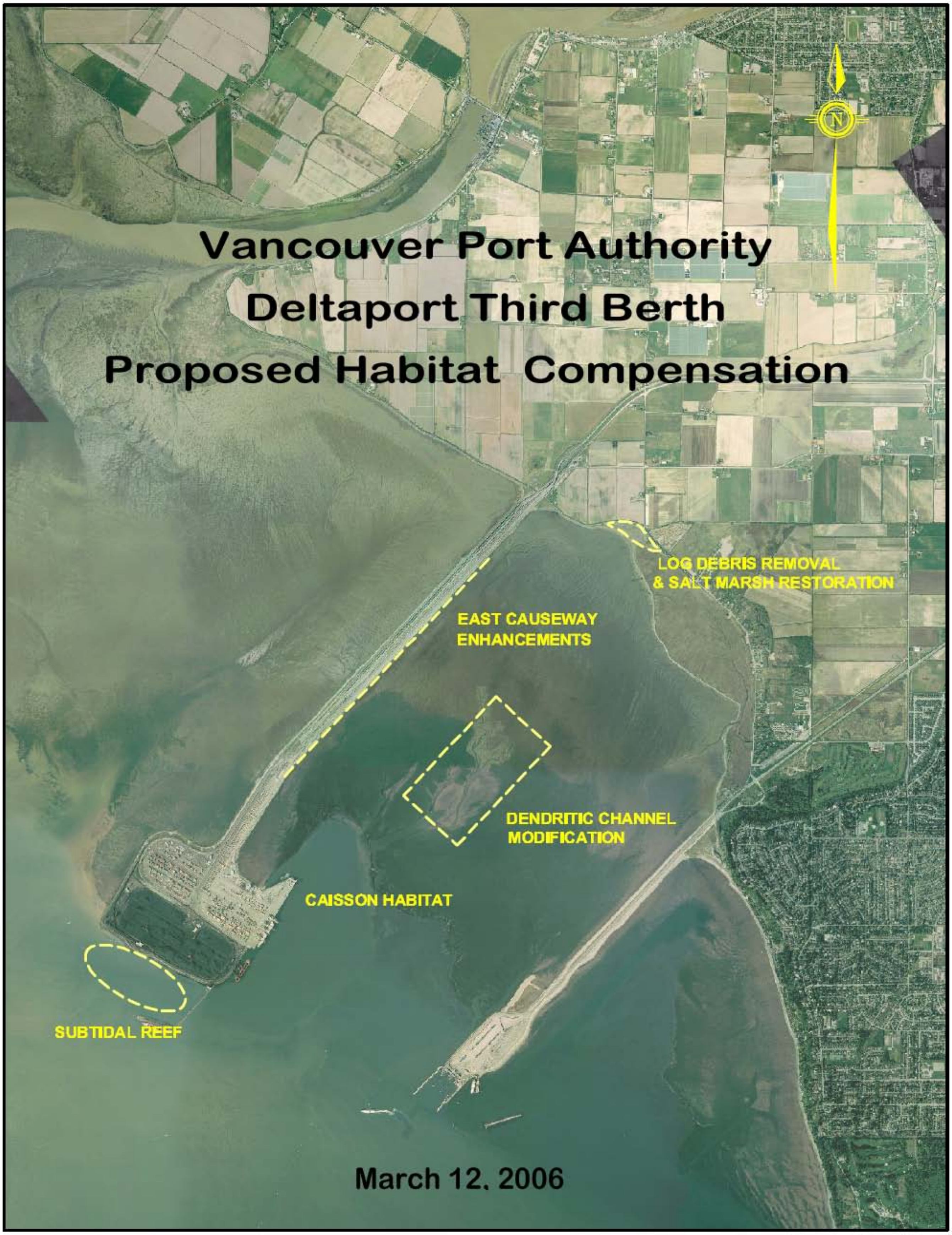
Vancouver Port Authority
Deltaport Third Berth
Proposed Habitat Compensation



March 12, 2006

Vancouver Port Authority
Deltaport Third Berth
Proposed Habitat Compensation

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MPT Land Surveying Co. Ltd.

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1. INTRODUCTION

The proposed Deltaport Third Berth Project is required to meet Canada's needs as a gateway for Pacific trade and is one component of several initiatives to improve Canadian port infrastructure. Vancouver Port Authority (VPA) recognizes that port development must be sustainable and that the 8,000 ha Roberts Bank area provides important habitat for maintaining fish and waterfowl.

One of the regulatory processes that is critical to achieving sustainable port development is ensuring no net loss of fish habitat, as outlined by the Department of Fisheries and Oceans (DFO) national fish habitat policy. The Deltaport Third Berth project is of national significance and meets the project justification/rationale requirements of the DFO policy.

In keeping with the mitigation requirements as part of the project review, VPA has revised terminal design by:

- decreasing the project footprint approximately 32% from the initial planning concept VPA proposed in 2003, from 32 ha to 21.9 ha to reduce impacts at the site, achieved by optimizing container operations to a state-of-the-art facility;
- decreasing tug basin dredging from 26,000 m^3 to 14,600 m^3 to reduce dredging impacts for, a final dredge area of 12.71 ha;
- redirecting stormwater outlets from the embayment area to improve environmental quality for potential fish and waterfowl.

There has been an intensive effort to identify and assess on-site and off-site habitat compensation options, both internally and in consultation with DFO and Canadian Wildlife Service (CWS). Conceptual compensation options were summarized for several on-site options (Williams and Millar 2005). Following review of the options, the primary environmental review agencies, DFO and CWS, requested further detail on the compensation package and consideration was given to several off-site options. On October 13, 2005, VPA and the agencies, as well as Ducks Unlimited visited several potential sites on Roberts Bank and the lower South Arm marshes, and Sturgeon Bank on October 25.

This revised report was prepared to address the Working Group comments on the VPA Deltaport Third Berth proposed habitat compensation, draft report, dated November 7, 2006. A series of graphical illustrations showing cross sections of the habitat concepts proposed for the east causeways enhancements were prepared and included in the report to further improve the explanation of the compensation package. This final report will serve as a guiding document for the environmental agencies and consultant design team during the detailed design phase.

2. DESCRIPTION OF ON-SITE COMPENSATION OPTIONS

Five on-site compensation options are presented:

i. east causeway salt marsh and barrier island;
ii. log debris removal and salt marsh tidal channel;
iii. subtidal reef;
iv. sand bar stabilization by dendritic channel modification;
v. caisson habitat.

The options were initially identified and described in a previous report Williams and Millar (2005), and have been further developed following topographical survey of the east causeway and adjacent intertidal marshes, additional engineering design, and geomorphological process assessment. Land tenure for all of the indicated options is being finalized by VPA to ensure that the compensation plans are feasible and that long-term protection of the compensation sites will be secured.

2.1 East Causeway Channel and Barrier Island

Converting the eastern shoreline of the causeway to stable, high quality salt marsh and backshore habitat would provide value-added habitat for fish and water birds. Consideration will also be given to creating other vegetated and unvegetated habitat features that will increase habitat diversity for fish and water birds. Examples of some of the potential habitat features include mudflat for fish and shorebird feeding, sand/gravel beaches for forage fish, such as surf smelt or sand lance, and nursery areas for juvenile crab. The final determination of the habitats to be constructed will be based on further assessments of biological, engineering and geomorphic processes and factors, and discussion with DFO and CWS to maximize the habitat diversity and productivity along the causeway.

Existing fish habitat along the eastern shore of the Roberts Bank causeway consists of a linear rock rip rap protected bank (Fig. 1), which is fully exposed to marine processes and offers limited habitat value for fish and water birds. The backshore consists of an unpaved bench used by vehicular traffic and a narrow band of grass and herbaceous vegetation (Fig. 2). The tidal habitat is confined to a rock rip and lower cobble and sand beach face. Being open to marine processes, most influential being wind and waves, especially during storms, the area has limited productive capacity. Constructing salt marsh, mudflat, and planting of shrubs and small trees would increase productive capacity by providing potential for a broader range of species and functions to use the site, and subsequently increase habitat and species diversity. Salt marsh and backshore trees and shrubs would provide cover and nutrient inputs for fish, invertebrates, and water birds. The total area along the east causeway available for habitat compensation is 6.7 ha.

This approach is in keeping with the development of habitat compensation in the Fraser estuary to meet the DFO's national fish habitat policy that promotes the creation of higher value habitat in close proximity to the site of impact (DFO 1986; Anon. 1998; Adams and Williams 2004). The design team are mindful of creating compensation habitat that benefits water birds as well, and several options benefit both or are specific to improving avian habitat (i.e. selection of food producing and nesting plant species, roosting sites, and refuge areas).


Figure 1. Rock rip rap east bank.


Figure 2. East bank backshore.

2.1.1 Review of Design Criteria

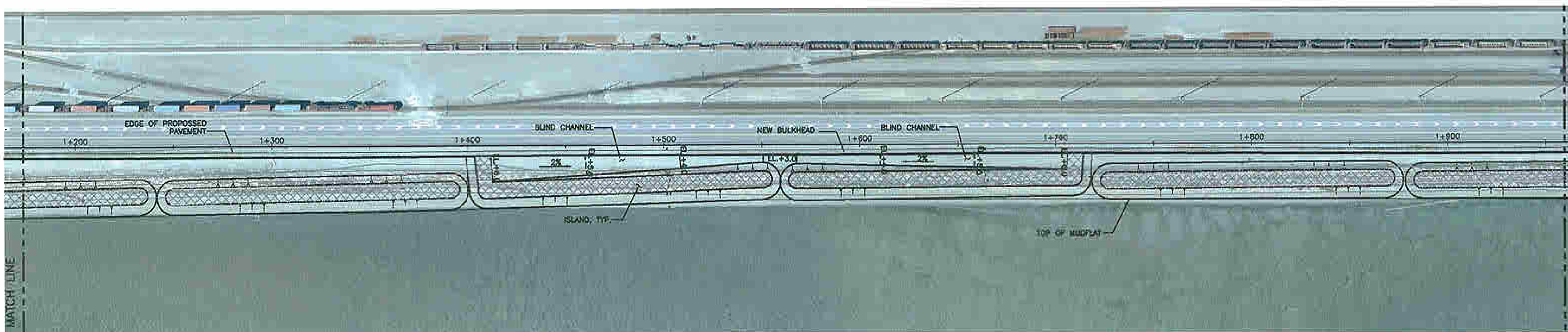
The design criteria for the east causeway habitat compensation development included:

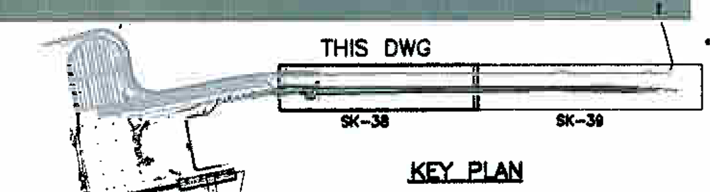
- a continuous pullout along the existing road to meet Ministry of Transport requirements (e.g. 4 m wide);
- ensuring adequate shoreline protection against storms and waves of the upland area;
- maintaining existing rip rap access for Tsawwassen First Nations (TFN) to the flats;
- limiting habitat compensation works to between the causeway and the existing toe of rock rip to minimize impacting the adjacent mudflat;
- maximizing area and diversity of high quality fish, crab, and water bird habitat;
- limiting the size of backshore trees planted to minimize eagle perching;
- protection of created habitat from physical processes occurring in the inter- causeway area, including storm events;
- considering appropriate lane surfacing and mitigation measures along causeway to protect habitat compensation areas;
- protecting habitat compensation areas from anthropogenic disturbance, e.g. dumping, vehicle or pedestrian trampling, should it be necessary..

The proposed east causeway compensation design will include a range of habitat features to maximize species and functions diversity. A series of plan views of the design layout, superimposed on the aerial photograph of the east causeway shows the proposed spatial arrangement (Fig.3, Drawing SK-38, and Fig. 4, Drawing SK-39). To provide further detail, illustrative cross sections are provided of each habitat option in the following subsections.

The basic habitat concept is the creation of a barrier island with crest at 6.5 m elevation to provide a vegetated area to support fish and wildlife, behind which salt marsh, mudflat, beach or gravel/cobble habitat can be constructed.

To increase biodiversity, several additional habitat features are proposed. Blind channels or sloughs that include a gradient or range of constructed habitats are shown in Figures 3 and 4, and could provide additional benefits to juvenile crabs, forage fishes, several species of water birds, and wildlife. At the southern limit of the site (Fig. 3) a spit is proposed to provide water bird habitat, specifically for brant geese and other waterfowl. This feature will require modifications outside the causeway footprint, so will need to be investigated further to ensure there are benefits to fish as well as water birds. Along the northern section of the causeway (Fig. 4), another proposed habitat feature is an open salt marsh about 15 m wide that connects directly to the existing mudflat. Alternately, the elevation could be lowered to form additional mudflat habitat. The main focus of the proposed habitat compensation design is to create higher value habitat following more intensive assessment of coastal geomorphological, engineering, and biological considerations.





KEY PLAN

20m 0m 20m 40m

PRELIMINARY
NOT FOR CONSTRUCTION

Ref.No.	REFERENCE

IN ASSOCIATION WITH:

KLOHN CRIPPEN

Moffatt & Nichol

No.	Date	REVISION	Dr'n	Ch'd
C	NOV.07/05	ISSUED FOR CLIENT REVIEW	MC	
B	OCT26/05	ISSUED FOR CLIENT REVIEW	JL	
A	OCT14/05	ISSUED FOR CLIENT REVIEW	JL	

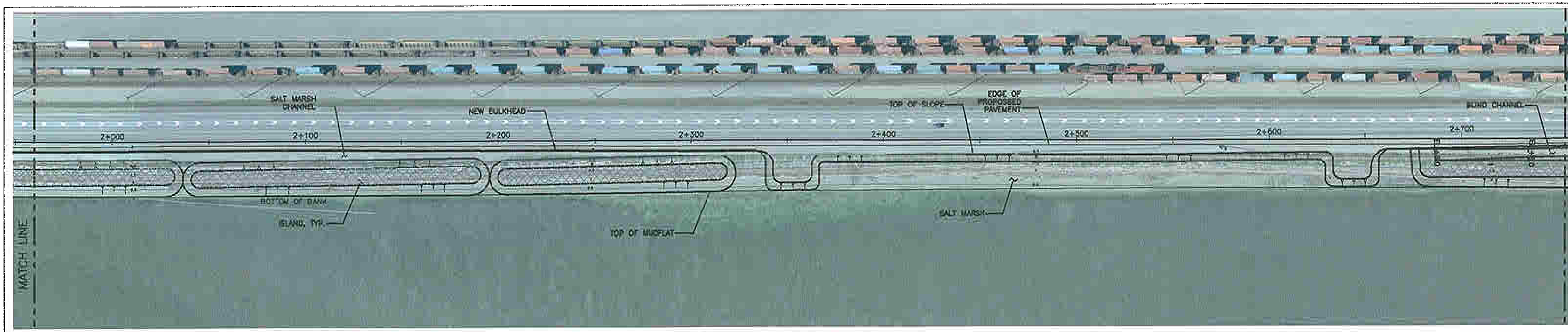
PORT VANCOUVER

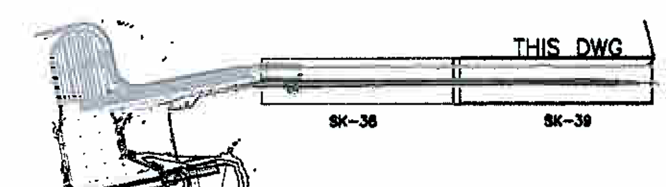
VANCOUVER PORT AUTHORITY
ENGINEERING DEPARTMENT

DESIGN BY	MC (MN)
DRAWN BY	JL (MN)
APPROVED	
DATE	JULY11/05
SCALE	AS SHOWN
VPA SITE	

DELTAPORT BERTH 3 MARINE WORKS
COMPENSATION CONCEPTS
EAST CAUSEWAY SHORELINE
SHEET 1

SIZE	DWG.	SHEET	REV.
D	5610-SK-38	1 of 2	C





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DELTAPORT BERTH 3 MARINE WORKS
COMPENSATION CONCEPTS
EAST CAUSEWAY SHORELINE
SHEET 2

SIZE	DWG.	SHEET	REV.
D	5610-SK-39	2 of 2	C

Some initial comments on the habitat features are discussed in the coastal geomorphologic processes memo (Appendix I). Further analysis will be conducted as part of the detailed design. Increasing habitat diversity along the east causeway will include constructing habitat features that provide a variety of vegetation and substrate set at appropriate elevations and exposure to support species functions. The critical tidal elevations for compensation design along the inter-causeway shoreline are shown in Table 1.

Table 1. Critical tidal elevations.

