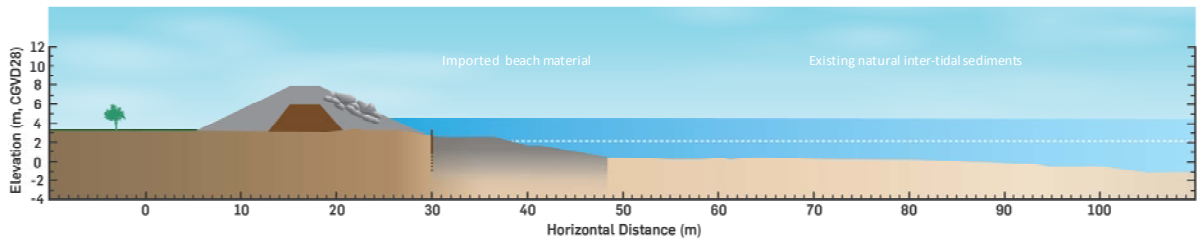


Figure 15: Hard Alternative with 1 m SLR and Storm Surge
(waves and existing house not shown)

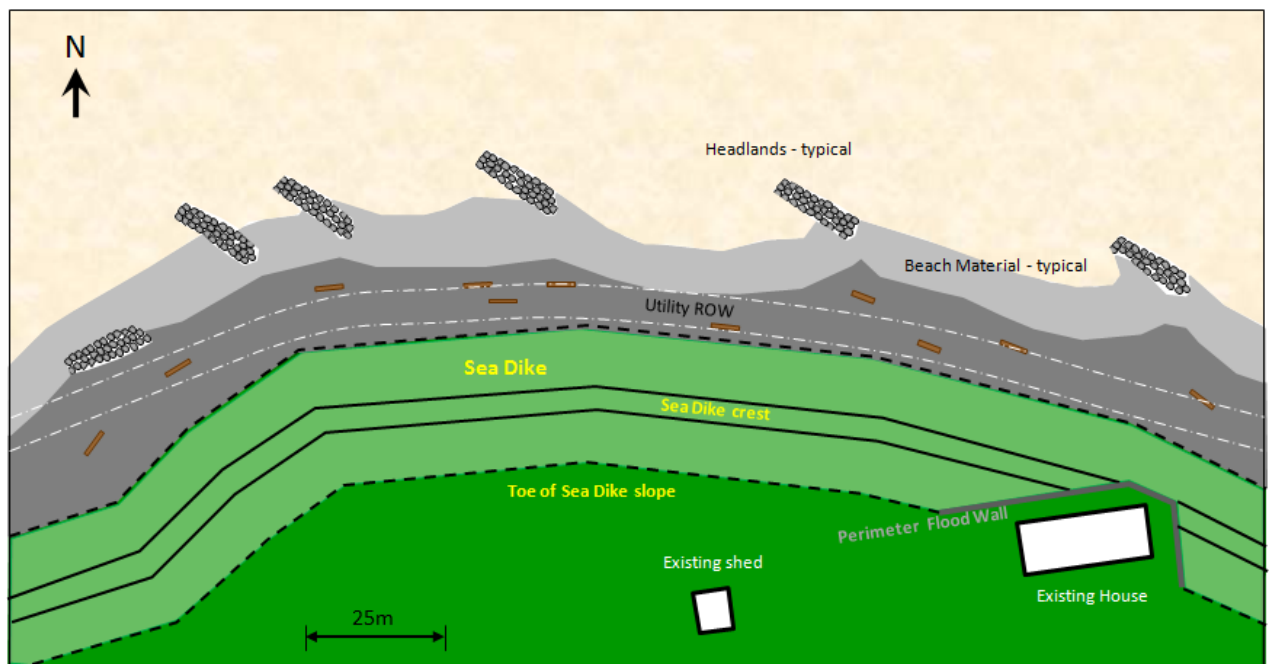



Figure 16: Hard Alternative showing Sea Dike along Property Boundary

| | | |
|--|--|------------------|
|  | GREENING SHORELINES TO ENHANCE RESILIENCE | PAGE: 24 of 44 |
| | AN EVALUATION OF APPROACHES FOR ADAPTATION TO SEA LEVEL RISE | DATE: 2014/06/30 |
| | | REVISION NO.: 0 |

4.3.4 Soft Alternative

The soft alternative for this case example would be to modify the location, length or height of the headland structures and to provide additional beach material, so that the crest of the headland controlled beach remained seaward of the original property line.

Analysis of the changes required to the headland structures to preserve the function of the headland – beach system revealed that additional rock armour would need to be placed on the seaward slopes and crest of the headlands as indicated in Figure 17. Additional imported beach material would also be required.

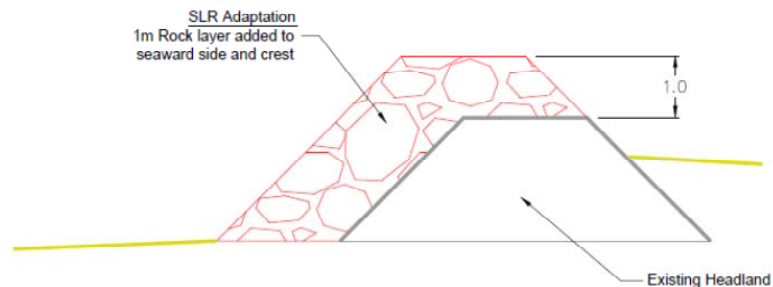


Figure 17: Showing Seaward Extension Required on Existing Headlands for a 1 m SLR Rise

The overall system for a 1 m sea level rise is shown in Figure 18 and all changes are accommodated over the foreshore seaward of the property and the utility corridor right of way, as was the existing system.

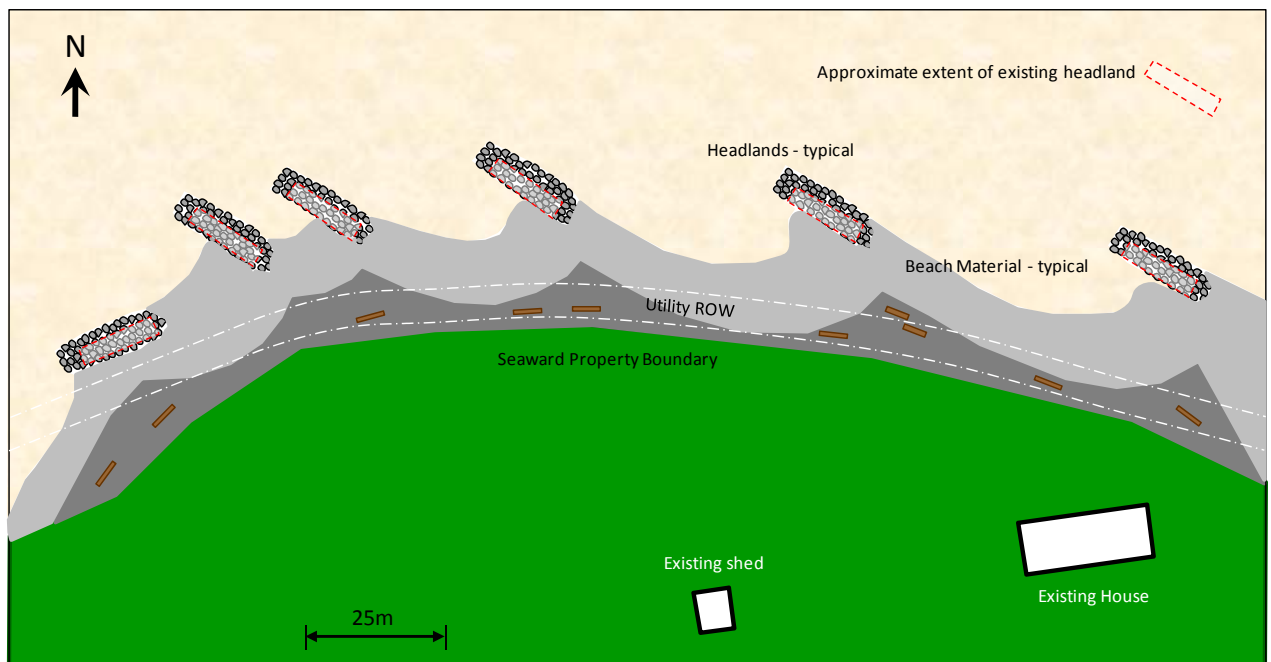



Figure 18: Soft Alternative Showing Expanded Headland Beach System

| | | |
|--|--|------------------|
|  | GREENING SHORELINES TO ENHANCE RESILIENCE | PAGE: 25 of 44 |
| | | DATE: 2014/06/30 |
| | AN EVALUATION OF APPROACHES FOR ADAPTATION TO SEA LEVEL RISE | REVISION NO.: 0 |

5.0 ASSESSMENT OF CASE EXAMPLE ALTERNATIVES

5.1 Ecological Assessment of Case Example Alternatives

It should be noted that the case examples selected for this study all had pre-existing conditions along their respective shorelines that meant none of them were untouched native shorelines against which the respective hard or soft alternative could be evaluated in a relative way. In particular, for Case Example 2, the limitations of the existing shoreline were already recognized by the Community and a restoration program was underway. In Case Example 3, a soft solution had already been constructed some years ago to replace a hard solution constructed more than 40 years ago. For the purpose of this assessment, an estimate of the effects on ecological services of the existing condition was also made so that the net cumulative effect of either the hard or the soft alternative could be evaluated in a consistent fashion.

5.1.1 Case Example 1

The shoreline along the stretch of Qualicum Beach considered for this case example consists essentially of a 1.4 m high concrete seawall located at the top of a beach intertidal profile consisting in the upper tidal portion of the profile of gravels, pebbles and small cobble materials. An extensive wide zone of fine sand extends seaward towards the low tide (0 m CD) portion of the foreshore.

Along the seawall there is a 2.5 m wide paved walkway, which in places is backed by a strip of lawn or landscaping consisting largely of shrubs or grasses.

An overview assessment of the ecological services that exist at this site and the likely changes to be expected for either the hard or the soft alternative is provided in Table 3. The basis for the assessment framework is summarized in Appendix 1. The rationale for the assigned ecological services scoring for each service is provided below:

- ES 1. Raising the existing seawall is not expected to materially change the shoreline interaction with the alongshore transport processes; however, provision of substantial quantities of imported gravels or sand will allow coastal processes to persist within the individual cells of a soft alternative.
- ES 2. Raising the existing seawall will restrict or prohibit cross-shore movement of organic or inorganic materials between the foreshore and upland; however, provision of substantial quantities of imported gravels or sand, and the expected dynamically stable character of the beach material crest line will permit movement.
- ES 3. Raising the existing seawall will almost certainly eliminate any marine riparian vegetation that exists or can exist along more than 50 per cent of the shoreline. Provision of a dynamically stable storm beach crest at the riparian boundary will allow the maintenance or enhancement of the existing marine riparian vegetation along nearly all of the project shoreline.
- ES 4. As the intertidal foreshore of this Case Example is quite wide, it is not expected that either the hard or the soft alternative will have any material effect on submerged or emergent vegetation.
- ES 5. Raising the existing seawall and the anticipated scour protection that will be required to protect the existing buried utilities on the foreshore is unlikely to enhance the existing foreshore habitat. Any benefit that might accrue from the rock (scour protection) habitat could be offset by the loss of beach wrack related services that are known to exist in this area. Provision of substantial quantities of imported gravels or sands will likely improve the mix of benthic foreshore habitats.

- ES 6. Raising the existing seawall and the anticipated scour protection that will be required, will likely result in the loss of any existing habitat diversity in the upper intertidal portion of the shoreline. Provision of substantial quantities of imported gravels or sands will most likely simply preserve the existing diversity.
- ES 7. Raising the existing seawall will likely result in increased wave reflections during storms, localized increases of wave energy over the beach profile and scouring of the beach profile seawall of the raised wall. Provision of substantial quantities of imported gravels or sands will essentially make no change to the incident wave exposure or rate of wave energy dissipation, except at very high water levels.

Table 3: Assessment Template for Case Example 1

| Ecological Service | | Existing | Hard Alternative | Soft Alternative | Comment |
|--------------------|----------------------------------|-----------|------------------|------------------|---------|
| ES1 | Alongshore Transport | -1 | -1 | +2 | |
| ES2 | Upland – Foreshore linkages | -2 | -2 | +2 | |
| ES3 | Marine Riparian vegetation | -2 | -2 | +2 | |
| ES4 | Emergent or Submerged Vegetation | 0 | 0 | +1 | |
| ES5 | Foreshore Habitat Supply | 0 | -1 | +1 | |
| ES6 | Foreshore Habitat Diversity | -2 | -2 | 0 | |
| ES7 | Foreshore – Offshore linkages | 0 | -2 | 0 | |
| | Total Score: | -7 | -10 | +8 | |

The results of the evaluation of the ecological services of the hard and soft alternatives suggest that a significant overall improvement of ecological services should be expected from the soft alternative. In contrast, the hard alternative is not expected to improve the conditions that presently exist on the existing shoreline.

5.1.2 Case Example 2

The shoreline along the stretch of the District of West Vancouver considered for this Case Example consists essentially of a 3 m high concrete and lock-block seawall located above a degraded beach intertidal profile of exposed vegetated cobbles, interstitial sands and underlying bedrock.

Landward of the seawall is a 6 m wide paved walkway, which in places, is backed by additional retaining walls and landscaping.

An overview assessment of the ecological services that exist at the Case Example site and the likely changes to be expected for either the hard or the soft alternative is provided in Table 4. The basis for the assessment framework is summarized in Appendix 1. The rationale for the assigned ecological services scoring for each service is provided below:

- ES 1. The hard alternative - raising the existing seawall while also raising the intertidal rock structures in phase with sediment accumulation on the foreshore - will help to maintain (and enhance) the natural alongshore processes. The soft alternative – will also assist the sediment accumulation to about the same degree.

- ES 2. Raising the existing seawall will further restrict or prohibit cross-shore movement of organic or inorganic materials between the foreshore and upland. The soft alternative provides no significant improvement because the existing seawall would remain in place.
- ES 3. Raising the existing seawall will almost certainly result in elimination, during storms, of any marine riparian vegetation that may accumulate along at least 50 per cent of the shoreline. Augmenting the offshore rock structures over time should; however, increase the likelihood of retaining marine vegetation at the top of the beach portion of the shoreline.
- ES 4. Both the hard and the soft alternatives should result in enhancement of the density of submerged or emergent vegetation.
- ES 5. Both the hard and the soft alternatives should result in restoration or enhancement of the foreshore marine habitats; however, because the soft alternative conceptually provides a greater degree of protection to the foreshore sediments it should be rated slightly more favourably in this criterion.
- ES 6. Both the hard and the soft alternatives should result in enhancement of the diversity of foreshore habitats
- ES 7. Both the hard and the soft alternatives should reduce wind and wave exposure and improve sedimentation in the foreshore as a result of the offshore rock structures. The soft alternative is rated higher than the hard alternative because it is expected the increased crest elevations of the rock structures will be achieved sooner.