Tidal Level	Chart Elevation (m)	Chart Elevation (ft)
extreme high tide	5.4	17.7
HHWL[1] (large tide)	4.8	15.7
HHWL[1] (mean tide)	4.1	13.5
mean tide	3	9.8
LLWL[2] (mean tide)	1.1	3.6
LLWL[2] (large tide)	0.1	0.3
extreme low tide	-0.4	-1.3

Notes: [1] HHWL = higher high water level; [2] LLWL = lower low water level

Topographical surveys were conducted on September 16th, 2005, to determine salt marsh elevations along the causeway and the compensation marsh at BC ferries, as well as other habitat zones. Bulrush and colonizing patches of pickleweed and arrowgrass colonized the upper mudflat (i.e. 3.5 to 3.9 m), while salt marsh saltgrass and pickleweed colonized from 3.8 up to 4.5 m or the lower limit of dunegrass. The optimum design elevation for the salt marsh compensation was set at 4.0 m.

2.1.2 Habitat Features

In response to the Work Group Comments illustrative cross sections were prepared by Sharp and Diamond, Landscape Architects, with technical input from GL Williams & Associates. The five illustrative cross sections show:

- barrier island and tidal saltmarsh channel;
- open salt marsh;
- open mudflat;
- habitat gradient behind the barrier island;
- spit.

For each of these habitat compensation options, it was assumed that rock rip rap slopes would be incorporated into the design to provide increased diversity compared to a vertical wall. The final habitat compensation design will be developed following further technical investigation and in consultation with DFO and CWS.

2.1.2.1 Barrier Island

To provide suitable conditions for establishing high quality fish and water bird habitat, the barrier island habitat concept was selected as the main habitat treatment (Figure 5). The barrier island concept would be created between the causeway and toe of existing rock rip rap, avoiding mudflat habitat. The coastal geomorphology assessment prepared by Northwest Hydraulics Consultants (NHC) indicated that storm events would generate 0.8 m waves relatively frequently, requiring adequate shoreline protection (Appendix I). The proposed design concept consists of an offshore barrier island, crest elevation 6.5 m and outer slope of 1.75:1. Large rock rip rap, i.e. 600-800 mm diameter would provide the armouring needed to protect against storm events. Cobble or smaller diameter rock would be used to line the inside of the created channel. Backshore vegetation would be planted along the causeway and along the crest of the barrier island, established at 6.5 m. Salt marsh would be transplanted in the tidal channel between the causeway and barrier island. Salt marsh and suitable grasses and herbaceous vegetation would also naturally colonize the rock rip rap slopes.

Backshore Plantings

The new habitat features include a 2.5 –3.5 m wide strip of backshore plantings along the entire length of the causeway. As well as increasing the value of shoreline habitat for fish and wildlife, the small trees and shrubs will help to screen the causeway from the inter-causeway habitat. Species will be selected that are tolerant of sea spray: trees such as shore pine and Pacific crabapple and shrubs such hawthorn, ocean spray, red elderberry, etc. (Table 2). Large trees may be avoided to prevent utilization by bald eagles as perches for observing prey such as waterfowl or shorebirds. This will be determined during consultations with VPA and CWS during the detailed design phase.

Backshore plantings will occur in the spring or fall following completion of the shoreline protection and barrier island construction. A layer of topsoil will be installed over the structural fill to provide a proper growing medium for the planted vegetation.

Several design criteria address the need to control anthropogenic impacts, e.g. from vehicles, dumping and trampling from human access, and runoff water quality issues. During detailed design measures will be investigated to mitigate and control water quality issues and vehicular impacts during use of the pullout.

Pedestrian access to the habitat compensation areas is not provided because of VPA port security concerns. Temporary fencing may be installed to protect habitat plantings and, if there is a need, a habitat management strategy will be developed and more permanent fencing will be erected if required.

Backshore plantings will be part of habitat compensation works and as such, will require a DFO authorization. The authorization will include the monitoring requirements and remedial works, if the constructed habitats area not functioning as intended.

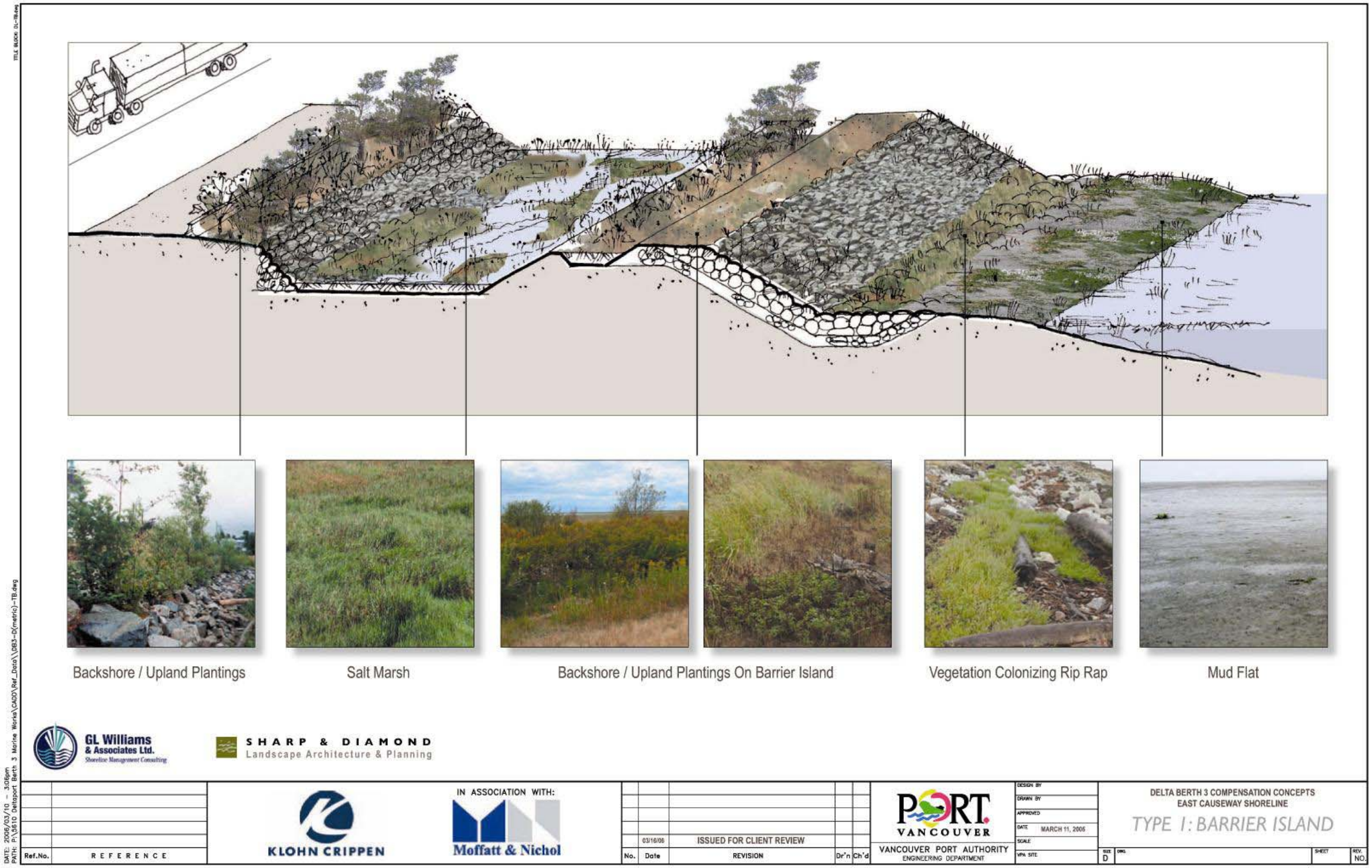

Figure 5. Barrier Island and tidal channel concept for east causeway habitat compensation option.

Table 2. Preliminary species list of backshore and intertidal marsh vegetation.

Scientific Name	Common Name
Trees	
Acer macrophylum	bigleaf maple
Alnus rubra	red alder
Arbutus menziesii	arbutus
Betula papyriera	paper birch
Cornus nuttallii	flowering dogwood
Crataegus douglasii	black hawthorn
Malnus fusca	Pacific crabapple
Pinus contorta	shore pine
Picea sitchensis	Sitka spruce
Shrubs	
Gaultheria shallon	salal
Holodiscus discolour	ocean spray
Lonicera ciliosa	western trumpet honeysuckle
L. involucrate	black twinberry
Mahonia nervosa	dull oregon-grape
Menziesia ferruginea	false azalea
Myrica gale	sweet gale
Rosa gymnocarpa	baldhip rose
Rubus spectabilis	salmonberry
Salix hookeriana	Hooker's willow
Sambucus racemosa	red elderberry
Spiraea douglasii	hardhack
Symphoricarpos spp.	snowberry
Herbs	
Ambrosia chamissonis	silver burweed
Carex mavrocephala	large-headed sedge
Lathyrus nevadensis	purple peavine
Leymus (Elymus) mollis	dunegrass
Sanicula crassicaulis	Pacific sanicle
Salt marsh	
Bolboshoenus (Scirpus) maritimus	seacoast bulrush[1]
Distichlis spicata	saltgrass
Grindelia integrifolia	gumweed
Plantago maritima	seacoast plantain
Salicornia virginica	pickleweed
Schoenoplectus (Scirpus) americanus	three-square bulrush[1]
Triglochin maritima	seacoast arrowgrass[1]

Notes: [1] = brackish

Tidal Salt Marsh

In the tidal channel created between the causeway and the barrier island, salt marsh habitat would be created where the island would offer shelter from storm waves and winds. Openings will allow tidal cycling and complete flushing of the channel, as well as tidal access for juvenile salmonids and other organisms.

Salt marsh is one of the most productive estuarine intertidal habitats and has a limited distribution within the Fraser River estuary. Juvenile salmonids, particularly chum and chinook salmon, utilize salt marsh for refuge and feeding, and juvenile Dungeness crab, as well as several other species of crab, use salt marsh for nursery areas. Saltmarsh vegetation is eaten by waterfowl (e.g. Canada geese, widgeon, pintail) and shorebirds (e.g. long-billed dowitcher and sora rail), and provides nesting cover for ducks, e.g. shoveller and cinnamon teal (Martin *et al.* 1951). Salt marsh also provides several other ecological services including shoreline stabilization, nutrient cycling, contaminant filtering, etc. Salt marsh is also an important contributor of detritus to nearshore waters for the marine detritus food web that sustains numerous invertebrates preyed upon by fish, water birds and marine mammals.

Channel salt marsh will have a base elevation of 4.0 m and be transplanted with saltgrass, pickleweed and other suitable salt marsh species (see Table 2). The interior slopes of the saltmarsh channel will be lined with rock, but the smaller size and more sheltered environment may encourage high salt marsh colonization, especially orache, dune grass, and gumweed. Adding soil to the slope could enhance vascular plant growth and increase productivity.

During detailed design the specifications for the salt marsh will be determined and detailed plans will be prepared, in consultation with DFO and CWS to ensure that the needs of fish and water birds will be addressed. As with backshore plantings, transplanted salt marsh habitat is covered by the DFO authorization, which specifies monitoring requirements and remedial measures, should they be required.

Rock slope Habitat

The rock rip rap armouring will provide several types of marine and brackish habitat. The rock will provide stable, hard substrate for the attachment of macroalgae (Fig. 6), such as rockweed (*Fucus*) and sea lettuce (*Ulva*), and invertebrates (Fig. 7), such as barnacles, mussels, and oysters. The interstitial spaces between the rocks will also provide cover for invertebrates and feeding areas for fish and numerous species of crab and invertebrates. The types of rock colonization will be determined by the salinity levels, exposure and elevation and will vary along the causeway.

Figure 6. Large rock rip rap along causeway supporting attaching macroalgae.

Figure 7. Barnacles colonizing cobble in areas of high salinity.

2.1.2.2 Open Salt Marsh

In less exposed areas, e.g. at the northern end of the causeway (see Figure 4), open salt marsh may be created adjacent the existing mudflat without the need for a barrier island. The habitat concept includes creating a 2-4 m wide backshore area of shrub and small tree plantings along the causeway to screen the salt marsh from vehicular traffic and excavating an embayment into the causeway (Fig. 8). A rock rip rap slope would be created to protect the causeway and the open salt marsh would be transplanted at approximately 4.0 m elevation. Depending on the location of the open salt marsh, saltgrass and pickleweed would be the dominant species transplanted, but if freshwater inputs create brackish conditions, arrowgrass, seacoast bulrush or three-square bulrush could be used to encourage habitat diversity.

Examples of salt marsh compensation projects include Stanley Park (Fig. 9), Port Moody Arm (Fig. 10), and Tsawwassen Ferry terminal. Saltgrass and pickleweed are the typical transplant species because they can tolerant the higher salinity of coastal waters and colonize newly exposed soils quite readily.

Figure 9. Salt marsh compensation constructed above a cobble beach

Figure 10. Salt marsh in rock rip rap with planted backshore shrubs above.

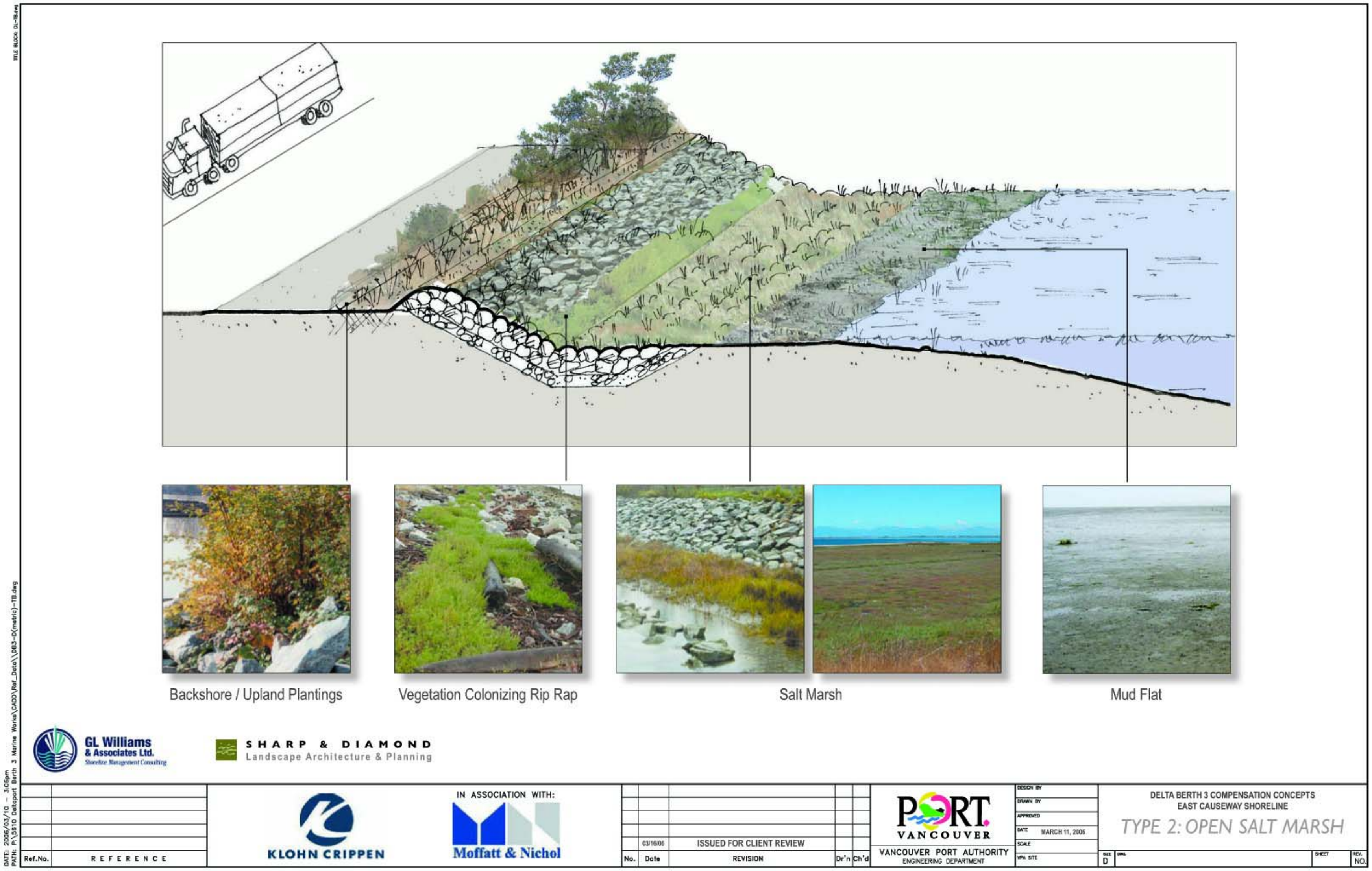

Figure 8. Open salt marsh concept for east causeway habitat compensation option.

2.1.2.3 Open Mudflat

As an alternative to the open salt marsh in less exposed areas, open mudflat could be created, e.g. at he northern end of the causeway (Fig. 4). This alternative habitat concept was part of the discussions with DFO and CWS and offers the creation of mudflat by excavating the causeway to lower elevation than salt marsh and providing increased unvegetated habitat for fish and water bird feeding, as well as infaunal invertebrate colonization. This option is considered less productive than salt marsh, and will be further investigated during detailed design.

Similar to the salt marsh option, the habitat concept includes creating a 2-4 m wide backshore area of shrub and small tree plantings along the causeway to screen the mudflat from vehicular traffic and excavating an embayment into the causeway (Fig. 11). A rock rip rap slope would be created to protect the causeway and slope down to below the mudflat elevation of approximately 2.5 m. Boulder clusters could be considered to enhance habitat diversity but no intertidal plantings would be undertaken.