Table 4: Assessment Template for Case Example 2


| Ecological Service | | Existing | Hard Alternative | Soft Alternative | Comment |
|--------------------|---|-----------|------------------|------------------|---------|
| ES1 | Alongshore Transport | -1 | +1 | +1 | |
| ES2 | Upland – Foreshore linkages | -2 | -2 | 0 | |
| ES3 | Marine Riparian vegetation | -2 | -1 | +1 | |
| ES4 | Emergent or Submerged Vegetation | 0 | +2 | +2 | |
| ES5 | Foreshore Habitat Supply | 0 | +1 | +2 | |
| ES6 | Foreshore Habitat Diversity | 0 | +1 | +1 | |
| ES7 | Foreshore – Offshore linkages | 0 | +1 | +2 | |
| | Total Score: | -5 | +3 | +9 | |

The results of the evaluation of the ecological services of the hard and soft alternatives suggest that both alternatives can be expected to provide a significant overall improvement, compared to the existing shoreline; however, the soft alternative should provide a better ecological service, largely due to the expected faster pace at which it would be implemented.

5.1.3 Case Example 3

The existing shoreline along this Case Example consists almost entirely of a natural beach intertidal setting; consisting of a gravel/pebble/cobble upper inter-tidal substrate and an extensive natural sandy lower inter-tidal substrate.

The property inland of the waterfront property boundary consists mainly of extensive landscaped grounds over at least half of the property and wooded grounds over the other half of the property.

| | | |
|--|--|------------------|
|  | GREENING SHORELINES TO ENHANCE RESILIENCE | PAGE: 28 of 44 |
| | | DATE: 2014/06/30 |
| | AN EVALUATION OF APPROACHES FOR ADAPTATION TO SEA LEVEL RISE | REVISION NO.: 0 |

An overview assessment of the ecological services that exist at the Case Example site and the likely changes to be expected for either the hard or the soft alternative is provided in Table 5. The basis for the assessment framework is summarized in Appendix 1. The rationale for the assigned ecological services scoring for each service is provided below:

- ES 1. Neither alternative is expected to make a significant difference to the natural alongshore processes in this area; however, because the hard alternative (a sea dike with the seaward toe exposed to storm water levels and breaking wave energy) will likely result in more wave energy reflection than the soft alternative, it is rated slightly lower than the soft alternative.
- ES 2. The hard alternative is rated lower than the soft alternative because it is expected that the seaward face of the sea dike will need to be armoured, which together with the higher crest elevation of the sea dike, will tend to restrict movement of materials between the upland and the foreshore.
- ES 3. The hard alternative is rated lower than the soft alternative because the sea dike will likely eliminate most of the habitat for the existing riparian vegetation. However; it may be possible for some offsetting vegetation to exist on the seaward face of the dike.
- ES 4. Neither alternative is expected to materially change the conditions for any vegetation in the lower foreshore.
- ES 5. Neither alternative is expected to affect the existing naturally occurring benthic foreshore habitats.
- ES 6. Neither alternative is expected to affect foreshore habitats at the site.
- ES 7. As both the hard and soft alternative only consider works (the sea dike or headland structures and imported beach material) that are placed on either the shoreline (the hard alternative) or the upper inter-tidal profile, neither alternative is expected to reduce exposure or improve sedimentation through protection provided by offshore structures.

Table 5: Assessment Template for Case Example 3

| Ecological Service | | Existing | Hard Alternative | Soft Alternative | Comment |
|--------------------|---|-----------|------------------|------------------|---------|
| ES1 | Coastal Processes | +2 | -1 | 0 | |
| ES2 | Upland – Foreshore linkages | +2 | -2 | 0 | |
| ES3 | Marine Riparian vegetation | 0 | -1 | 0 | |
| ES4 | Emergent or Submerged Vegetation | 0 | 0 | 0 | |
| ES5 | Foreshore Habitat Supply | 0 | 0 | 0 | |
| ES6 | Foreshore Habitat Diversity | +1 | 0 | 0 | |
| ES7 | Foreshore – Offshore linkages | 0 | 0 | 0 | |
| | Total Score: | +5 | -4 | 0 | |

The results of the evaluation of the ecological services of the hard and soft alternatives suggest that the hard alternative introduces elements that tend to reduce the ecological services, especially compared to the existing shoreline. Not surprisingly, because the soft alternative is a continuation of the present shoreline treatment, the soft alternative has a neutral effect on the ecological services.

5.1.4 Summary of Ecological Services Assessment

A summary of the total scores evaluated for each Case Example is provided below in Table 6.


Table 6: Summary of Ecological Services Assessment

| Case Example | | Existing | Hard Alternative | Soft Alternative | Comment |
|--------------|-------------------------------|-----------|------------------|------------------|--|
| 1 | Qualicum Beach | -7 | -10 | +8 | The existing shoreline treatment was constructed in the early 1960s on what is understood to have been a relatively natural shoreline |
| 2 | Marr Creek Inter-tidal | -5 | +3 | +9 | The existing shoreline treatment was constructed in the 1960s. The ongoing SPP, which is underway on the existing shoreline shows a net benefit. |
| 3 | Private Residence | +5 | -4 | 0 | The existing shoreline treatment replaced a vertical cedar post seawall originally built in the 1960s |

5.2 Capital Cost

A summary of the anticipated costs of both hard alternatives and the alternate soft option is provided below. As detailed cost information for specific case examples was generally not available, the cost estimates have been prepared using the unit construction costs prepared and presented in [7]. The unit costs are in 2012 dollars and can be summarized as follows:

- Site preparation: \$15/m³ – for clearing and removal of existing topsoil and for removal of existing structures where necessary
- Beach materials and impermeable dike materials: \$40/m³ – supply and placement.
- Armour Rock materials placed on or adjacent to land: \$50/m³ – supply and placement
- Armour Rock material expected to be placed from floating equipment: \$100/m³ – supply and placement
- Surface Restoration: \$100/m² – for provision or restoration of an existing walkway or roadway
- Reinforced Concrete: \$750/m³ – for seawall or similar structures – the volume based on volumetric estimating norms for the overall geometry of the structure.
- Utilities Relocation: as this assessment is a comparison between hard and soft alternatives it was assumed that both concepts would require utility relocation and the costs would be the same.
- Land and right of way acquisitions: not included as the Case Examples span too many site specific combinations of public and private lands and the costs, though likely significant, are not expected to be much different for the specific Case Examples.
- Environmental offsets: not included because of the lack of existing marine habitat definition for the Case Examples. Where appropriate, an average cost of \$250/m² was used in [7].

| | | |
|--|--|------------------|
|  | GREENING SHORELINES TO ENHANCE RESILIENCE | PAGE: 30 of 44 |
| | | DATE: 2014/06/30 |
| | AN EVALUATION OF APPROACHES FOR ADAPTATION TO SEA LEVEL RISE | REVISION NO.: 0 |

The costs presented below are intended to provide guidance in evaluating between the options. They include an allowance of 15% for indirect costs (engineering and construction management for example) and a 40% contingency which is intended to reflect the level of site specific detail information and the stage of design development for the concepts.

The cost estimates do not include any allowances for escalation, either since 2012 or for any escalation, which might occur before the concepts were implemented. In some cases, options might be implemented in stages over time. The cost estimates do not include allowances for staging of the construction or for seismic related foundation improvements.

The Unit Cost summaries in Table 7 are considered to be equivalent to Class D or Order of Magnitude estimates. The estimate accuracy range for a Class D estimate varies somewhat but is typically in the range of ± 50 per cent.


Table 7: Summary of Unit Costs / m of shoreline

| Case Example | | Hard Alternative | Soft Alternative | Comment |
|--------------|------------------------|------------------|-----------------------|--|
| 1 | Qualicum Beach | \$33,000/m | \$10,000 - \$14,000/m | Depending on choice of sand or gravel/pebble/cobble. |
| 2 | Marr Creek Inter-tidal | \$35,000/m | \$25,000/m | Does not include cost of maintaining dry high tide access on existing walkway. Does not include the sunk costs of existing rock features already on site. Assumes all materials procured on the same basis as described above for all Case Examples. |
| 3 | Private Property | \$8000/m | \$4000/m | Does not include sunk cost of existing headland beach system |

It is clear from the results presented in Table 7 that soft alternatives provide a significant cost advantage over the hard alternatives.

In the specific case of Case Example 2, the SPP program is intentionally intended to be implemented in stages as opportunities present themselves. It is possible that the soft alternative cost estimate is high Case Example 2 because natural sediment accumulation may offset some of the more costly rock materials assumed in the cost estimating exercise.

It should also be noted that the scale of the project, and specifically the length of shoreline, over which the project is undertaken, may also have an important influence on total cost. This is most likely the case for projects in front of private properties where the length of project is most likely to be short. In these cases, the cost of the transition to the adjacent property can be significant. For the purpose of this assessment, transition costs are one component of the contingency allowance carried in the cost estimates presented in Table 7.

| | | |
|--|--|------------------|
|  | GREENING SHORELINES TO ENHANCE RESILIENCE | PAGE: 31 of 44 |
| | | DATE: 2014/06/30 |
| | AN EVALUATION OF APPROACHES FOR ADAPTATION TO SEA LEVEL RISE | REVISION NO.: 0 |

6.0 SUMMARY AND RECOMMENDATIONS

6.1 Summary

The evaluations outlined in this report demonstrate that soft shore approaches, as outlined in the Green Shores™ program, can provide effective flood protection against climate change related sea level rise and related issues. The flood protection is effectively provided by ensuring that the soft approaches initially satisfy the same flooding related guidelines and standards as alternative harder approaches, as laid out by the provincial guidelines referenced in this study.

In the three case examples considered, it was found that the soft alternative always provides a significant cost advantage over the hard alternative. The margin of cost saving varies, ranging from approximately 35 per cent of the cost of the hard alternative for Case 1 to 75 per cent of the cost of the hard alternative for Case 2.


It should be noted that for this study, the implications of maintenance costs for soft approaches, which are sometimes considered, anecdotally, to be greater for soft approaches, were essentially equalized because the implicit design basis is that both approaches must provide the required protection against flooding, after the design storm has occurred. However, both hard and soft approaches may require some expected maintenance or minor repair after the severe storm scenario that is considered in the design basis.

Based on the evaluation framework for ecological services developed for this study the soft alternatives provided improved or similar assessment scores for the provision of ecological resilience of the shoreline. It should be noted that limited environmental information was available at each site for detailed framework evaluation. Even so, when using the information available, the framework clearly indicated, in Case 2, that a hard alternative, when combined with supporting ecological based efforts, could provide an improved opportunity for ecological resilience. This outcome suggests that the evaluation framework could provide a robust methodology for the evaluation of the ecological attributes of future flood protection projects when a fully integrated design approach is undertaken.


6.2 Recommendations

Based on the results of this study, the following recommendations can be made:

1. Both soft and hard alternatives should be considered as equivalent alternatives for flood protection, provided it can be shown that they conform to the mandatory elements for Flood Protection as laid out, for instance, in the ***Dike Maintenance Act***, and related guidelines, and that they provide equivalent ecological services.
2. Cost comparisons between hard and soft alternatives for flood protection must include consideration of equivalent ecological services. Soft alternatives should continue to be considered as very likely providing cost effective solutions for both Flood Protection, and for shoreline protection projects. Although this study did not include an accounting of the value of the ecological services provided by the soft and hard alternatives, it is likely that the cost advantage of soft alternatives will be further increased if these values were included.
3. The Evaluation Framework developed for this study should be further developed and applied in the evaluation of adaptation strategies for Flood Protection. The framework appears to be robust enough to provide balanced guidance for both soft and hard approaches and the framework should be further developed, and pilot tested, as means of defining a quantitative process for evaluation of ecological services, resilience, or diversity provided by alternative adaptation strategies.


| | | |
|--|--|------------------|
|  | GREENING SHORELINES TO ENHANCE RESILIENCE | PAGE: 32 of 44 |
| | | DATE: 2014/06/30 |
| | AN EVALUATION OF APPROACHES FOR ADAPTATION TO SEA LEVEL RISE | REVISION NO.: 0 |

4. A formalized process, with the framework identified in this study, is needed to assess the ecological benefits during the approval process of future flood protection works. Procedures to formalize the assessment and incorporation of ecological resilience, ecological services or the maintenance or improvement of ecological diversity should continue to be advanced for Flood Protection Program evaluation. These procedures could include a provision that proposed projects are certified by a program such as Green Shores™ or alternatively, that they demonstrate, using a quantitative evaluation process such as the Evaluation Framework, a net ecological benefit.
5. Further work to develop a formalized process, based on the results of this study, should be pursued by the Flood Protection Program and other agencies to assist communities considering flood protection works in light of climate change and sea level rise.


| | | |
|--|--|------------------|
|  | GREENING SHORELINES TO ENHANCE RESILIENCE | PAGE: 33 of 44 |
| | | DATE: 2014/06/30 |
| | AN EVALUATION OF APPROACHES FOR ADAPTATION TO SEA LEVEL RISE | REVISION NO.: 0 |

7.0 REFERENCES

- [1] Marine Shoreline Design Guidelines. Johannessen, J., A. MacLennan, A. Blue, J. Waggoner, S. Williams, W. Gerstel, R. Barnard, R. Carman and H. Shipman. Washington Department of Fish and Wildlife. Olympia, Washington. 2014.
- [2] Guidelines for Management of Flood Protection Works in British Columbia. Public Safety Section, Water Management Branch, Province of British Columbia, Ministry of Environment, Lands and Parks. March 1999.
- [3] Dike Design and Construction Guide: Best Management Practices for British Columbia. Flood Hazard Management Section, Environmental Protection Division, Province of British Columbia, Ministry of Water, Land and Air Protection. July 2003.
- [4] Coastal Habitats Shield People and Property from Sea-Level Rise and Storms. Letters, Nature and Climate Change, Advance Online Publication, www.nature.com, 14 July 2013.
- [5] A Stronger, More Resilient New York – Chapter 3 Coastal. plaNYC, June 2013, <http://www.nyc.gov/html/sirr/html/report>
- [6] Coastal Development Rating System, Version 1.0. Online Report of The Stewardship Centre for British Columbia, http://stewardshipcentrebc.ca/PDF_docs/greenshores/GreenShoresCDRS.pdf
- [7] Cost of Adaptation – Sea Dikes & Alternative Strategies, Final Report. Report prepared for MFLNRO by Delcan, October 2012.
- [8] Costs of Adapting Coastal Defenses to Sea-Level Rise – New Estimates and their Implications. Jonkman et al, Journal of Coastal Research, Pre-print on-line 19 April 2013.

| | | |
|--|--|------------------|
|  | GREENING SHORELINES TO ENHANCE RESILIENCE | PAGE: 34 of 44 |
| | | DATE: 2014/06/30 |
| | AN EVALUATION OF APPROACHES FOR ADAPTATION TO SEA LEVEL RISE | REVISION NO.: 0 |

APPENDIX A
Ecological Services Framework

| | | |
|--|--|------------------|
|  | GREENING SHORELINES TO ENHANCE RESILIENCE | PAGE: 35 of 44 |
| | | DATE: 2014/06/30 |
| | AN EVALUATION OF APPROACHES FOR ADAPTATION TO SEA LEVEL RISE | REVISION NO.: 0 |

A 1 BACKGROUND

This Appendix provides a detailed description of the context and basis for the Ecological Evaluation Framework developed for this project.