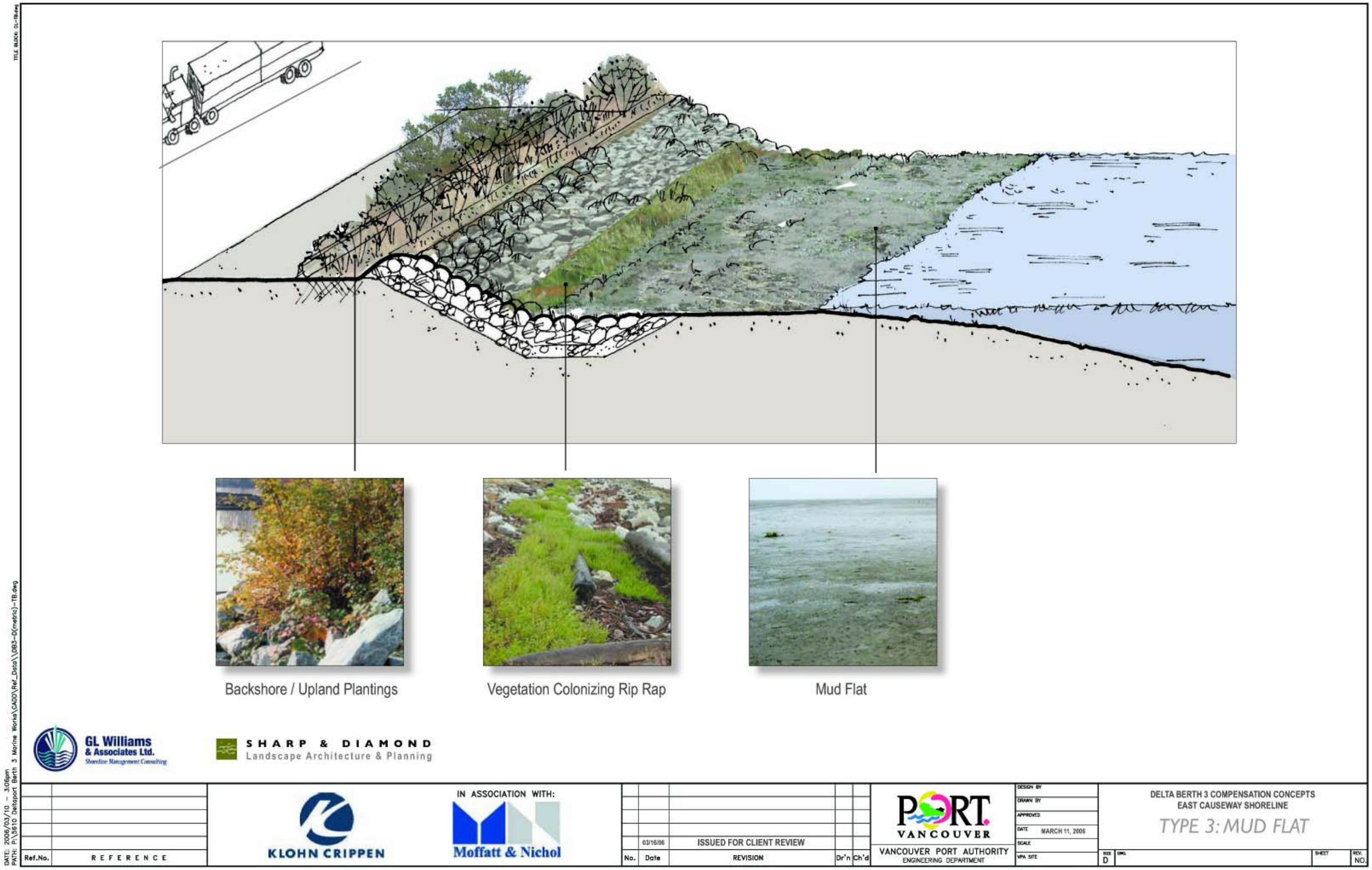

Figure 11. Open mudflat concept for east causeway habitat compensation option.

2.1.2.4 Habitat Gradient

In keeping with the compensation design principles to promote habitat diversity, an opportunity may exist to establish sand lance or surf smelt spawning habitat as part of the compensation works. Sand beaches are not currently present along the east causeway. Sand lance and surf smelt are important forage species for diving sea birds, ducks, larger fish, including juvenile salmon, and marine mammals. Surf smelt spawn in coarse sand or pea-sized gravel (1- 7 mm) in the upper intertidal zone, from approximately 3.2 –3.8 m (Levy 1985; Pentilla 1978). Most of the known surf smelt spawning areas are in Burrard Inlet. Sand lance have a slightly larger spawning range, from 2.6- 3.8 m, and spawn in sandier substrates. During detailed design, creating spawning beaches for sand lance and/or surf smelt will be further investigated and incorporated into the habitat compensation works if the technical assessment indicates they would be successful.

Roberts Bank also provides habitat for Dungeness crabs and habitat features that provide cover and feeding areas for juvenile crabs will be investigated during the detailed design phase. For example, the type and size of substrate and cover (e.g. macroalgae, shell, gravel/boulder, etc.) will be reviewed and appropriate features will be incorporated into the habitat compensation works.

This habitat concept involves creating a habitat gradient in the tidal channel behind the barrier island (Fig. 12), which would be closed off at both ends and opened in the center. The channel elevations would be set to provide backshore areas above high tide for planting trees and shrubs, a lower terrace of dunegrass and other non-woody vegetation. To continue the shoreline habitat gradient, a tidal gradient would be created to provide salt marsh, and unvegetated gradient of ranging from sand to cobble. Coarser substrate, e.g. cobble and boulder, would be placed around the opening, set perpendicular to the gradient axis, to ensure maintain substrate stability during tidal exchanges (i.e. lower energy) and storms (higher energy).

In the proposed package two habitat gradient areas were shown, but the final configuration and type of habitats created along the gradient will be determined following further investigation of coastal processes along the causeway and consideration of species utilization. The suite of habitats provided will encourage a diverse assemblage of conditions for numerous fish, invertebrate, and avian species.

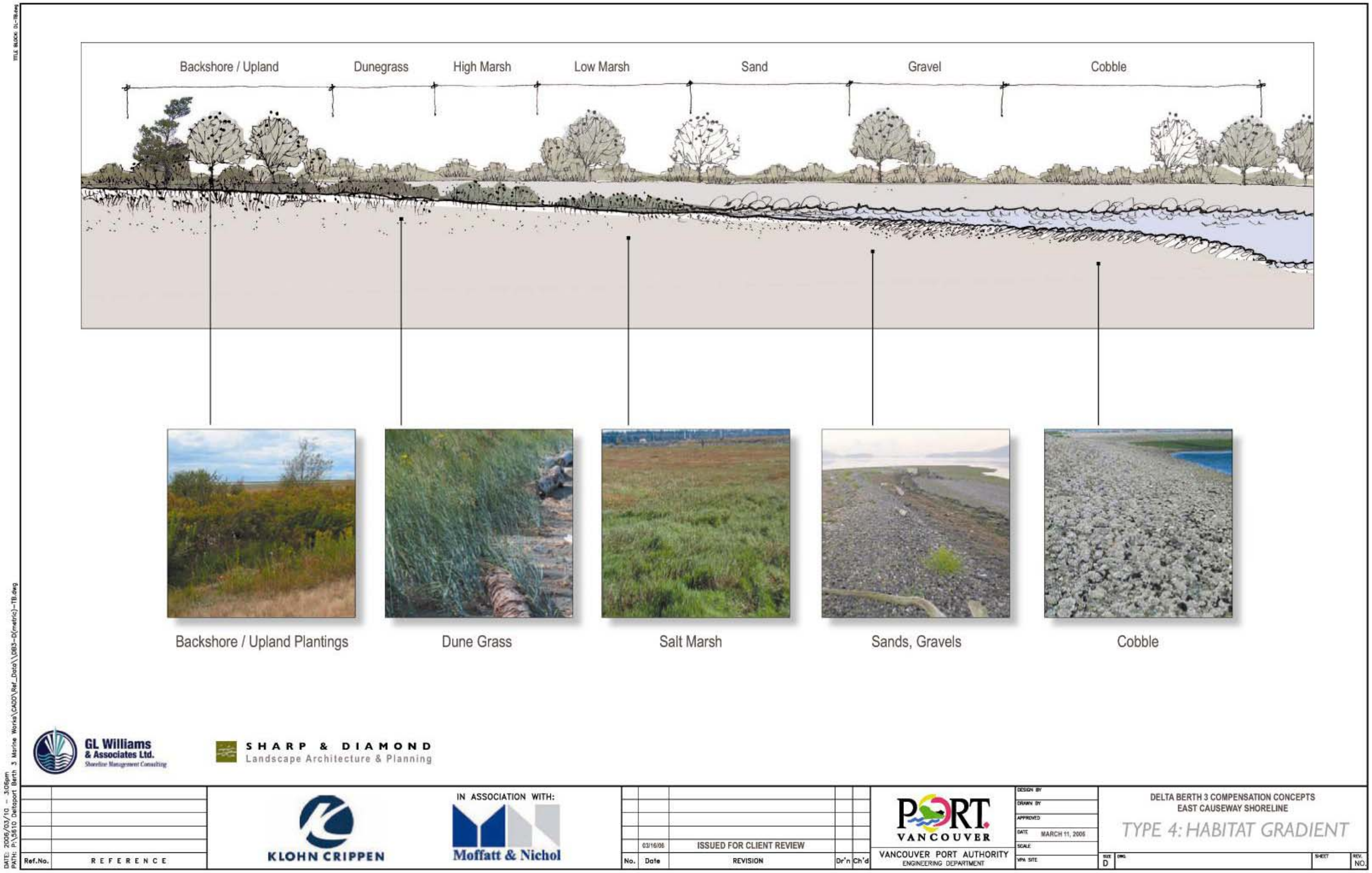

Figure 12. Habitat gradient concept for east causeway habitat compensation option.

2.1.2.5 Spit

A new habitat feature, a tidal spit, is shown located conceptually at the southern end of the proposed habitat compensation design (Fig. 3, Drawing SK-38). The main objective of the spit is to provide habitat for brant geese, but it would also provide habitat for fish and other wildlife.

The spit feature shown in Figure 13 consists of a cobble-gravel ramp originating on mudflat (i.e. 1.5 m elevation) adjacent eelgrass (i.e. *Zostera marina*) beds located about 60 m from the causeway shore. The elevation would increase along the spit to reach the backshore vegetation tide elevation (e.g. 6.5 m) as it approached the barrier island. The optimum shape of the spit to reduce scour from tidal exchanges and build-up of debris is to have the section adjoining the causeway angled at 45° and the more distal section located parallel to the causeway.

The spit offers a unique habitat feature with the obvious benefits to waterfowl, particularly brant geese, but would also be utilized by other species of water birds. However, there are some concerns, particularly from DFO, that the impacts of constructing the spit on the existing mudflat would reduce the net habitat gains for fish substantially. As well, preliminary coastal assessments indicate the spit may cause localized scour to the mudflat, requiring mitigative measures, and the spit itself would probably require rock protection to keep the gravel in place. Location and orientation of the spit, and selection of the appropriate types and sizes of substrate and shoreline protection will be determined following analysis of coastal geomorphic processes and targeted fish and wildlife functions.

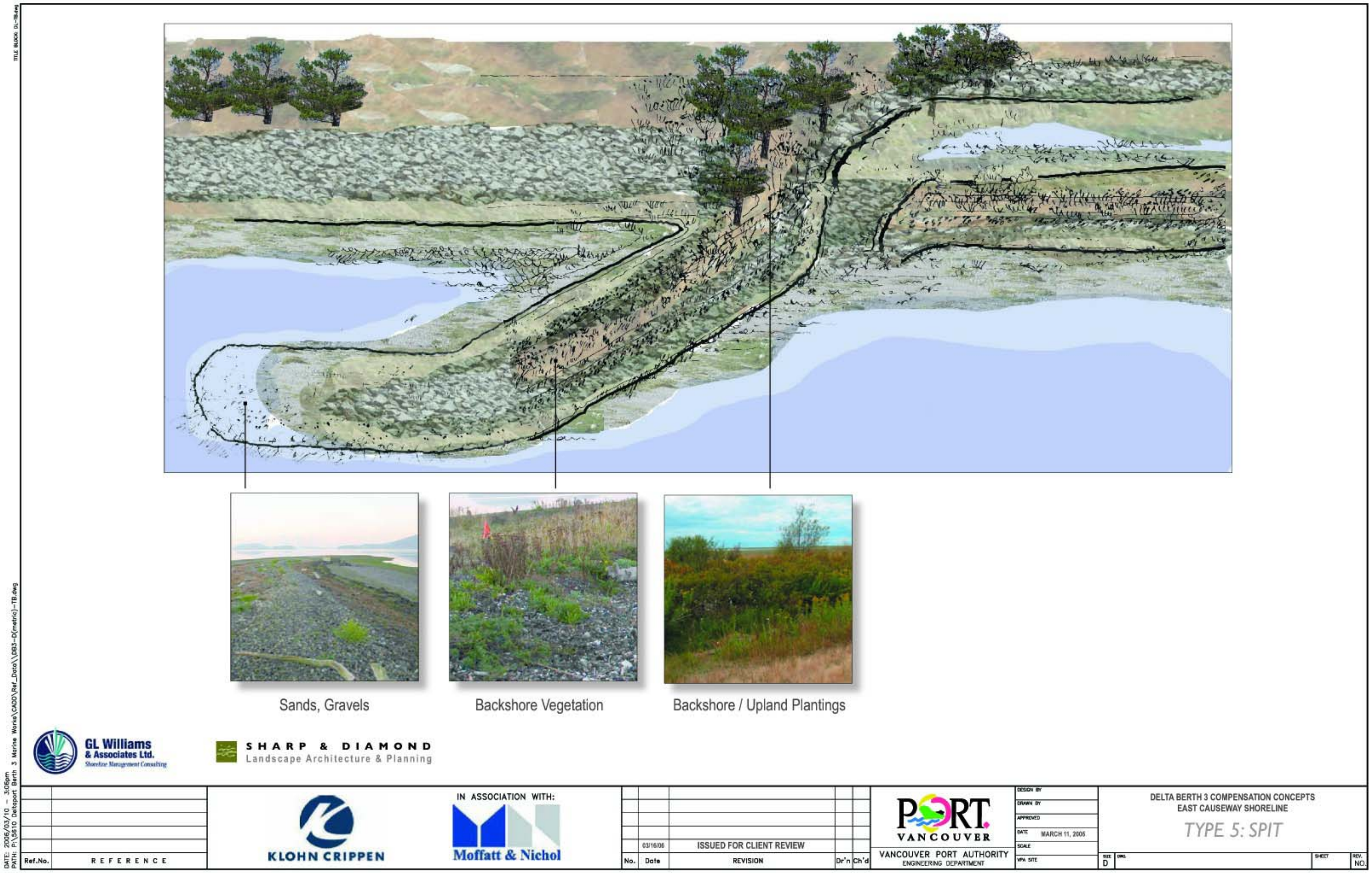

Figure 13. Spit concept for east causeway habitat compensation option.

2.1.2.6 Causeway Breach

A breach in the causeway was investigated to determine the influence a breach would have on intercauseway flushing and providing access to juvenile salmonids migrating to Roberts Bank from the Fraser River. The breach concept involved installing three 1.2 m diameter culverts, at the upper tidal level (to avoid scouring and sedimentation problems anticipated if the pipe inverts were set at a low tide elevation), which could be installed through the causeway using proven technology and still maintain uninterrupted rail operations. Several engineering options were investigated and a topographic survey completed and incorporated into the final design. A coastal geomorphic assessment was also conducted.

The results of the prefeasibility work and preliminary design indicated that the proposed culvert breach would not affect intercauseway flushing because of the small flows relative to the total intercauseway volume. The culvert could provide fish access but flows were low and the short period the culvert was flooded would limit salmonid utilization. The estimated cost to install the feature was approximately $1 million dollars and it was felt that the costs far outweighed the benefits, and that the monies and effort would generate much greater benefits if applied to an alternative option. As well there were significant difficulties in assessing a value to the breach for the purposes of the compensation package.

2.1.2.7 Finalization of the East Causeway Compensation Habitats

The previous sections of this report identify some of the design criteria and guiding principles for east causeway habitat compensation. The habitat compensation options presented are preliminary and will be further developed to maximize habitat diversity and productivity in the detailed design stage. During detailed design, further coastal geomorphology processes, engineering, geotechnical and biological input will be incorporated into the habitat feature development. There will also be regular consultations with DFO and CWS to ensure the final habitat compensation package meets agency requirements.

Many reviewing agencies expressed concerns about the monitoring of the works, and the remedial or mitigative measures that would be initiated if the proposed habitat compensation is not successful. These items are addressed in the DFO authorization that will be prepared as part of the DFO approval of the habitat compensation package once the detailed design is completed and review agencies are in agreement that the proposed package meets the compensation requirements for fish and water birds.