Climate change is expected to manifest itself in coastal areas through increased freshwater run-off, increased storm (wave) intensity, and higher sea levels. These processes act to directly increase flood risk to coastal developments, and they act to directly increase erosion, which can also indirectly enhance flood risk.

Greenshore (GS) approaches are shoreline stabilization techniques that maintain or enhance natural coastal properties to allow shorelines to become more resilient to sea level rise (SLR) and concomitant coastal flooding and erosion. The GS guiding principles are:

- 1) Preserve the integrity or connectivity of coastal processes,
- 2) Maintain or enhance habitat diversity and function,
- 3) Minimize or reduce pollutants to the marine environment, and
- 4) Reduce cumulative impacts to the coastal environment.

GS approaches provide an alternative to hard engineering approaches such as seawalls which are intended to protect property, but ultimately: reflect wave energy, increase erosion to adjacent properties, decrease amount of organic matter, increase erosion in front of seawall, reduce shoreline or riparian vegetation, remove natural shoreline slope, resulting in loss of upper intertidal, concentrate wave and current energy at the ends of the wall, increasing erosion on adjacent properties, and seawalls cannot be adapted effectively to SLR.

Some examples of GS shoreline alternatives to traditional hard engineering approaches include: maintaining or enhancing a salt marsh buffer, widening a coastal marsh, planting a marsh with a sill, beach nourishment (elevating land surface), upland bank grading, re-vegetating foreshore, adding an offshore berm or biogenic reef, enhancing submerged vegetation (e.g. eelgrass). In some instances traditional hard engineered and GS hybrid approaches are effective (and necessary).

A 2 ECOLOGICAL OR ECOSYSTEM RESILIENCE

In this assignment the shoreline and intertidal zone were collectively referred to as the foreshore. Ecological resilience was defined as the capacity of the foreshore to absorb disturbance without shifting to an alternative state and losing its function and services (Cote and Darling 2010). Resilience encompasses two separate processes: Resistance to disturbance, that is how well a habitat can tolerate disturbance without shifting to a 'new' state, and Recovery from disturbance, or the inherent biology/ecology of component species, the condition of the habitat before the event, and the nature/duration of the impact will dictate is recovery. Several important ecological properties or services underlie ecological resilience in coastal marine ecosystems. For this undertaking, we have selected seven key processes or ecosystem functions (Table 1) that drive ecological services in the foreshore to evaluate sites undergoing engineering modification for protection from coastal erosion, or inundation from sea level rise. The assumption is that sites that maintain these ecosystem-level services will have a greatest ability to maintain ecological resilience to sea level rise and related affects.

A 3 FRAMEWORK FOR ASSESSING THE ECOLOGICAL SERVICES OF SHORELINE PROTECTION

A site's shoreline protection measures were evaluated with respect to seven ecological services described in Table A1. The ecological services represent some of the key elements required to maintain or enhance the shoreline's ecological resilience to sea level rise. There are several challenges that should be kept in mind when performing an evaluation, including:

- The local and regional morphological and hydrodynamic conditions (e.g., alongshore drift cell, sediment supply, and dominant wave exposure axis) will influence site conditions.


- The seabed slope in the foreshore and the slope and soil conditions in the upland will dictate in part the engineering approach that is suitable for a site.
- The regional context of shoreline development must also be considered. What are the upstream/downstream neighbors doing and how will it influence the ecological services of the site?
- The timeline for maintaining or enhancing foreshore ecological services depends upon many factors and will ultimately require monitoring or re-assessment of effectiveness by a qualified environmental professional.
- The design criteria used for any soft engineering approach is critical to the success of the approach towards enhancing ecological services. Standards should be followed where possible.

Each ecological service will be given a score of +2, +1, 0, -1 or -2 depending upon how the shoreline protection measure or engineering approach (EA) affects the ecological service. The following sections provide generic descriptions and guidelines for deriving ecological services scores. Sites that use EAs that generate high positive scores (max + 16) will provide the greatest opportunities for maintaining ecological resilience of foreshore habitats.

The GS coastal development rating system (CDRS) is based on GS principles and the GS rating system and is intended to guide design and assess design performance. The table below illustrates the connections between the ecological services and CDRS prerequisites.

Table A1: Seven Ecological Services Required To Enhance Ecological Resilience Of Foreshore Habitats.

| Ecological Service | Link to CDRS | Ecosystem role |
|---|----------------|--|
| ES 1. Long shore transport | Prerequisite 4 | Conservation of coastal sediment processes |
| ES 2. Upland-foreshore linkages | Prerequisite 5 | Connectivity processes |
| ES 3. Marine riparian vegetation | Prerequisite 3 | Ecosystem structure and function |
| ES 4. Emergent and submerged aquatic vegetation | | Ecosystem structure and function |
| ES 5. Foreshore habitat supply | Prerequisite 2 | Ecosystem structure and function |
| ES 6. Foreshore habitat diversity | Prerequisite 2 | Ecosystem structure and function |
| ES 7. Foreshore-offshore linkages | new | Connectivity processes |

| | | |
|--|--|------------------|
|  | GREENING SHORELINES TO ENHANCE RESILIENCE | PAGE: 37 of 44 |
| | | DATE: 2014/06/30 |
| | AN EVALUATION OF APPROACHES FOR ADAPTATION TO SEA LEVEL RISE | REVISION NO.: 0 |

ES 1. Connectivity – Alongshore transport processes


Objective: To maintain natural alongshore processes without modifying water current velocity or direction and/or wave energy.

Ecological services: The maintenance of alongshore transport processes, such as coastal currents, will contribute to increasing foreshore ecological resilience through two major avenues. First, alongshore drift cells, which repeat at different linear spatial scales along the shoreline, include sediment sources, a transport zone and a sediment deposition zone. The transport zone is critical for moving sediment from sources to deposition zones. Over time, the modification of alongshore currents by physical structures in the foreshore can interrupt the natural flow of sediment. Maintaining naturally functioning drift cells may be critical for maintaining upper foreshore spawning habitats of key forage fishes such as surf smelt, Pacific sand lance, and rock sole. Also, maintaining alongshore transport ensure sediment supply to the maintenance and expansion of submerged aquatic vegetation (e.g., eelgrass) and emergent vegetation (e.g., marshes).

Second, alongshore coastal currents connect multiple levels of biological organization (e.g., species or assemblages) and allow ecosystems to self-organize and recover from disturbance (e.g., Bernhardt and Leslie 2012). Connectivity among species, populations and ecosystems enhances the capacity for recovery by providing sources of larvae and young-of-the-year and marine-derived nutrients such as nitrates, in a nitrate-deprived environment. The maintenance of alongshore coastal currents is critical for supply and source/sink dynamics of larval fishes and invertebrates; Source-sink dynamics of larvae operate at coastal spatial scales of about 20-30 km (Robinson et al. 2005).