The DFO authorization is a comprehensive document, detailing the proposed habitat compensation, monitoring requirements to ensure the works are functioning as intended. For example, typically backshore vegetation plantings are monitored for three years and salt marsh transplants for five years, by which time the vegetation has usually established. In the event that monitoring results show that remedial measures are required, VPA will be required to implement the measures and continue monitoring to demonstrate compliance. Should the works not prove successful, VPA will be required to create new compensation works, with post-construction monitoring.

2.2 Log Debris Removal and Saltmarsh Tidal Channel

The Tsawwassen salt marsh is a stable high intertidal marsh that has established and persisted behind a flood-protection dyke extending between the existing Deltaport and Tsawwassen ferry causeways. This area supports the largest continuous area of salt marsh within the inter-causeway area. It maintains its marine tidal influence through two separate pairs of culverted-openings and a separate, open span section that provides for tidal flushing of the marsh. The marsh vegetation is characterized by pickleweed, saltgrass and orache, which colonize the high tidal zone (e.g. above 4.0 geodetic). Several tidal channels penetrate into the interdike marsh from a main channel that parallels the landward face of the outer dyke.

The high intertidal salt marsh at Tsawwassen has been described by Hillaby and Barrett (1976). Yamanaka (1975) investigated the primary production and reported on selected plant and soil characteristics along a transect north of Roberts Bank causeway and through the Tsawwassen salt marsh. More recently, the Tsawwassen salt marsh was the focus of more intensive studies as part of the dyke improvement plan to improve flood control (Bernard and Bartnik 1987; Moody 1985).

Salt marsh vegetation provides an important source of primary production in the inter-causeway area and provides nutrients and habitat for a variety of species. Given the ecological importance of saltmarsh habitat to biological productivity, habitat function, ecological sensitivity and regional rarity, salt marsh is highly valued and rated as highly productive or “red coded” habitat under the Fraser River Estuary Management Program (FREMP) classification system.

Past studies of habitat restoration opportunities at the saltmarsh site have recommended the removal of excessive log debris accumulations within the salt marsh for the benefit of salt marsh expansion, to reducing nutrient loading to the system and to improving tidal flushing within the marsh. Log debris removal and tidal channel development is proposed as a component of the Deltaport Third Berth habitat compensation package.

Eutrophication:

Dunster and Dunster (1996) define eutrophication as:

> “The natural, but more commonly, human-induced addition of nutrients (especially nitrogen and phosphorus) to a body of water, resulting in high organic production rates that may overcome the natural self-purification processes. Eutrophication produces several undesirable effects, including algal blooms, seasonally low oxygen levels and reduced survival opportunities for fish and invertebrates. Excessive nutrient inputs are frequently derived from sources of pollution on the adjacent lands. Water bodies in this state are said to be eutrophic.”

Marine eutrophication occurs when nutrient input to a system exceeds its capacity of assimilation. In the extreme, effects of eutrophication can include population explosions of macroalgae coupled with oxygen depletion and ultimately widespread species mortality. For this assessment, marine eutrophication has been defined as an enrichment of nutrients in the inter-causeway area that affects, or has the potential to affect, the health and stability of the marine ecosystem at Roberts Bank.

For marine eutrophication to arise, a number of factors and conditions have to occur. There has to be increased nutrients to the ecosystem, nitrogen and phosphorous being the most problematic. The second is an impediment to tidal flushing, which would otherwise mix and flush the system, and exchange the water/algal biomass accumulations with “new” marine water. Changes to tidal systems that decrease or increase flushing rates affect the marine eutrophication process. Slow moving or stagnant waters allow nutrient concentrations to rise in the water column, triggering the eutrophication process and ultimately reducing biological productivity.

The existing accumulation of woody debris in the northwestern quadrant of the inter-dyke area (Fig. 14) is decaying over time and contributing to the nutrient loading of the foreshore and inter-causeway marine area. Although tidal flushing volumes in the inter-causeway area are large, tidal (and nutrient) flushing within the northwestern inter-dike area is less effective due to restricted openings through the dyke and debris-clogged channels that drain the area. (Fig. 15).

The proposed works involve removal of rafted log debris from approximately 2.3 ha of potentially productive saltmarsh habitat on the northwest sector of the interdike area (Fig. 16, Drawing SK-44). The debris removal will allow the saltmarsh to expand into the high intertidal area where the dense rafted log debris presently excludes nearly all vegetation. The existing tidal channel network and tidal flushing will be improved by extending existing channels approximately 630 m back into the debris removal areas. Two 1.2 m culverts will be installed through the existing dyke, increasing productivity by improving the integrity and efficiency of marine tidal flushing in the northwestern 6 ha of the inter-dike marsh. Approximately 4.5 ha of this area will be drained through an improved drainage network directly leading to the proposed culvert. Receding tidal waters from the remaining 1.5 ha area will be served by either the new culvert or by the existing culvert set to the south.

Wide tracked backhoes equipped with buckets and thumbs working from within the disturbed area of the salt marsh will be used to remove log debris. Waste wood will be piled in disturbed areas near the dike access and lifted out of the marsh area and loaded into trucks or containers. Large woody debris that is stable and provides habitat for fish and wildlife will be left in place. Material suitable for use as hog fuel, mulch, or compost will be processed and distributed appropriately. Waste material will be disposed of at an approved landfill site.

NHC has reviewed this compensation concept and concludes: “The total volume of water than is contained in this area during a mean tide (HHW = 4.4 m) s is approximately 63,000 m^3 (i.e. 4.5 ha x 1.4 m). The rate of change of water level at this level is typically 0.6 m/hour, producing a mean discharge rate of 8.8 m^3/s over a 2 hour period.” The expected response of this saltmarsh area to the installation of twin1.2 m diameter culverts through the dike is that a portion of the water in the 6 ha area will drain directly into the northern end of the inter-causeway tidal flats, rather than draining eastwards towards the main opening at the Tsawwassen causeway. Based on the hydraulic head available, nhc expected that the flow through the culverts would amount to 2 m^3/s under peak conditions. Small tidal channels are expected to develop at the outlet of the culverts, but these should dissipate within 20 to 50 m over the flats (similar to the conditions that developed at the existing culverts through the dyke). No significant adverse physical impacts are predicted to develop as a result of this compensation measure.

Figure 14. Heavy log accumulations in the northwest sector of the Tsawwassen salt marsh.

Figure 15. Log debris impeding tidal channel drainage.

KEY PLAN
N.T.S.

PRELIMINARY
NOT FOR CONSTRUCTION

40m 0m 40m 80m
SCALE: 1 : 2000

Ref.No.	REFERENCE

IN ASSOCIATION WITH:

KLOHN CRIPPEN — Moffatt & Nichol

No.	Date	REVISION	Dr'n	Ch'd
A	NOV2/05	ISSUED FOR CLIENT REVIEW	JL	

PORT VANCOUVER
VANCOUVER PORT AUTHORITY
ENGINEERING DEPARTMENT

DESIGN BY	MC
DRAWN BY	JL
APPROVED	
DATE	OCT31/05
SCALE	AS SHOWN
VPA SITE	

DELTAPORT BERTH 3 MARINE WORKS
COMPENSATION CONCEPTS
LOG DEBRIS REMOVAL &
SALT MARSH RESTORATION

SIZE	DWG.	SHEET	REV.
D	SK-44	1 of 1	A

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2.3 Subtidal Reef

VPA proposes to create new reef segments as part of the Deltaport 3rd Berth compensation package to increase the productive capacity and habitat diversity at the site. The Roberts Bank Environmental Review Committee highlighted the value of the reef compensation (Figs. 17 and 18) in their 1995 Progress Report.

> "The two prototype reefs constructed at Roberts Bank in 1983 were subsequently found to support a vast diversity of fish and other aquatic organisms. For this reason, reef creation will be an important part of any compensation program for the port expansion".

Observations during installation of the existing reefs indicated the surrounding substrates were unconsolidated sands and silts, and did not support stable or productive infaunal communities. The mobility of the sediments restricts successful colonization by epibenthic (e.g. macroalgae and attaching invertebrates). The net sediment transport is to the northeast, with velocities higher during the flood tides.

In 1983, subtidal reefs were constructed to provide habitat compensation to offset unavoidable habitat loss related to the Roberts Bank port development. Three hard surface subtidal reefs were constructed off the seaward margin of the Deltaport facilities at Roberts Bank. One of the reefs is composed of 2.5 m long sections of 60 cm diameter concrete pipe loosely stacked on a silty bottom between –10 m and – 14 m water depth (tide and chart datum). A second reef was constructed with broken sections (i.e. 10 to 20 m length) of 90 cm diameter piling. The reefs were monitored for colonization by marine organisms and for fish usage by DFO in 1983 and 1985 and later by Subsea Enterprises Inc. in 1992. Both surveys reported that the reefs were functioning as intended and supported numerous fishes, including lingcod, kelp greenling, striped and pile perch, and copper and quillback rockfish, in addition to several species of sculpin. Plant life was sparse due to water depth, but starfish and Dungeness crab were common.

In 1993 VPA constructed a third reef, and in 2000 a fourth, at the site using angular rock placed on top of a gravel mattress. The reef designs provided hard, stable substrates in the productive shallow sub-tidal zone to benefit fish, invertebrate, and algal communities.

The reef was constructed in two sections using 0.9 m diameter quarry rock set on a pad of quarry tailings and crushed rock. The base elevation for the reefs ranged from –2.5 m to –3 m depth (chart datum) and rose to a 3 m wide crest at approximately –1 m elevation. Strong tidal currents flush the seaward margin of the Deltaport facility and provide an excellent marine environment to support a diverse and productive marine community on the hard, stable surfaces of the reef and within the voids of the artificial structure itself. The Port reports that the rock reef features remain physically stable and continue to perform well, sustaining a diverse and productive marine community. In addition to supporting an abundant fish and invertebrate community, subtidal vegetation algae e.g. *Nereocystis*) is well established.

Figure 17. Existing reef off Deltaport.

Figure 18. West reef at low tide (September 2005).

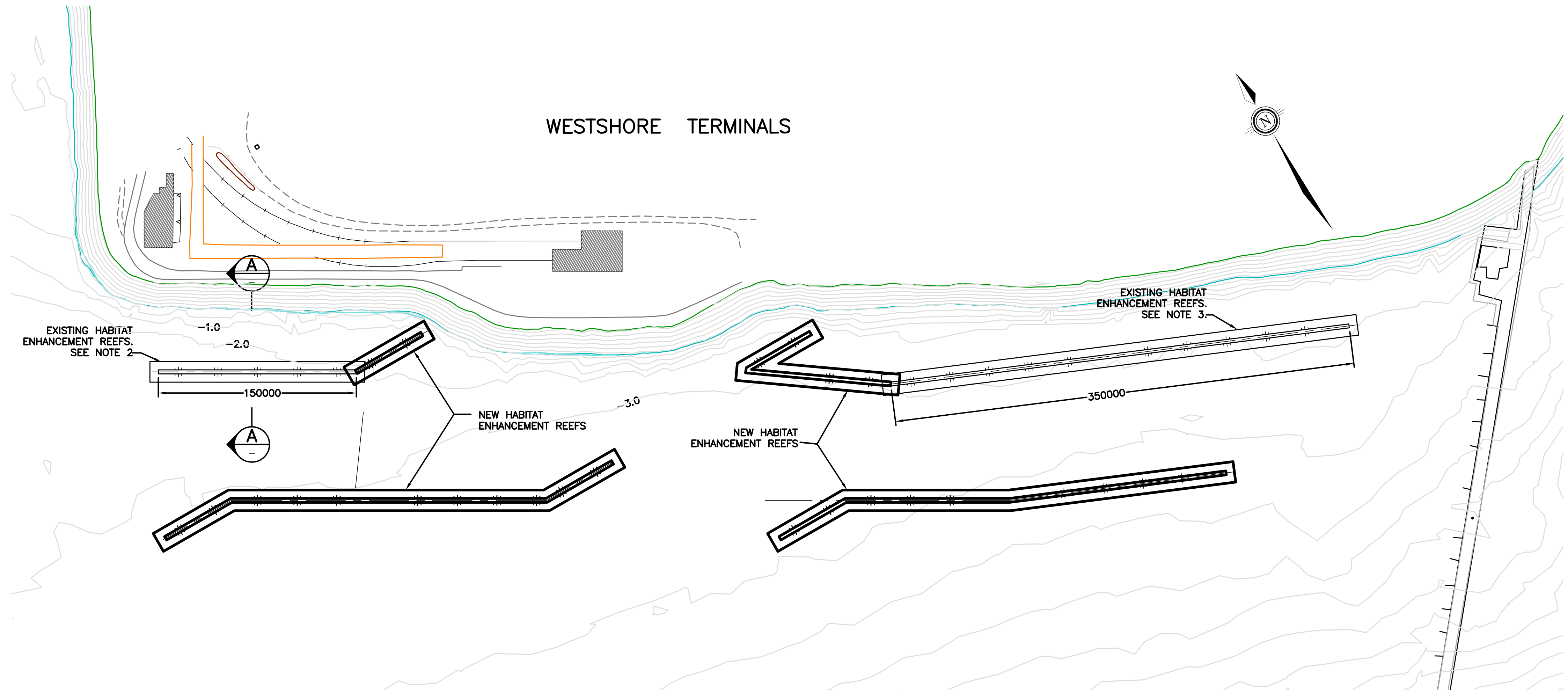
The existing reefs were constructed using large angular riprap that was randomly stacked to create large crevices and provide a large surface area for sessile organisms to attach. Crevices of varying size in the interstitial spaces of subtidal reefs are well documented to provide excellent habitat for a wide variety of resident fish. The open matrix of a well-constructed rock rubble reef also promotes good exposure to strong tidal flushing that increases food and oxygen availability within the reef structure itself. Lingcod, for example, typically select habitats with these characteristics for their nest sites as they promote successful spawning and offer good egg attachment substrates. Exposure to strong and efficient tidal flushing has been shown to ensure efficient oxygen delivery to the center of lingcod nests (Cass *et al.* 1990).

During winter 2004, a series of dive transects were conducted to survey benthic fish at the existing rocky reef compensation site off the seaward margin of the Deltaport facility. These surveys confirmed that that the artificial rocky reefs function to provide important habitat diversity and complexity at the site and do support an abundant and diverse community of fish, invertebrates and algae.

Lingcod were encountered during these surveys at both reef locations and egg masses were observed on the outside of both reefs. Kelp greenling (*Hexagrammos decagrammus*), copper and quillback rockfish (*Sebastes caurinus/malinger*), cabezons (*Scorpaenichthys marmoratus*) and pile perch (*Rhacochilus vacca*) were also observed at the reef sites. A lingcod Egg Mass Survey (LEMS) by Triton (2004) confirmed earlier findings by Malcolm and Martell (2004) that egg mass densities on shallow rocky riprap and reef habitats at the site were considered high when compared with other spawning sites in Georgia Strait. Octopi (*Enteroctopus dofleini*) have been reported along the base of the artificial reefs during past reef inspections. At least two big skate (*Raja binoculata*) specimens were recorded on SIMS imagery west of the artificial reefs during the Deltaport project marine studies. In 1997, divers reported a large number of big skate egg cases on artificial concrete pipe pile reef structures at the site (Subsea Enterprises, 1997).

The plan view and a typical cross-section of the proposed reef compensation for the Deltaport Third Berth Expansion are shown in Figure 19, Drawing SK-32. The design crest of the proposed reefs is between –1 m and –2 m (chart datum), which will support marine algal communities and provide habitat zonation in the well-flushed shallow subtidal region. The reefs are sited in subtidal waters so that they will not impede or obstruct the out-migration of juvenile salmon, particularly chum and pink that sweep around the end of the Deltaport facility during the Fraser River’s springtime out-migration.

Rocky reef spurs, cresting at approximately –1 m, will connect the existing artificial reefs to the riprap face of the Deltaport shoreline. Two new curved sections of reef will be constructed roughly parallel to and seaward of the existing reefs. The shape, elevation and configuration of the new reefs is intended to maintain unimpeded passage for juvenile salmon as they migrate seaward from the Fraser River or move through the area to summer rearing habitats. The reef spurs and curved shape of the new reefs may also create small pockets in the lee of the predominant northwest current to encourage the local sandy sediments to consolidate and provide improved habitat conditions for the establishment of a more diverse and productive infaunal community at the site.