Table ES1: Ecological Service Scores for Alongshore transport (EA = engineering approach).

| Score | Comments |
|-------------|--|
| + 2 | EA results in > 50% of a vegetated shoreline with no hard structures such as seawalls and riprap, or the EA results in the placement of subtidal structures parallel to the shoreline outside of the foreshore zone and poses no significant influence on alongshore transport processes (e.g., nearshore berm). |
| + 1 | EA results in < 50% of a vegetated shoreline with no hard structures such as seawalls and riprap, or the EA results in the placement of subtidal structures parallel to the shoreline outside of the foreshore zone and poses no significant influence on alongshore transport processes (e.g., nearshore berm). |
| 0 (neutral) | In light of the site's history, the EA does not modify alongshore transport processes. |
| - 1 | EA results in placement of hard structures such as seawalls or riprap parallel to and along <50% of the shoreline that act to reflect wave energy. |
| - 2 | EA results in placement of hard structures running perpendicular to the shoreline (e.g., groins). Both groins and jetties trap sand that is probably flowing to a neighboring beach. Thus, if a groin on one beach is functioning 'well', it might be causing erosion elsewhere by "starving" another beach. |

| | | |
|--|--|------------------|
|  | GREENING SHORELINES TO ENHANCE RESILIENCE | PAGE: 38 of 44 |
| | | DATE: 2014/06/30 |
| | AN EVALUATION OF APPROACHES FOR ADAPTATION TO SEA LEVEL RISE | REVISION NO.: 0 |

ES 2. Connectivity – Upland-foreshore linkages

Objective: To maintain or enhance the bi-directional movement of organic and inorganic materials between the foreshore and upland.


Ecological services: The transition area between the upland and foreshore (e.g., higher high water mark) provides many environmental services which ultimately contribute to the ecological resilience of foreshore ecosystems. These services include the movement of nutrients from the foreshore (e.g., beach wrack) into the upland, the movement of nutrients from freshwater flowing from the upland into the foreshore, and movement corridors in both directions for a wide variety of invertebrates (e.g., crabs) and vertebrates (e.g., river otters).

Hard engineering structures such as vertical seawalls replace naturally sloping shorelines and eliminate gradual changes in water depths thereby presenting impassible barriers to organic and inorganic moving between the foreshore and upland. For example, seawalls prevent the exchange and resupply of sand between upland sources and the foreshore beach. Armoured shorelines have also been shown to truncate the delivery of upland sediment and organic material to the foreshore and result in decreased tidal deposition of fine sediment and beach wrack (Romanuk and Levings 2005). Armoured seawalls can also isolate adjacent upland habitats. For example, a seawall can prevent wrack from moving into a salt marsh, and a upland seawall may reduce runoff over marshes and concentrate flow into a few foreshore areas (Chapman et al. 2011). Seawalls also typically reduce or eliminate shoreline and riparian habitats and their flood storage capacity.

GS approaches should act to maintain, and if not, enhance the connection between the foreshore and upland. One commonly used method, bank enhancement and grading with vegetation to reduce flood risk and erosion allows for natural slopes and transitions between upland and foreshore habitats. Poorly designed GS approaches can however result in barriers to fauna. For example, beach nourishments that place too much sediment on the backshore result in wider and higher backshore that is not re-worked after storms and results in vertical scarps that restrict movement of fauna across the beach (Jackson et al. 2010).

**Table ES2: Ecological Service Scores for across shore linkages
(EA = engineering approach).**

| Score | Comments |
|-------------|--|
| + 2 | EA provides natural access along 100% of the shoreline for movement of organic and inorganic materials between the upland and foreshore (e.g., intertidal marsh, marine riparian vegetation, beach dunes). |
| + 1 | EA provides natural access to at least 50% of shoreline for movement of organic and inorganic materials between upland and foreshore (e.g., intertidal marsh, marine riparian vegetation, beach dunes). |
| 0 (neutral) | In light of the site's history, the EA poses no significant barrier or enhancement to across shore movement of organic and inorganic materials between the upland and foreshore. |
| - 1 | EA uses hard vertical structures (e.g., seawalls or bulkheads) on <50% of shoreline that prohibits movement of organic and inorganic materials between upland and foreshore. |
| - 2 | EA uses hard vertical structures (e.g., seawalls or bulkheads) on >50% of shoreline that prohibits movement of organic and inorganic materials between upland and foreshore. |

| | | |
|--|--|------------------|
|  | GREENING SHORELINES TO ENHANCE RESILIENCE | PAGE: 39 of 44 |
| | | DATE: 2014/06/30 |
| | AN EVALUATION OF APPROACHES FOR ADAPTATION TO SEA LEVEL RISE | REVISION NO.: 0 |

ES 3. Ecosystem structure and function - marine riparian vegetation


Objective: To maintain or enhance the presence of marine riparian vegetation in a 5 m strip along the shoreline between the upper foreshore and upland.

Ecological service: Marine riparian vegetation (MRV) is recognized as a dynamic ecozone extending both landward and seaward from the high water level of marine shorelines. It is usually defined to occur at the land-water interface at the higher high water large tide or high water mark (HWM); the average of all the higher high waters from 19 years of predictions). The shoreline on CHS charts is shown as HWM, but in practice, the marine riparian zone is usually best determined in the field from the spatial extent of vegetation and driftwood. MRV includes numerous species of grasses, sedges, shrubs, herbs, and trees found at or near HWM. Since many plants along the shoreline (except for halophytes) are limited by the presence of salt water, their seaward growth into the middle intertidal zone is restricted. On sandy beaches, dune grass (*Elymus mollis*) and shore pine (*Pinus contorta*) are known as species which stabilize shifting sand. There is a general need for a linear buffer or leave strip for marine riparian along the upper foreshore. The Coastal Development Rating System suggests a marine riparian buffer of 5m. There are several ecological services of the marine riparian that will contribute to foreshore resilience, including:

- Soil stability and sediment control: sloughing and mass wasting of fine sediment and suspended solids onto beaches and fish habitat may be accelerated on shores where marine riparian vegetation has been removed. High sediment loads and excess turbidity can affect fish habitat productivity at all elevations of the beach and the material can also be transported alongshore by currents.
- The presence of marine riparian vegetation has a direct influence (via shading) on incubation success for forage fish species such as surf smelt (*Hypomesus pretiosus*) and Pacific sand lance (*Ammodytes hexapterus*), two species which spawn and incubate their eggs in substrate on high elevation areas of beaches.
- MRV provides wildlife habitat and nutrient and leaf litter input; enhances feeding conditions of young salmon (e.g., Romanuck and Levings 2005); and enhances upper foreshore habitat complexity (e.g., logs).
- MRV also acts as to filter of upland water flowing into the foreshore, enhancing water quality.

Table ES3: Ecological Service Scores for marine riparian vegetation (EA = engineering approach).

| Score | Comments |
|-------------|---|
| + 2 | EA involves restoring or enhancing > 50% of the shoreline with endemic MRV within a minimum 5m zone adjacent to the HWM. |
| + 1 | EA involves restoring or enhancing < 50% of the shoreline with endemic MRV within a minimum 5m zone adjacent to the HWM. |
| 0 (neutral) | In light of the site's history, the EA does not destroy or enhance shoreline MRV. |
| - 1 | EA results in removal of up to 50% of the endemic MRV, and/or reduces the MRV zone to < 5m wide adjacent to the HWM, and/or replaces endemic MRV with grass or hardened surfaces (e.g., asphalt). |
| - 2 | EA results in removal of > 50% of the endemic MRV, and/or reduces the MRV zone to < 5m wide adjacent to the HWM, and/or replaces endemic MRV with grass or hardened surfaces (e.g., asphalt). |

| | | |
|--|--|------------------|
|  | GREENING SHORELINES TO ENHANCE RESILIENCE | PAGE: 40 of 44 |
| | | DATE: 2014/06/30 |
| | AN EVALUATION OF APPROACHES FOR ADAPTATION TO SEA LEVEL RISE | REVISION NO.: 0 |

ES 4. Ecosystem structure and function – Emergent and submerged aquatic vegetation

Objective: To maintain or enhance regions of emergent or submerged aquatic vegetation in the lower foreshore


Ecological services: Soft approaches such as coastal wetlands (CW) can help protect shorelines from floods and erosion by absorbing waves and slowing the flow of high water. Coastal wetlands can take various forms depending upon an area's physical characteristics but typically include tidal basins, salt marshes, mud flats, rocky shores and pebble beaches (San Francisco Bay Conservation and Development Commission 2011).