PLAN

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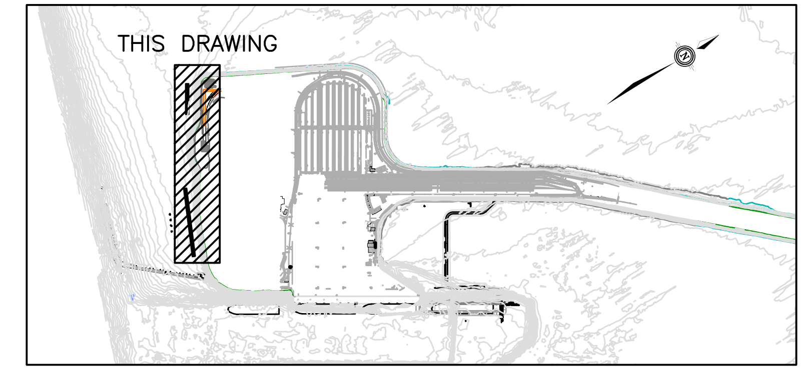
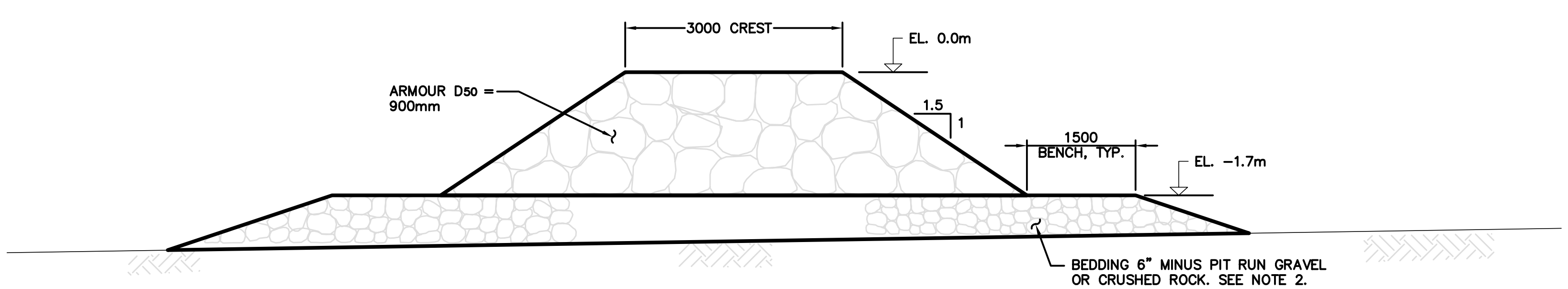


KEY PLAN



SECTION A

1m 0m 1m 2m

NOTES:

1. ALL ELEVATIONS SHOWN ARE TO TIDE AND CHART.
2. THE LOCATION OF THE EXISTING HABITAT ENHANCEMENT REEFS ARE APPROXIMATE.

PRELIMINARY
NOT FOR CONSTRUCTION

Ref.No.	REFERENCE

IN ASSOCIATION WITH:

KLOHN CRIPPEN

Moffatt & Nichol

No.	Date	REVISION	Dr'n	Ch'd
A	OCT14/05	REVIEW SUBMISSION	MC	--

PORT VANCOUVER

VANCOUVER PORT AUTHORITY
ENGINEERING DEPARTMENT

DESIGN BY MC (MN)
DRAWN BY JL (MN)
APPROVED
DATE SEPT27/05
SCALE
VPA SITE

DELTAPORT BERTH 3 MARINE WORKS
COMPENSATION CONCEPTS
SUBTIDAL REEFS

SIZE	DWG.	SHEET	REV.
D	SK-32	1 of 1	A

Approximately 880 m of new subtidal rocky reef will be constructed at the site on a footprint of roughly 13,000 m^2 over shifting sandy substrates, creating a new surface area of approximately 8800 m^2 of stable productive habitat. However, the 0.9 m average diameter rock used to construct the reef will create a stable, irregular surface with large, stable voids greatly increasing the functional surface area of the structure (factored at 2.5 times) and improving habitat diversity over existing conditions. The estimated habitat area gain of this feature is 22,000 m^2. Further habitat gains will be achieved through stabilizing pockets of shallow subtidal sandy sediments as an artefact of reef placement.

Functional habitat considerations:

Issues of concern that have been considered with respect to the subtidal reefs relate to juvenile salmonids, rockfish and lingcod. One general issue of concern is that construction and operation of the Deltaport Third Berth facility could potentially obstruct juvenile salmon movements, or otherwise harmfully alter, disrupt or destroy juvenile salmonid rearing habitat. Juvenile salmonids do migrate past the site where the proposed artificial reefs will be constructed. To insure unimpeded passage for juvenile salmonids during their out-migration and rearing periods, the reefs have been designed to be entirely subtidal and have been oriented roughly parallel to the shoreline and the existing reefs. Pink and chum salmon juveniles are present in the area between December and late May and chinook juveniles can occur in the area between June and July.

Lingcod spawning occurs between December and March and egg incubation lasts approximately six weeks with hatching taking place between March and April (King 2001). Reef construction timing will avoid these sensitive periods.

In general, fishes using the existing subtidal reef habitats may be displaced during construction. These fish are expected to move into undisturbed reef areas or rip rap habitats along the southern margin of the existing terminal until reef construction is complete and they can return to the existing or new reef structures. Given the large increase in subtidal reef habitat that will be created by this project, the productive capacity of the rocky reef community is expected to increase dramatically through recruitment and colonization.

NHC have reviewed the reef design (Appendix I) and concluded: “The proposed new reefs are aligned parallel to the dominant tidal currents and will have minimal impact on the flows and sediment movement patterns. There will be some minor deposition in the lee of the structures due to the sheltering effect from wave action.” These small pockets of sandy habitat located in the lee of the new reef structures may provide adequate areas of substrate stability to encourage the establishment of local infaunal communities. Further design of the reefs will include ensuring that navigation and adult crab migrations will not be affected.

2.4 Sand Bar Stabilization by Dendritic Channel Modification

Dendritic channel formation in the inter-causeway region has resulted in a substantial area of unvegetated substrate in the midst of dense eelgrass. The total area associated with the dendritic channel is 31.9 ha, 21.7 ha of which are comprised of large sand bars at the landward end of the main trunk channel (D. Ray, nhc, pers. comm.). Currently these sandbars are not stable because of complex, tidally-induced hydraulic processes. Stabilization of the sandbars would provide habitat for invertebrates and/or eelgrass colonization and increase the habitat productivity of the inter-causeway area. The nhc technical memo describing the dendritic channel modifications recommended to achieve stabilization is included in Appendix II.

Northwest Hydraulic Consultants have studied the formation and evolution of the inter-causeway tidal channels in detail as part of the 2004 Roberts Bank Container Expansion Coastal Geomorphology Study. In addition to the examination of the historical evolution of the inter-causeway channels, all of the channels that have formed on the tidal flats between Canoe Pass and Point Roberts, as well as in Boundary Bay, were investigated. The investigations included detailed air photo analysis, numerical modeling, field measurements of flow velocity and volume, and detailed field observations. The following summary provides a general outline of the processes driving water and sediment movement in the tidal channel system, focusing on the largest of the tidal channels.

Although a smaller version of the present channels had formed prior to 1984, the present channels formed after the dredging of the ship turning basin and installation of the crest protection structure. The edge of the ship turning basin extends into the tidal flats at an elevation of approximately 1 m above chart datum. This cut into the tidal flats initiated the channel formation at the over-steepened nick point, in what is known as a head-cutting process. The twice-daily rise and fall of the tide over the tidal flats has continued to drive the shoreward extension of the tidal channels. At present this channel system has expanded into a highly complex system comprising a series channels draining from the upper tidal flats into a main trunk channel that drains out over the crest protection structure (Figure 20).

Concurrent with the expansion of the tidal channels, the extent of eelgrass beds in the inter-causeway area has increased dramatically. The eelgrass beds appear to exert a strong hydraulic influence on flow over the tidal flats. The presence of eelgrass creates a lag effect of flow, not only on the dropping tide where flow is released more slowly from the eelgrass, but also on the rising tide. The friction of the eelgrass on the surrounding tidal flats causes a marked acceleration of flow through the tidal channels. Tidal processes, eelgrass, and the extent of the channels themselves have created a self-sustaining system that has progressed well beyond the initial head-cutting process that acted to initiate the channels.

At present the large sandy bars at the head of the main trunk channel are of concern as they are displacing eelgrass. Because the sandy material is highly mobile, these areas are not likely suitable habitat for other organisms. Field observations during the early stages of the rising tide revealed that there is super-critical flow over the sand bars for a period of approximately 30 minutes. This flow transports a tremendous amount of sand and the depth of disturbance over most areas of the bar could reach up to 0.3 m.

Figure 20. Crest protection and downstream end of tidal channel.

The sand bars were initially thought to have formed from sand eroding from the upper tidal flats. However, field evidence suggests that there is significant shoreward sand transport in the main trunk channel as well. The dominant process seems to be erosion of the upper flats with transport into the main trunk, and then strong flood-tide flow pushing this sand upwards onto the sand bars.

Attempts have been made to slow or halt channel formation both at the present site and at other locations on the tidal flats. Any attempts to employ methods that physically block the tidal channels with hard structures have resulted in a temporary apparent success followed very quickly by formation of a new channel eroding around the structure. These observations indicate that the placement of any hard structure on the soft tidal flats will result in scour (see Photo 4, Appendix I; Figure 2 – 2002, Appendix II), and this approach is not recommended for the dendritic channel modifications.

Investigation of the other tidal channels on Roberts Bank and Boundary Bay indicated that there are numerous locations where dredging has occurred but that significant channels have not formed. Two main reasons for this were identified:

1. the "drainage area" of some of these channels is insufficient to expand the channel network;
2. some of the channels have been naturally paved with oyster (or clam) shells, preventing further erosion.

Proposed Stabilization Measures

Works to stabilize the tidal channels in the inter-causeway area will be completed in a phased, adaptive manner. The initial phase will be a relatively small-scale intervention in the sand-bar area, followed by a period of monitoring to gauge the channel response, and if necessary, modify the measures. This approach will also minimize the risk of any adverse impacts to adjacent eelgrass habitat. Two measures are planned for the first phase of the work:

- carefully excavating a channel through the sand bar, using appropriate equipment to ensure the works do not impact surrounding areas, to reduce the lateral instability and spilling that occurs during flooding tides;
- strategic armouring of portions of the tributary channels to reduce potential scour and to arrest development of new channels.

Once the stability of the site is improved, a subsequent phase of work would be implemented to modify or optimize the type of habitat that is present. This may include blocking off some inactive channels to promote eelgrass establishment or other measures deemed appropriate.

The pilot channel excavated through the middle of the sand bar (Fig. 21) will equalize water levels in the adjacent channels during flooding tides and will reduce velocity gradients and lateral spills into the adjacent eelgrass areas. The channel should extend landward into the two tributary channels that join together just shoreward of the head of the bar. This will stabilize the alignment of the two tributary channels.

The total lengths of this excavation are:

- sand bar: 350 m
- main channel upstream of sand bar: 200 m
- tributary channels: 75 m each

The pilot excavation through the sand bar and main channel will have a width of 20 m and a depth of 1.5 m. It is expected that once constructed the channel will widen and eventually develop a top width of approximately 50 m. If the rate of growth is slower than anticipated, it may be necessary to carry out additional excavation at a later date. The total quantity of material that would be excavated amounts to 11,000 m^3 in the bar area and approximately 3,100 m^3 in the tributary channels.

In addition to the above measures, the bottom of the tributary channels will be armoured with a blanket or scour protection apron in order to prevent any further channel incision. The aprons extend 160 m along each tributary. The apron would also extend for a distance of 50 m along the main channel at the head of the sand bar. The thickness of the apron would be approximately 200 mm and would cover the bottom of the channels. The approximate volume of armour material is 2,000 m^3.

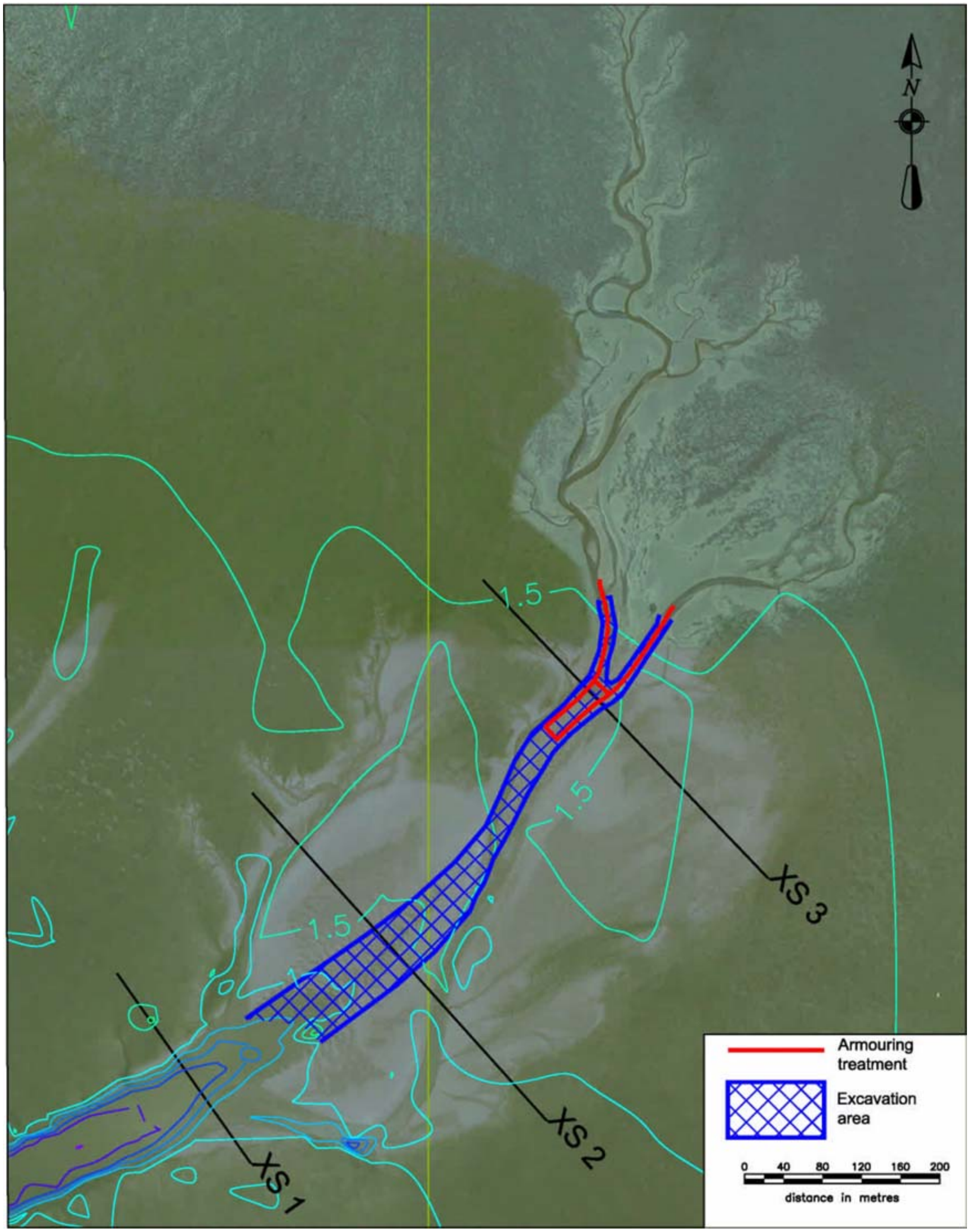


Figure 21. Proposed dendritic channel modification to stabilize sandbar
(see Figure 5, Appendix II).

The design velocity for the armouring was estimated to be 2 m/s. Natural gravel and cobble material was considered appropriate for the scour protection apron. Other materials, such as a mixture of oyster shells and gravel, could also be used for this purpose, if there were other advantages in terms of habitat creation.

The initial physical response to the proposed measures would be relatively rapid. This is because once the water levels are equalized across the bar, the driving forces promoting lateral instability and spilling would be eliminated. The main physical changes would include reduced high velocity spills, reduced scour and reduced sediment movement. The total area in this zone is estimated as follows:

- new channel through sand bar: 3.4 ha;
- area on north side of sand bar: 5.3 ha;
- area on south side of sand bar: 9.5 ha
- total area stabilized by measures: 18.2 ha

Channel impacts landward of the sand bar in the two smaller tributary channels would take somewhat greater time, probably stabilizing over a period of two to five years. This landward area amounts to an additional 1.0 ha.

The goal of the proposed sand bar stabilization component of the Deltaport Third Berth compensation package is to achieve sand bar (i.e. north and south) stabilized habitat of 14.8 ha, to be documented by physical and biological (e.g. invertebrate and/or eelgrass) sampling data. A conservative estimate is that a minimum area of 5 to 10 ha of sand bar could be stabilized within the five-year period. The construction timing and monitoring requirements will be developed during the detailed design phase. All proposed work will follow conditions outlined in a future habitat authorization process.

2.5 Caisson Habitat

Caisson refuge and berth face design options will be investigated to improve habitat complexity to enhance fish migration and feeding behaviour. Since the early 1990's VPA has introduced a number of innovative environmental enhancement strategies to complement port development projects, including caisson marine refugia, constructed within the terminal dock structure that has increased living space for intertidal and subtidal communities in marine waters. For the Deltaport Third Berth project, options for developing habitat complexity along the berth face will be reviewed and incorporated wherever feasible. The options will be aimed at fish and invertebrate migrations and feeding.

Container terminals docks are typically constructed of concrete caisson structures. Concrete caissons are large cellular reinforced concrete boxes containing fill material that function as a gravity retaining wharf structure. The proposed Deltaport Third Berth project will be constructed of caissons similar to the existing Deltaport wharf caissons (Fig. 22). Caisson refugia were created by installing 1 m diameter openings in the caisson face to allow typical intertidal and subtidal communities inside the dock structure.

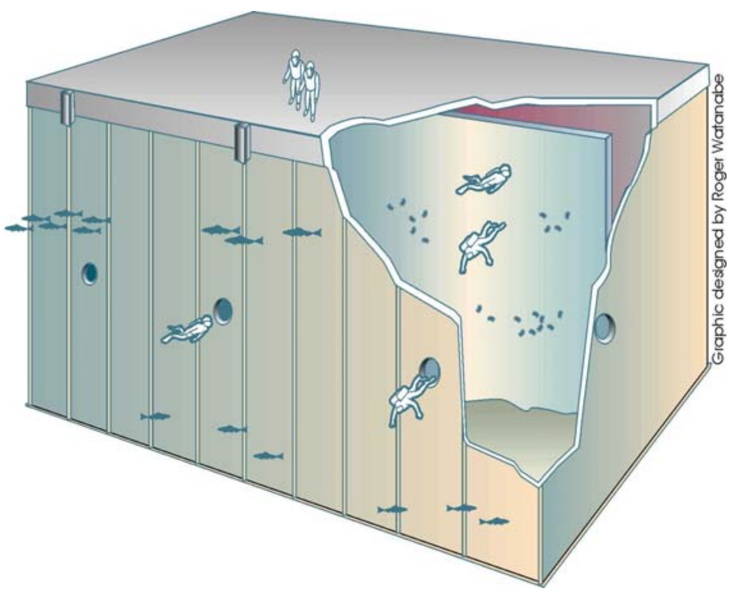


Figure 22. Schematic of a caisson refugia.

The productivity at the Deltaport refugia includes large numbers of organisms and many taxa as well as established communities (Table 3). The pattern of distribution of observed dominant organisms was generally even on the interior walls of the refugia but there was a comparatively higher abundance of filter feeding organisms in the area surrounding the entrance holes. Also, observed near the entrance was higher density of coonstripe shrimp, (*Pandalus danae*).

Table 3. Dominant/key species and approximate densities per m² found in Deltaport refugia.

Location		*Dominant Marine Species*		Approximate Density[1] (# per m²)
Caisson	Refuge	Common Name	Scientific Name	
4	1	calcareous tube worm	*Serpula vermicularis*	60
		lampshell	*Terebratalia transversa*	5
		coonstripe shrimp	*Pandalus danae*	++
		Pacific staghorn sculpin	*Leptocottus armatus*	+
		sea star	*Pisaster spp. & Evasterias sp.*	+
		Doris nudibranch	*Onchidoris sp.*	
4	2	calcareous tube worm	*Serpula vermicularis*	145
		lampshell	*Terebratalia transversa*	+
		coonstripe shrimp	*Pandalus danae*	+
		Pacific staghorn sculpin	*Leptocottus armatus*	+
		sea star	*Pisaster spp. & Evasterias sp.*	+
		Doris nudibranch	*Onchidoris sp.*	8
8	1	calcareous tube worm	*Serpula vermicularis*	62
		lampshell	*Terebratalia transversa*	30
		coonstripe shrimp	*Pandalus danae*	4
		Pacific staghorn sculpin	*Leptocottus armatus*	0
		sea star	*Pisaster spp. & Evasterias sp.*	+
		Doris nudibranch	*Onchidoris sp.*	10
8	2	calcareous tube worm	*Serpula vermicularis*	85
		lampshell	*Terebratalia transversa*	7
		coonstripe shrimp	*Pandalus danae*	5
		Pacific staghorn sculpin	*Leptocottus armatus*	0
		sea star	*Pisaster spp. & Evasterias sp.*	0
		Doris nudibranch	*Onchidoris sp.*	30
13	1	calcareous tube worm	*Serpula vermicularis*	134
		lampshell	*Terebratalia transversa*	68
		coonstripe shrimp	*Pandalus danae*	++
		Pacific staghorn sculpin	*Leptocottus armatus*	3
		sea star	*Pisaster spp. & Evasterias sp.*	++
		Doris nudibranch	*Onchidoris sp.*	4
13	2	calcareous tube worm	*Serpula vermicularis*	182
		lampshell	*Terebratalia transversa*	4
		coonstripe shrimp	*Pandalus danae*	+++
		Pacific staghorn sculpin	*Leptocottus armatus*	+
		sea star	*Pisaster spp. & Evasterias sp.*	+
		Doris nudibranch	*Onchidoris sp*	+

Notes:

[1] Number of organisms per m² and relative estimated abundance inside the refuge for mobile organisms when individuals were not observed in side the quadrat. Key: (-) rare; (+) low abundance/patchy; (++) moderate abundance/uniform; (+++) abundant/dense occurrence.

Dominant species present at the circular entrance to each refuge are typical of assemblages found in shallow sub-tidal hard-surface habitats in the Pacific Northwest marine environment (Fig. 23). The most commonly observed species were anemones such as the plumose anemone (*Metridium senile*) and tealia species (*Tealia sp.*), sea stars (e.g., *Pisaster sp.*) and barnacles (*Balanus sp.*). Many of these species take advantage of feeding opportunities associated with tidal/current action that occurs along the wharf face and at the entrance to the refugia.

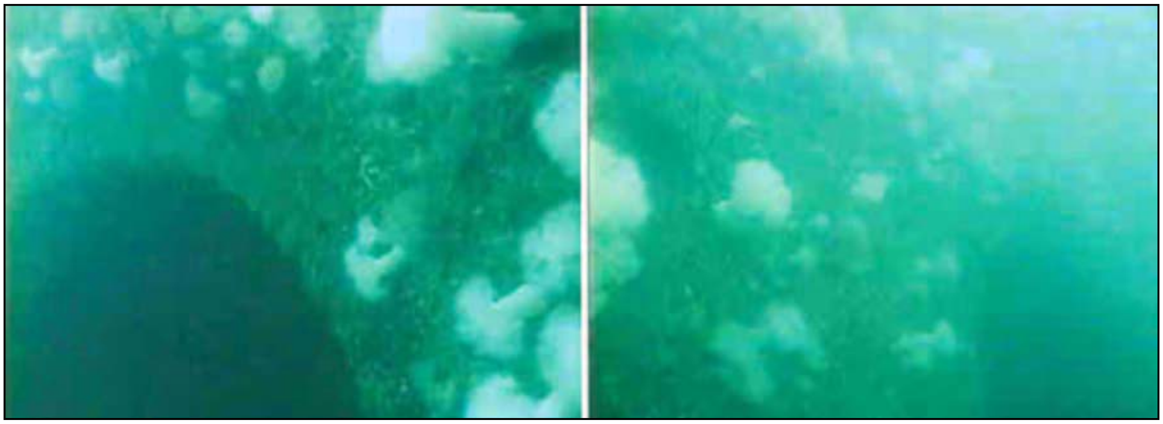


Figure 23. Caisson wall and entrance to refugia.

Preliminary calculations of the area of marine refugia associated with Deltaport Third Berth indicates approximately 0.3 to 0.5 ha of new habitat. Incorporating habitat complexity into the caisson berth face could increase the habitat value directly, e.g. by adding roughness to promote macroalgae or invertebrate attachment sites, or, indirectly by adding habitat features aimed at specific species to enhance functioning, e.g. migration or feeding. During detailed design, options will be identified and investigated to further improve the habitat complexity and habitat function of the caissons. Any feasible options will be incorporated into the final design.

3.0 Off-Site Compensation Options

In addition to the on-site compensation for the Deltaport Third Berth Project described in the previous sections of this report, VPA is committed to securing and developing a minimum of 7.5 hectares (18.5 acres) of fish and wildlife habitat at off-site locations. Off-site compensation will be developed based on defined habitat utilization criteria and at an appropriate location(s) to be defined as generally within the following geographic areas in the Fraser River estuary:

- South Arm Marshes
- Brunswick Point
- Sturgeon Bank
- Roberts Bank
- West side of Westham island
- Such other area as may be identified in the immediate vicinity

The objective of the off-site habitat compensation plan is to develop fish and migratory bird habitat as mitigation for the Deltaport Third Berth Project. To ensure the development of off-site compensation, VPA is entering into a habitat creation agreement with Ducks Unlimited Canada (DUC), DFO and CWS to ensure that the off-site compensation is delivered in a timely and efficient manner. VPA will commit $1.5 million for development of the off-site compensation program.

There are a variety of fish and migratory bird compensation options that are feasible on properties owned by DUC within the geographic area of interest. The basic habitat concepts will involve the creation of intertidal habitat features designed to benefit both fish and waterfowl, and that may include the creation of mudflat and tidal channels to provide full tidal access to the area and refuge at low tide, construction of deep water ponds for fish and wildlife utilization, and planting of marsh and riparian vegetation. All habitat compensation and enhancement designs will be determined following appropriate hydraulic and engineering assessments and discussions with DUC, DFO, CWS, and other agencies as appropriate.

4.0 Habitat Compensation Summary

The proposed compensation package, which includes on-site as well as off-site compensation, more than compensates for the impacts caused by the Deltaport Third Berth. The design principles promote creating habitat diversity at the Roberts Bank site, and the habitat compensation measures will benefit juvenile salmonids, Dungeness crab and other fish and invertebrates utilizing the area. Most of the measures also benefit migratory birds. Off-site compensation will also benefit fish and wildlife that utilize the Roberts Bank site by providing wetland habitat for important life history stages, such as rearing habitat for juvenile salmonids and feeding and refuge areas for waterfowl, shorebirds, and other migratory birds. The habitat summary and target species is shown in Table 4.

Table 4. Habitat compensation summary showing estimated area and target species for each compensation option.

Proposed Compensation	Estimated Area (ha)	Target Species
On-site		
Tsawwassen Salt Marsh	4.5	juvenile salmonids; waterfowl, wading birds (great blue heron)
East Causeway	6.7	juvenile salmonids, juvenile crabs, forage fish, waterfowl, wading birds, shorebirds
Dendritic Channels	5.0	waterfowl, salmonids, marine fishes, crab
Caisson Refugia	0.5	adult crab, lingcod, shrimp, deep water invertebrates
Subtidal Reef	2.2	marine fishes, adult crab, invertebrates, diving ducks
subtotal	**18.9**	
Off-site		
Sites to be determined	**7.5**	salmonids, waterfowl, shorebirds, wading birds
Total on-site and off-site	**26.4**	

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Appendix I

Northwest Hydraulics Consultants Memo: Compensation Measures – Physical Response

MEMO

To:	Trevor Peach, Vancouver Port Authority
From:	Dave McLean, Northwest Hydraulic Consultants Ltd.
Date:	October 10, 2005
Subject:	Compensation Measures – Physical Response

1. SCOPE OF WORK

A series of habitat structures will be constructed in the inter-causeway area as part of the mitigation/compensation package for the Deltaport Third Berth Project. This memo describes the physical characteristics of the tidal flats and adjacent riprap embankment in the vicinity of these proposed structures, as well as a discussion of the physical processes affecting this area. Three areas are assessed in this memorandum:

1. habitat structures along the east causeway
2. log removal and opening in a corner of the inter-causeway inter-dike area
3. artificial reef structures off the end of the causeway

The location and biological description are contained in the interim report by Williams & Associates, September 19th, 2005.

2. MEASURES ALONG EAST SIDE OF CAUSEWAY

2.1 Site Conditions

A detailed discussion of the Inter-Causeway area is contained in the Coastal Geomorphology Study. Information regarding the wind, wave, and tidal current climate within the Inter-Causeway area is contained in Appendix A and B, while Appendix C outlines the physical environment. The following comments summarise the specific physical environment and physical processes specifically pertaining to the project area along the east side of the causeway.

2.1.1 Physical Environment

The Deltaport causeway extends south-westwards across the tidal flats from the shoreline near Tsawwassen for a length of approximately 4 km, with a slight jog at approximately 3 km. The roadway on top of the causeway is at approximate elevation 7 m (CD). Photo 1 and Photo 2 show the shoreline along the base of the causeway. A protective rip-rap embankment extends out into the tidal flats for approximately 25 m, with a side slope of approximately 6H:1V. The mudflats at the edge of the rip-rap embankment slope away from the causeway for a distance of approximately 90 m to intersect with a shallow swale that parallels the road near the seaward end of the causeway. The mudflats adjacent to the rip-rap embankment range in elevation from 3 m at the shoreward edge of the tidal flats to 2.5 m near the seaward end. The elevation of the swale is at 1 m near the seaward edge and grades into the upper tidal flats approximately halfway along the length of the causeway.

The sediments along the base of the causeway were examined by digging a series of test pits in August 2004. The material typically consisted of a thin layer of fine silt/clay underlain by clean sand.

2.1.2 Wave Climate

The east side of the causeway is primarily exposed to waves generated by southerly and south-easterly winds. Figure 1 shows the variation in wave height and wave direction in the Inter-Causeway area at a High Tide. Incident deep water wave conditions for each run are summarized in Table 1.

Table 1: Incident Wave Conditions

Incident Direction	H_s (m)	T_p (sec)
South	1.75	6.4
South East	2.6	7.4

The frequency of exceedance of the offshore deepwater waves is approximately 6 hours/year in each case. It can be seen that for incident southerly and south-easterly waves the significant wave height (Hs) varies between 0.85 m to 0.65 m along the base of the Causeway over most of its length for both incident directions. The water depth under these conditions was typically between 2.8 to 3.3 m. The corresponding RMS bed velocity was computed to be 0.17 to 0.28 m/s. Under a Mean Tide, the significant wave height at the base of the Causeway was considerably lower, typically varying between 0.25 to 0.56 m.

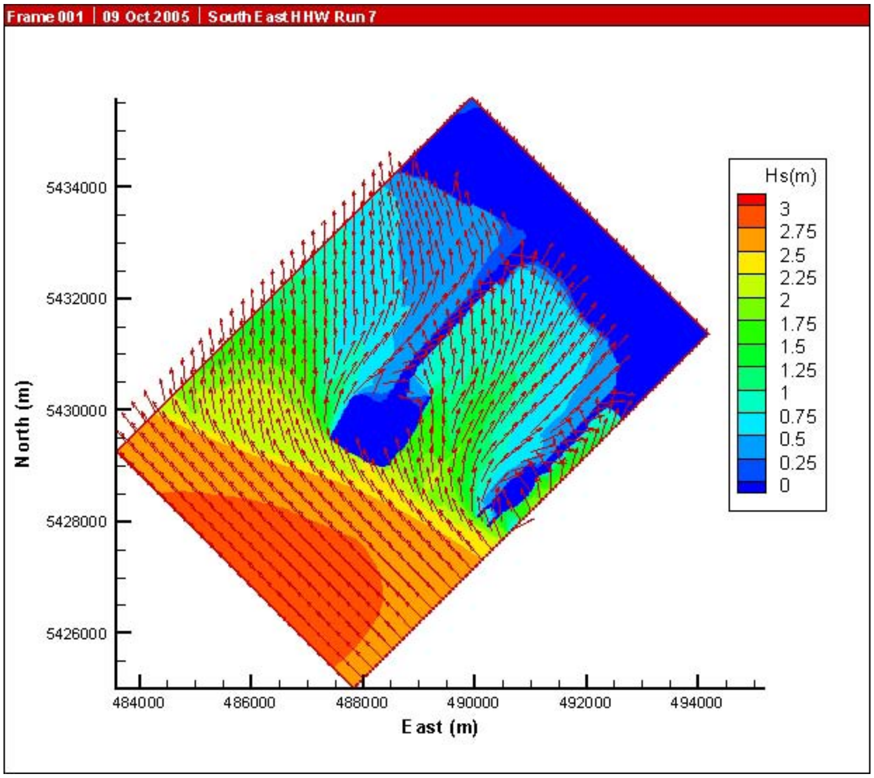
2.1.3 Tidal Currents

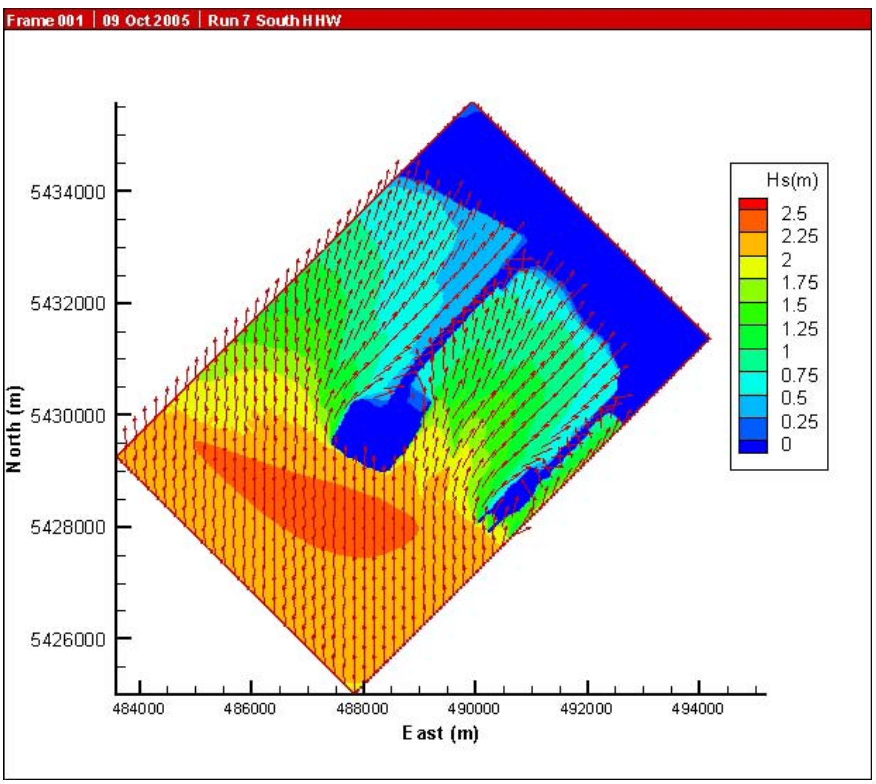
The table below lists the tidal range based on the Tsawwassen Tide Gauge.