Because CWs are typically wider than linear armouring structures, they require more land adjacent to the foreshore. CWs are naturally adapted to sea level rise as long as three conditions are met. First, the CW must be able to migrate inland. Second, the CW must be supplied with sediment to respond vertically to SLR. And third, the CW habitats require time to establish and to adapt (migrate) to SLR. In California, it is recognized that CW can be very cost-effective flood protection strategies if a buffer or set-back area exists between developed places and today's shoreline. Borsje et al. (2011) describe how in the Netherlands, willow-planted intertidal plains have been used to dampen wave impact on dikes (60-80% reduction in wave height), and therefore allow for a considerably lower dike height (by about 0.8m). A lower dike costs less to construct, maintain and the willow flood plan enhances ecological value and aesthetics.

The US Environmental Protection Agency notes that the effectiveness of wetlands for flood abatement will vary depending upon the size of the wetland, the type and condition of the vegetation, the location of the wetland in the flood path, and the saturation of the soils before flooding. A one acre wetland can absorb about three-acre feet of water (1 million gallons). Combined with water storage ability, wetland vegetation can help slow the speed of flood waters, and can actually reduce flood heights and destructive wave potential.

Table ES 4: Ecological Service Scores for emergent and submerged aquatic vegetation (EA = engineering approach).

| Score | Comments |
|-------------|--|
| + 2 | EA plants or enhances the density of emergent or submerged aquatic vegetation along > 50% of the shoreline. |
| + 1 | EA plants or enhances the density of emergent or submerged aquatic vegetation along at least 50% of the shoreline. |
| 0 (neutral) | In light of the site's history, the EA does not enhance or reduce the existing emergent or submerged aquatic vegetation. |
| - 1 | EA results in a reduction in emergent or submerged aquatic vegetations along < 50% of the shoreline. |
| - 2 | EA removes all existing emergent or submerged aquatic vegetations along > 50% of the shoreline. |

| | | |
|--|--|------------------|
|  | GREENING SHORELINES TO ENHANCE RESILIENCE | PAGE: 41 of 44 |
| | | DATE: 2014/06/30 |
| | AN EVALUATION OF APPROACHES FOR ADAPTATION TO SEA LEVEL RISE | REVISION NO.: 0 |

ES 5. Ecosystem structure and function – foreshore habitat supply

Objective: To maintain or enhance the existing naturally occurring suite of benthic foreshore habitats.


Ecological service: The foreshore habitats present at a site have adapted to the local hydrodynamic conditions, namely exposure to winds, waves, tidal currents, and/or river (freshwater) flow. The alterations of existing foreshore habitats by engineering approaches will ultimately degrade the productive capacity and ecological resilience of the site. For example, vertical engineered structures such as sea walls replace naturally sloping shorelines and eliminate gradual and diverse changes in upper foreshore water depth thereby reducing functioning of habitats and flood storage capacity. Ultimately, maintaining the existing spatial amount of each type of benthic foreshore habitat at a site was the foundation and key rationale for DFO's no-net-loss habitat principle of the pre 2013 Fisheries Act. Although the Fishery Act has changed to focus on avoiding or mitigating serious harm to fish or fish habitat, the principle of ES5 remains core to soft approach for enhancing ecological resilience of the foreshore. Some of the key functions of marine habitats for maintaining or enhancing ecological resilience at site include:

- The intrinsic capacity of foreshore habitats to produce primary and secondary prey (e.g., micro, meso and macro benthos) for consumption by tertiary vertebrates such as fish, birds, and mammals.
- The physical 2 and 3 dimensional structure of habitats plays a key role in the nursery function for fish and invertebrates (e.g., young rockfish, Dungeness crabs).
- Ultimately, the combination of habitat structure, increased water temperatures, and enhanced foraging opportunities of the foreshore provide the necessary conditions for enhanced survival and growth of young of the year fish and invertebrates.

Several foreshore habitats, such as eelgrass meadows, have been frequently identified as contributing disproportionately to the ecological resilience of the foreshore through their wave-dampening properties, sediment stabilizing capability, and nursery functions for young fishes and invertebrates. Accumulations of decaying eelgrass in the high intertidal, as part of beach wrack, may also provide enhanced wave-dampening properties. Particular emphasis should be placed on maintaining eelgrass.

Table ES5: Ecological Service Scores for marine riparian vegetation (EA = engineering approach).

| Score | Comments |
|-------------|---|
| + 2 | EA restores or enhances > 50% of the amount (m ²) of a naturally occurring foreshore habitat. |
| + 1 | EA restores or enhances < 50% of the amount (m ²) of a naturally occurring foreshore habitat. |
| 0 (neutral) | In light of the site's history, the EA does not reduce or enhance naturally occurring benthic habitats. |
| - 1 | EA reduces up to 50% of a naturally occurring foreshore habitat (m ²). |
| - 2 | EA reduces more than 50% of a naturally occurring foreshore habitat (m ²). |

| | | |
|--|--|------------------|
|  | GREENING SHORELINES TO ENHANCE RESILIENCE | PAGE: 42 of 44 |
| | | DATE: 2014/06/30 |
| | AN EVALUATION OF APPROACHES FOR ADAPTATION TO SEA LEVEL RISE | REVISION NO.: 0 |

ES 6. Ecosystem structure and function – Foreshore habitat diversity


Objective: Maintain or enhance the diversity of foreshore habitats at the site.

Ecological service: The diversity of habitats at a site, often termed the habitat mosaic, directly contributes to increased species diversity. Ultimately, the diversity of marine habitats within and beyond a site's foreshore will be directly related to the variety of species found at that site. Theory predicts that ecological resilience increases with compensatory species and the number of links per species in food webs, and that ecosystems with few links are extremely sensitive to the removal of any given species (Bernhardt and Leslie 2012). A large number of food web links among species, and longer food chains, may act to stabilize webs in the face of disturbance.

Hard engineering approaches like shoreline armouring can negatively impact foreshore habitat diversity by reducing the amount of intertidal habitat, reducing production of prey, and increasing water temperatures. However, design modifications, such as adding habitat benches within rip rap revetments have achieved the goal of increasing site habitat diversity (e.g. Toft et al. 2013). Other approaches have been used to modify shoreline armouring to enhance habitat diversity, including selecting certain types of porous rock to improve algal and macro faunal colonization. For example, concrete blocks with a fine or coarse surface were found to be more rapidly colonized by small green algae than those slabs with a smoother surface. Geometric structures within the slabs (e.g., cups and holes retained water longer during low tide and favoured the initial colonization by larger green algae (Borsje et al. 2011). Small adaptations of both texture and structure of concrete constructions within the intertidal zone led to better settlement, colonization and increased diversity of algae and macro benthos. Ultimately the creation of macro or micro habitats at a site through careful design will act to enhance foreshore habitat diversity and ultimately maintain ecological services.