	Mean Tide	**Large Tide**
Higher High Water	4.4	5.1
Mean Water Level	3.1	3.1
Lower Low Water	1.2	0

Figure 2 shows the percent exceedance for observed tide levels. This graph shows water levels exceeded 4.4 m about 10 % of the time in the period 1914 to 2004.

Tidal currents form in the Inter-Causeway area in response to the rise and fall of the tide in the Strait of Georgia. Figure 3 shows typical peak currents during ebb and flood tides during a large tide condition. Currents adjacent to the causeway are aligned parallel to it and are much less intense than those in the dendritic channels. Peak currents are typically less than 0.2 m/s along the base of the causeway when water depths are in the range of 2 m and up to 0.4 m/s further out on the mudflats.





note: 6 hr/year frequency of exceedance

Figure 1: Wave Conditions along East Side of Causeway

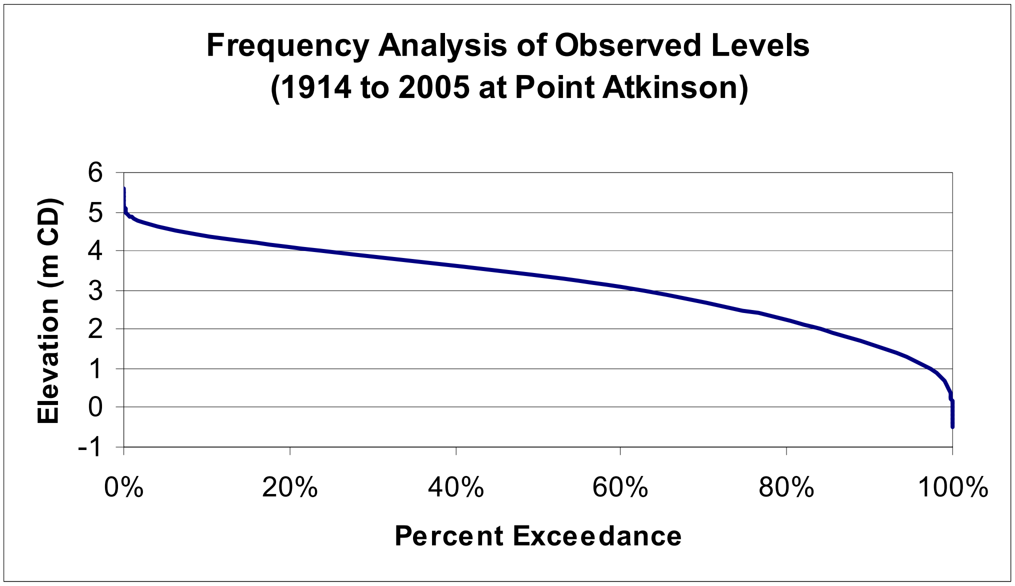


Figure 2: Frequency of Observed Water Levels

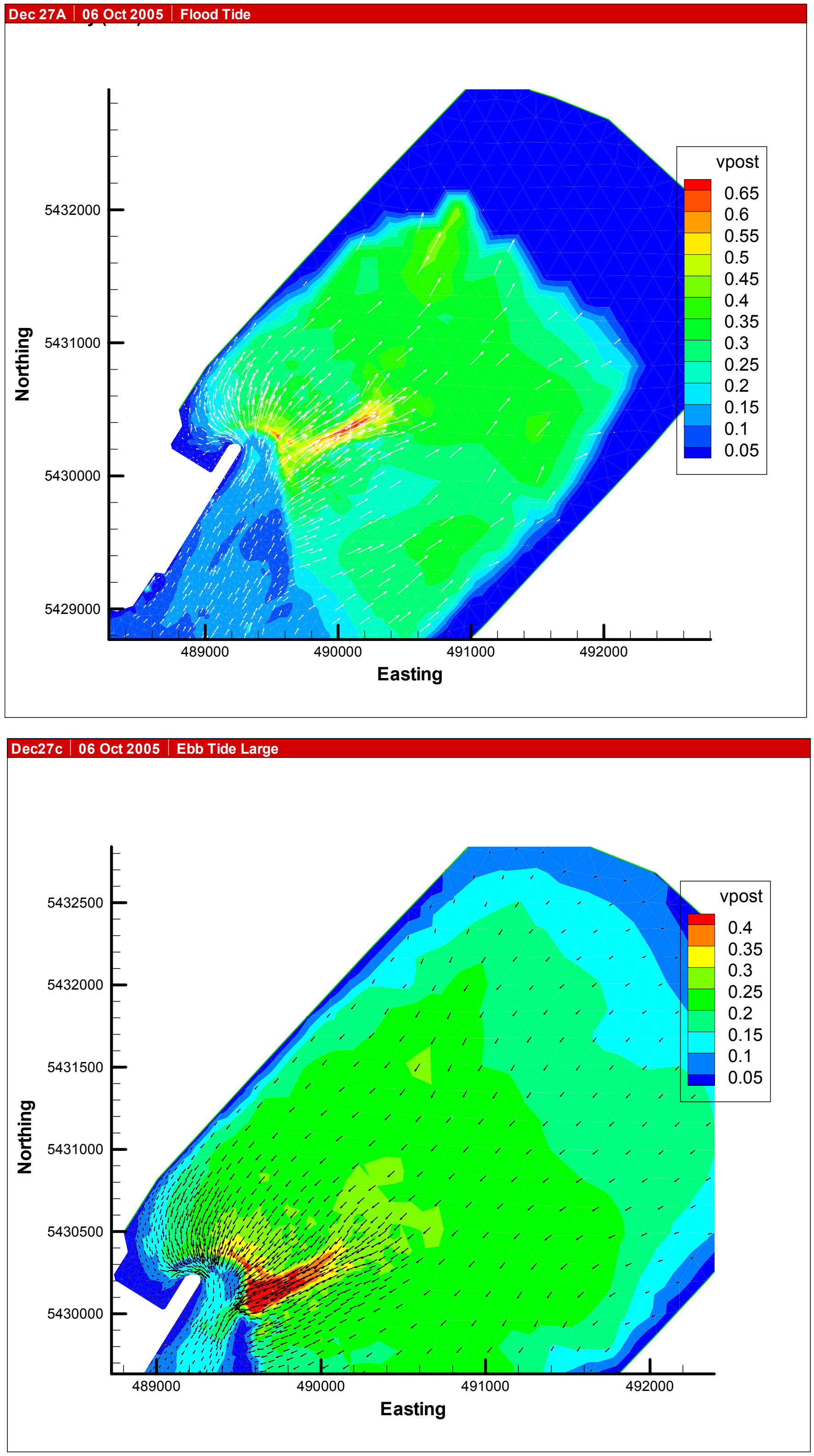


Figure 3: Tidal Currents Along East Side of Causeway

2.2 Restoration Measures

2.2.1 Scope of Measures

Williams & Associates developed conceptual plans to create habitat compensation features along the eastern side of the Deltaport causeway and has outlined the issues and objectives of these works in a memo dated September 19, 2005. The main structural features that were considered included:

1. Blind channel, set behind a rock berm or island to provide shelter from waves;
2. Salt marsh channel and island, consisting of a salt marsh at 3.5 m to 4.0 m behind a barrier island set at 6.0 m crest elevation.
3. Open salt marsh set at 3.5 m to 4.0 m
4. Spit, with a crest set at 5.5 m CD and width of approximately 10 m for water bird utilization. The length will extend up to 100 m.

Brief comments have been prepared for each of these features.

2.2.2 Hydrotechnical Considerations

General Considerations

The impact of the structures on the currents and waves will be governed by several factors, including:

- the distance they project out from the edge of the causeway towards the mudflats
- the elevation of their crest
- their orientation relative to the causeway
- the composition of the materials used in constructing them

There is good experience available on the effect and performance of past works along the north side of the Tswwassen causeway. Some photos of the marsh habitat structure and its overall effect on the surrounding tidal flats are shown in Photo 3 and Photo 4.

Blind Channel

The marsh channel will be excavated into the existing causeway slope and its outer bank will be protected by a riprap “island”. The crest of the island will extend to 6 m. The riprap will drop about 2 m at a slope of 1V:1.75H and the toe of the riprap will be near 4 m CD. The opening to the channel will be facing shoreward.

The channel will be protected by the outer island and will not be subject to high energy wave conditions or tidal currents. Water will drain on and off the habitat features in the channel in response to the normal tidal fluctuations on Roberts Bank. Therefore, cobble or boulder size material could be used to line the channel rather than heavy riprap (although some riprap would be needed in the vicinity of the entrance.

The revetment forming the outer side of the island will be subject to wave attack when storms coincide with high tides. A scour protection apron should be placed along the toe of the revetment to prevent wave-induced local scour at the base of the riprap slope.

Consideration should be given to providing a transitional slope of cobble/boulders so that the heavy riprap does not terminate directly on the fine sandy tidal flats.

Salt Marsh Channel and Island

This feature is structurally very similar to the blind channel except that the channel will be open at both ends, providing more tidal exchange. However, we expect the magnitude of the velocities in the channel will be comparable or lower than velocities on the tidal flats. Channel areas near the inlets will be exposed to locally higher energy conditions due to breaking waves.

Requirements for protecting the outer side of the riprap island structures will be similar to the blind channels.

Open Salt Marsh

This involves eliminating the outer riprap islands and leaving the salt marsh at elevation 3.5 to 4 m CD. This reduces the potential encroachment of the structures into the tidal flats. However, it also exposes the marsh to more direct wave attack. The wave refraction analysis carried out by Triton Consultants for the Coastal Geomorphology Study indicated that wave heights (H_s) near the toe of the causeway can exceed 0.8 m relatively frequently (Figure 1). These waves would be capable of mobilizing 200 mm cobble material and could erode most vegetation. Therefore, open salt marsh would be more suitable at the more sheltered shoreward end of the causeway where waves have been attenuated by breaking and bottom friction.

Spit

The artificial spit was intended to resemble natural spits that develop as a result of littoral drift. Some proposals show it could extend up to 100 m in length and would slope down from an elevation of 5.5 m CD down to the natural flats (around 2 m CD). Depending on its final arrangement, this structure could produce a considerable obstruction to tidal flows draining on and off the flats. This could lead to local scour around its end (the spit would behave in a similar manner as a spur or groin). There are two examples of local scour generated around riprap "spur-like" structures in the Inter-Causeway area:

- the small spur built off the inside of the crest protection structure (Photo 2);
- the short riprap sill off the end of the Tswwassen marsh compensation structure (Photo 4).

In each case the several metres of scour developed from the tidal flows at the ends of the structures.

In order to minimize potential adverse impacts consideration should be given to minimizing potential hydraulic impacts. This includes:

- reducing its elevation so that it will overtop during normal high tides;
- reducing the length that it projects into the tidal flats (to reduce the amount of flow that is obstructed);
- orient the structure in a curved shape to streamline it;
- site the structure towards the landward (east) end of the causeway to reduce the tidal flows that will drain around it;

- place a broad cobble-gravel apron around the end of the spit to provide a gradual transition between the rock riprap shank and fine sandy tidal flat sediments.

3. LOG REMOVAL AND DIKE OPENING

3.1 Concept

The measures involves removing log debris behind the existing dike in the northern corner of the Inter-causeway area and installing an opening through the dike to improve flow exchange with the tidal flats. The general area is shown in Photo 1. The gross area to be improved is about 4.5 ha.

3.2 Existing Conditions

The marsh at the upper end of the inter-causeway area is situated between two sets of dikes- the original sea dike situated on the landward side of the foreshore, and a newer dike that was built across a portion of the upper tidal flats. The seaward dike was constructed in the 1950's as part of a plan to reclaim a portion of the foreshore inter-tidal flats. The dike was never closed off completely, allowing sea-water to inundate the area between the seaward dike and the older landward dike during high tides. The total area of this marsh is approximately 60 ha. The marsh is dissected by a main tidal channel that runs eastward towards the opening in the dike near the Tsawwassen causeway and a series of smaller tributary channels (Photo 6). The marsh is also connected to the inter-causeway tidal flats by a series of culverts through the seaward dike (Photo 5). The elevation of the tidal flats near the base of the seaward dike is around 3 m CD.

Logs and debris at the northern corner of the marsh partially obstruct drainage and reduce its habitat value. It is proposed to remove the debris and to also install two culverts through the dike to improve the flow exchange. The total area in this corner is approximately 4.5 ha. The total volume of water than is contained in this area during a mean tide (HHW = 4.4 m) s is approximately 63,000 m^3 (4.5 ha x 1.4 m). The rate of change of water level at this level is typically 0.6 m/hour, producing a mean discharge rate of 8.8 m^3/s over a 2 hour period.

3.3 Expected Response After Dike Opening and Log Clearing

Installing two 1.2 m diameter culverts through the dike will allow a portion of the water in the 4.5 ha area to drain directly into the northern end of the inter-causeway tidal flats, rather than draining eastwards towards the main opening at the Tsawwassen causeway. Based on the hydraulic head available it is expected that the flow through the culverts will amount to 2 m^3/s under peak conditions. Small tidal channels will develop at the outlet of the culverts, but these should dissipate within 20 to 50 m over the flats (similar to the conditions that developed at the existing culverts shown in Photo 5). We expect no significant adverse physical impacts will develop as a result of this compensation measure.

4. SUB-TIDAL ROCK REEF

4.1 Concept

The design crest of the proposed reefs is between -1 and -2 m. The layout of the structures was shown in Figure 4 of the Williams & Associates memo. This plan shows two long straight reefs set parallel to the face of Westshore Terminals. Two short extensions were also shown extending from the face of the terminal to connect to existing habitat reefs, creating short structures resembling river training "spurs". The purpose of these structures was described as follows:

> "*These areas may serve to collect and stabilize mobile sediments transported across the shallow sub-tidal reaches of the site, providing infaunal colonization site, further increasing the productivity of the proposed reefs*"

4.2 Hydraulic Conditions

Figure 4 shows the existing currents that were measured during a large tide at a depth of 4 m off the terminal. The currents are predominantly north west during the rising (flooding) limb of the tide and are predominantly south east during the falling (ebb) tide. Velocities are generally higher on the flooding tide than during the ebb, which is consistent with more general observations and model results in the region. Peak velocities reached approximately 0.5 m/s during the flood tide.

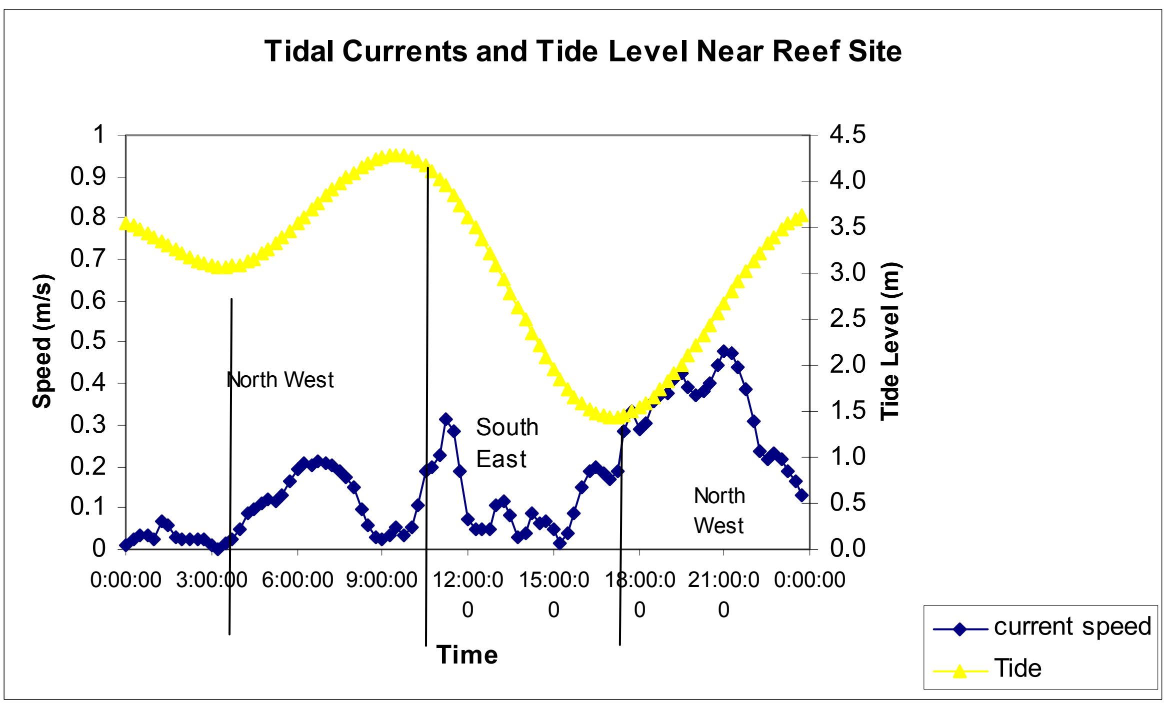


Figure 4: Tidal Velocity at Habitat Enhancement Reefs

Sediment transport conditions were estimated for sand-sized sediments (assuming a median size of 0.1 mm). The Shields Parameter was computed to reach up to 0.22, indicating that the sediment will move predominantly as bed load. The estimated transport rates and bed mobility is low. Using the van Rijn bed load equation, peak transport rates were computed to be 6 kg/hr/per metre of width. The net direction of sediment transport is from south east to north west.