Table ES6: Ecological Service Scores for enhancing habitat diversity (EA = engineering approach).

| Score | Comments |
|-------------|--|
| + 2 | EA increases foreshore habitat diversity by at least 2 benthic habitat types along the shoreline. |
| + 1 | EA increases foreshore habitat diversity by at least 1 benthic habitat type along the shoreline (e.g., habitat benches on rip rap revetments). |
| 0 (neutral) | In light of the site's history, the EA does not destroy or enhance foreshore or subtidal habitat heterogeneity. |
| - 1 | EA results in direct burial, removal or destruction of < 50% of existing foreshore habitats. |
| - 2 | EA results in direct burial, removal or destruction of > 50% of existing foreshore habitats. |

| | | |
|--|--|------------------|
|  | GREENING SHORELINES TO ENHANCE RESILIENCE | PAGE: 43 of 44 |
| | | DATE: 2014/06/30 |
| | AN EVALUATION OF APPROACHES FOR ADAPTATION TO SEA LEVEL RISE | REVISION NO.: 0 |

ES 7. Connectivity Processes – Foreshore-offshore linkages

Objective: Reduce wind/wave exposure and improve sedimentation in foreshore areas through protection provided by offshore structures.


Ecological services: Breakwaters in the lower intertidal or sub tidal areas have long been used to enhance ecological services in foreshore areas. For example, protection from wave exposure leads to reduced erosion of shorelines, and creates calm-areas behind breakwater structures to increase sedimentation and eventual colonization by submerged aquatic vegetation. Reef building species such as oysters (e.g., *Crassostrea gigas*) and mussels (e.g., *Mytilus edulis*) have been frequently used to modify local hydrodynamic processes (e.g., wave attenuation) and to increase sedimentation behind the reef. Biotic structures contribute to stabilizing intertidal habitats, clarify water and enhance local species diversity by providing 3-d structure on the seafloor (Borsje et al. 2011). Breakwater oyster reefs were also found to provide substrates for Pacific oyster recruitment and harboured a more diverse community of fishes and invertebrates compared to control areas without oyster reefs (Scyphers et al. 2011).

Although the concept seems straightforward, understanding habitat requirement of the biogenic species is required to achieve maximal benefit. In addition, the design criteria of the biogenic reef is critical because of the potential for the reef(s) to change in local alongshore currents, and the locating of reefs will cover and destroy existing seabed habitat. Borje et al. (2011) notes that a big issue facing the use of biogenic reefs is the need for better methods to create viable reefs in moderate to high wave exposed areas.

Martin et al. (2005) suggested placing non biotic defensive structures further offshore, minimizing their lengths, increase distances between adjacent structures and omitting enclosing groynes at either end of a row of structures to reduce changes in water flow and ultimately the accumulation of algal detritus. Others have placed reefs or boulders offshore from intertidal areas to successfully dampen wave action. However, a key consideration in the placement of any offshore breakwater structure is the impact on existing lower intertidal or upper sub tidal habitats and loss of their ecological services.

**Table ES7: Ecological Service Scores for sub tidal structures
(EA = engineering approach).**

| Score | Comments |
|-------------|--|
| + 2 | EA introduces a natural biogenic breakwater structure (e.g., oyster reef) perpendicular to the dominant wave exposure, in either the lower foreshore or sub tidal that does not modify coastal currents. |
| + 1 | EA introduces a non biogenic breakwater structure (e.g., boulders) perpendicular to the dominant wave exposure, in either the lower foreshore or sub tidal that does not modify coastal currents. |
| 0 (neutral) | In light of the site's history, the EA does not modify the intertidal or sub tidal with a breakwater structure |
| - 1 | EA introduces one continuous man-made or biogenic breakwater structure parallel to < 50% of shore. This poor design will lead to modification of alongshore currents and change sedimentation patterns in the foreshore. |
| - 2 | EA introduces one continuous man-made or biogenic breakwater structure parallel to > 50% of shore. This poor design will lead to modification of alongshore currents and change sedimentation patterns in the foreshore. |

| | | |
|--|--|------------------|
|  | GREENING SHORELINES TO ENHANCE RESILIENCE | PAGE: 44 of 44 |
| | AN EVALUATION OF APPROACHES FOR ADAPTATION TO SEA LEVEL RISE | DATE: 2014/06/30 |
| | | REVISION NO.: 0 |

References

- Berhardt, J.R. and H.M. Leslie. 2012. Resilience to climate change in coastal marine ecosystems. *Annu. Rev. Mar. Sci.* 5:371-92.
- Borsje, B.W., B.K. van Wesenbeeck, F. Deckker, P. Paalvast, T.J. Bouma, M.M. van Katwijk, and M.B. de Vries. 2011. How ecological engineering can serve coastal protection. *Ecological Engineering* 37:113-122.
- Chapman, M.G. and A.J. Underwood. 2011. Evaluation of ecological engineering of 'armoured' shorelines to improve their value as habitat. *Journal of Experimental Marine Biology and Ecology* 400:302-313.
- Coastal Development Rating System, Version 1.0. Online Report of The Stewardship Centre for British Columbia, http://stewardshipcentrebc.ca/PDF_docs/greenshores/GreenShoresCDRS.pdf
- Jackson, N.L., K.F. Nordstrom, S. Saini, and D.R. Smith. 2010. Effects of nourishment on the form and function of an estuarine beach. *Ecological Engineering* 36: 1709-1718.
- Lemieux, J.P., Brennan, J.S., Farrell, M., Levings, C.D., and Myers, D. (Editors). 2004. Proceedings of the DFO/PSAT sponsored Marine Riparian Experts Workshop, Tsawwassen, BC, February 17-18, 2004. *Can. Manuscr. Rep. Fish. Aquat. Sci.* 2680: ix + 84 p.
- Martin, D., Bertasi, F., Colangelo, M.A., de Vries, M., Frost, M., Hawkins, S.J., Macpherson, E., Moschella, P.S., Satta, M.P., Thompson, R.C. and Ceccherelli, V.U., 2005. Ecological impact of coastal defence structures on sediments and mobile infauna: evaluating and forecasting consequences of unavoidable modifications of native habitats. *Coastal Engineering*. 52, 1027-1051.
- Page, N., P. Lilley, I.J. Walker and R.G. Vennesland. 2011. Status report on coastal sand ecosystems in British Columbia. Report prepared for the coastal sand ecosystem Recovery Team. 83pp.
- Robinson, C.L.K., J. Morrison, and M.G.G. Foreman. 2005. Oceanographic connectivity among marine protected areas on the north coast of British Columbia, Canada. *Canadian Journal of Fisheries and Aquatic Sciences* 62:1350-62.
- Romanuck, T.N. and C.D. Levings. 2005. Stable isotope analysis of trophic position and terrestrial versus marine carbon sources for juvenile Pacific salmonids in nearshore marine habitats. *Fisheries Management and Ecology*. 12:113-121.
- San Francisco Bay Conservation and Development Commission 2011. Living with a Rising Bay: Vulnerability and Adaptation in San Francisco Bay and on its Shoreline. 187 pp. <http://www.bcdc.ca.gov>
- Scyphers, S.B., S.P. Powers, K.L. Keck Jr., and D. Brown. 2011. Oyster reefs as natural breakwaters mitigate shoreline loss and facilitate fisheries. *Plos One* 6(8)1-12.
- Toft, J.D., A.S. Ogston, S.M. Heerhartz, J.R. Cordell, and E.E. Flemer. 2013. Ecological response and physical stability of habitat enhancements along an urban armored shoreline. *Ecol. Engineering* 57:97-108.