4.3 Impact of Habitat Enhancement Reefs

The proposed new reefs are aligned parallel to the dominant tidal currents and will have minimal impact on the flows and sediment movement patterns. There will be some minor deposition in the lee of the structures due to the sheltering effect from wave action.

PHOTOS

Photo 1: Northern end of inter-causeway area with Tsawwassen marsh in background

Photo 2: View towards eastern side of causeway


Photo 3: View of marsh habitat at Tsawwassen Causeway


Photo 4: Scour at end of rock spur off Tsawwassen Causeway

Photo 5: Tidal channels draining marsh behind sea-dike

Photo 6: View of channel draining inter-marsh area towards Tsawwassen causeway

Appendix II

Northwest Hydraulics Consultants Memo:
Proposed Stabilization Measures at Tidal Drainage Network

nhc

MEMO

To: Trevor Peach, Vancouver Port Authority
From: Dave McLean, Northwest Hydraulic Consultants Ltd.
Date: October 5, 2005
Subject: Proposed Stabilization Measures at Tidal Drainage Network

This memo describes a conceptual design for restoration measures at the large tidal drainage channel situated in the middle of the Inter-Causeway area. The memo addresses only the physical processes and hydrotechnical aspects associated with the restoration works.

1. Site Conditions

A detailed discussion of the Inter-Causeway area and evolution of the tidal channels (commonly referred to as "dendritic channels") is contained in the Coastal Geomorphology Study, Appendix C. The following comments summarize our interpretation of the key factors that have governed their formation and development.

1.1 Channel Initiation

The tidal channel under discussion in this memo was triggered by a process of headcutting, in response to dredging of the Roberts Bank navigation channel and turning basin. The key parameter governing the rate of headcutting was the elevation difference between the edge of the dredge cut and the Lowest Low Tide level. In 1980, the turning basin cut extended past the +0.5 m contour line on the tidal flats, creating a "knickpoint" at low tide. The crest protection structure (shown in Figure 1), which was constructed in response to the channel formation, acted as a grade control structure and greatly reduced further channel formation. Several tidal channels either filled-in or became inactive and were covered by eelgrass. The largest tidal channel in the middle of the Inter-Causeway followed this same trend until the mid-1990s.

1.2 Channel Evolution

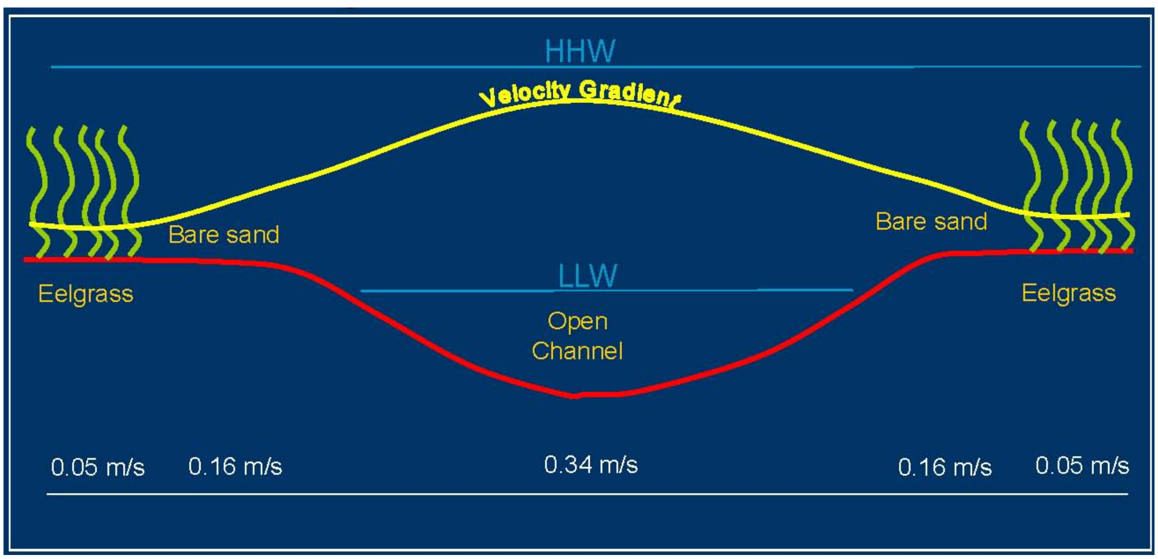
Figure 1 and Figure 2 show the changes in the Inter-Causeway area using air photos taken in 1979, 1991, 1995 and 2002. Figure 3 summarizes the overall changes in tidal channels, sand flat and eelgrass extent between 1989 and 2002. Since the mid 1990's the main tidal channel experienced three developments:

1. The lower end of the channel expanded sea-ward, partially by-passing the crest protection structure;
2. Drainage from the landward end of the tidal flats coalesced and formed tributary branch channels (identified as "Upper Tributaries" on Photo 1 and Photo 2) that fed into the main tidal channel. It appears at least some drainage at the upper north-west end of the flats, which formerly flowed parallel to the Causeway, began to drain south-east towards the main tidal channel;
3. A prominent sand bar developed near the shoreward end of the main channel at the junction of two tributary channels.

These developments appear to have been caused primarily by the increase in drainage flows concentrating in the main tidal channel. One factor governing the changed flow distribution on the tidal flats was the expansion of eelgrass laterally and in a landward direction about this time. The distribution of eelgrass affected the runoff distribution on the tidal flats by two mechanisms:

1. The hydraulic roughness of the eelgrass is much higher than bare sand flats, resulting in flow concentration in bare un-vegetated areas;
2. The eelgrass acts as a storage reservoir, retaining water and then releasing it during the ebbing tide, creating a phase lag and head difference between the water draining off the flats and the offshore, tidally-controlled sea level.

There are obvious feed-back mechanisms operating which tended to accentuate the expansion of the channel network. For example, as the main tidal channel began to by-pass the crest protection structure, more flow was captured from the higher levels on the tidal flats, accelerating their landward growth and expansion.



1.3 Bar Formation and Sedimentation

The large sandy bar at the head of the main tidal channel has developed at the head of the main trunk channel near the confluence with a tributary channel (identified as "Lower Tributary on Photo 1). The initiation of the bar is evident in the air photo taken in 1991 (Figure 1). In our opinion, the sedimentation pattern on the bar and the adjacent tidal flats has been governed entirely by fluvial processes; wave generated processes were inconsequential. Sediment on the tidal flats is being re-distributed during both ebbing and flooding tidal conditions. During ebbing tides, high flows concentrating in the tributary drainage channels cause channel incision, and sediment is transported seaward to the junction with the main tidal channel. During flood tides, strong flows push the sand upwards and landwards onto the sand bar area. Furthermore, small differences between water ponded on the bar and water flowing in the adjacent tributary channels triggers short periods of intense channel instability and sediment transport, causing water and sediment to splay over the adjacent eelgrass. During these short periods of shallow, high velocity flow, the entire bar surface can be re-worked by scour due to the formation of chutes and pools as well as anti-dunes.

1.4 Present Condition

The tidal channels and tidal flats have been monitored by a combination of ground inspections and overflights using fixed-wing aircraft in 2004 and 2005. Photo 1 through Photo 6, taken near low tide in June 2004 and September 2005, illustrate the present situation. The main trunk channel and sand bar appear to not have changed significantly. However, it was noticed that the tributary channels leading into the main trunk channel have become more incised and possibly wider. Figure 4 shows the generalized topography in the vicinity of the sand bar and its relation to the eelgrass. This map shows the sand bar and main trunk channel encroach into beds of *Zostera marina*, while the higher elevation tributary channels encroach into a transitional zone of *marina* and *japonica*.

Overall dimensions of the main channel features are as follows:

Main trunk tidal channel:

area:	4.1 ha
overall length:	700 m
top width:	80 m
depth:	2.5 m below LLW

Sand deposition zone:

area below tributary channels: 18 ha
area above tributary channels: 7 ha

2. Proposed Restoration Measures

2.1 Objectives

The main objective of the proposed work is to:

(1) reduce further lateral expansion of the channels into the lower eelgrass habitat;
(2) reduce the instability and high sediment transport rates on the existing sand bar
(3) promote development of stable, incised tributary channels landward of the present deposition zone.

2.2 Method of Approach

Restoration of the tide channels in the Inter-Causeway area will be phased, in an adaptive manner. The initial phase will be a relatively small-scale intervention in the sandbar area, followed by a period of monitoring to gauge the channel response and if necessary, modify the measures. This approach will also minimize the risk of any adverse impacts to adjacent eelgrass habitat. Two measures are planned for the first phase of the work:

- excavating a channel through the sand bar to reduce the lateral instability and spilling that occurs during flooding tides;
- armouring portions of the tributary channels to reduce potential scour and to arrest development of new channels.

Once the overall stability of the site is improved, a subsequent phase of work could be implemented to modify or optimize the type of habitat that is present. This could include blocking off some inactive channels to promote eelgrass establishment or other measures deemed appropriate.

2.3 Planned Phase 1 Measures

Figure 5 shows a plan view of the remedial works. Figure 6 shows typical cross sections. These preliminary designs are based on available bathymetry and will need to be updated for final design and cost estimating purposes.

Channel Excavation Through Sandbar

The pilot channel excavated through the middle of the sand bar will equalize water levels in the adjacent channels during flooding tides and will reduce velocity gradients and lateral spills into the adjacent eelgrass areas. The channel should extend landward into the two tributary channels that join together just shoreward of the head of the bar. This will stabilize the alignment of the two tributary channels. The total length of this excavation is as follows:

sand bar:	350 m
main channel upstream of sand bar:	200 m
tributary channels:	75 m each

The pilot excavation through the sand bar and main channel will have a width of 20 m and a depth of 1.5 m. It is expected that once constructed the channel will widen and eventually develop a top width of approximately 50 m. If the rate of growth is slower than anticipated, it may be necessary to carry out additional excavation at a later date. The total quantity of material that would be excavated amounts to 11,000 m^3 in the bar area and approximately 3,100 m^3 in the tributary channels.

Channel Armouring

In addition to the above measures, the bottom of the tributary channels will be armoured with a blanket or scour protection apron in order to prevent any further channel incision. The extent of this protection is shown in Figure 5. The aprons extend 160 m along each tributary. The apron would also extend for a distance of 50 m along the main channel at the head of the sand bar. The thickness of the apron would be approximately 200 mm and would cover the bottom of the channels. The approximate volume of armour material is 2,000 m^3.

The design velocity for the armouring was estimated to be 2 m/s. Natural gravel and cobble material was considered appropriate for the scour protection apron. Other materials, such as a mixture of oyster shells and gravel, could also be used for this purpose, if there were other advantages in terms of habitat creation. The photo below shows a tidal channel at the BC Hydro powerline crossing on Roberts Bank, which has armoured naturally by the presence of a shell bed, in spite of relatively high velocities.

Natural armouring of a tidal channel by oyster shells

3. Expected Channel Response

The initial physical response to the proposed measures would be relatively rapid. This is because once the water levels are equalized across the bar, the driving forces promoting lateral instability and spilling would be eliminated. The main physical changes would include reduced high velocity spills, reduced scour and reduced sediment movement. The total area in this zone is estimated as follows:

new channel through sand bar:	3.4 ha
area on north side of sand bar:	5.3 ha
area on south side of sand bar:	9.5 ha
total area stabilized by measures:	18.2 ha

Channel impacts landward of the sand bar in the two smaller tributary channels would take somewhat greater time, probably stabilizing over a period of two to five years. This landward area amounts to an additional 1.0 ha.

The impacts of the proposed works refer only to the physical characteristics of the site. No assessment has been made to the biological or habitat quality characteristics.

4. Conclusion

Under the present conditions the existing tidal (dendritic) channel network in the inter-causeway area will continue to grow laterally and extend shoreward until an equilibrium is achieved, regardless of whether any intervention is taken. By undertaking an adaptive program of intervention, it will be possible to stabilize and reclaim an area that is currently unproductive and both accelerate and influence the stabilization process.

The program proposed herein, which involves the excavation of a new primary channel combined with selective channel armouring should result in the stabilization of up to14.8 ha of currently unproductive sand bar. The stabilized bar would be similar in its physical characteristics to the surrounding tidal flats, representing an area of potential habitat for species colonisation.

The rationale for proposing this stabilization approach is derived from extensive study of tidal channels at Roberts Bank and in nearby Boundary Bay. We are confident that the adaptive approach proposed is appropriate to the local site conditions. However, as with many morphologic processes, the physical environment of Roberts Bank is dynamic and there is a level of uncertainty in terms of predicting the response time. Based on the observations of previous channel response on the tidal flats, we recommend adopting a time frame of five years for achieving a stable physical environment and for the sand bar to become available as productive habitat. We also feel, that it would be reasonable to expect that a minimum of 5 to 10 ha of sand bar could be stabilized within the five-year period. This figure should provide a conservative estimate of the overall effectiveness of the proposed measures.

PHOTOS

Photo 1: Viewing south west showing main tidal channel, June 2004

Photo 2: Viewing south showing tributary tidal channels draining into sand bar, June 2004

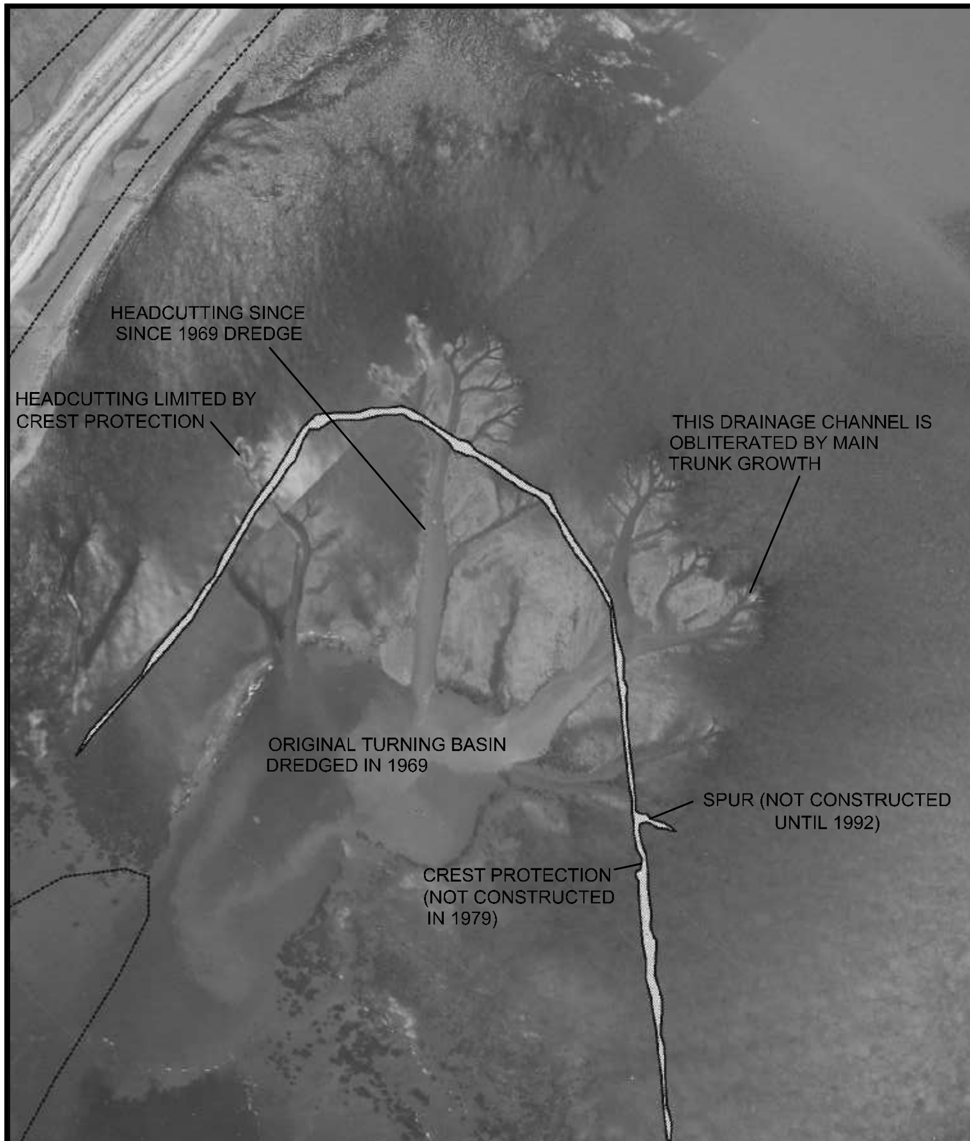
Photo 3: Viewing north east showing main trunk tidal channel, September 2005

Photo 4: Viewing east towards sand bar area, September, 2005

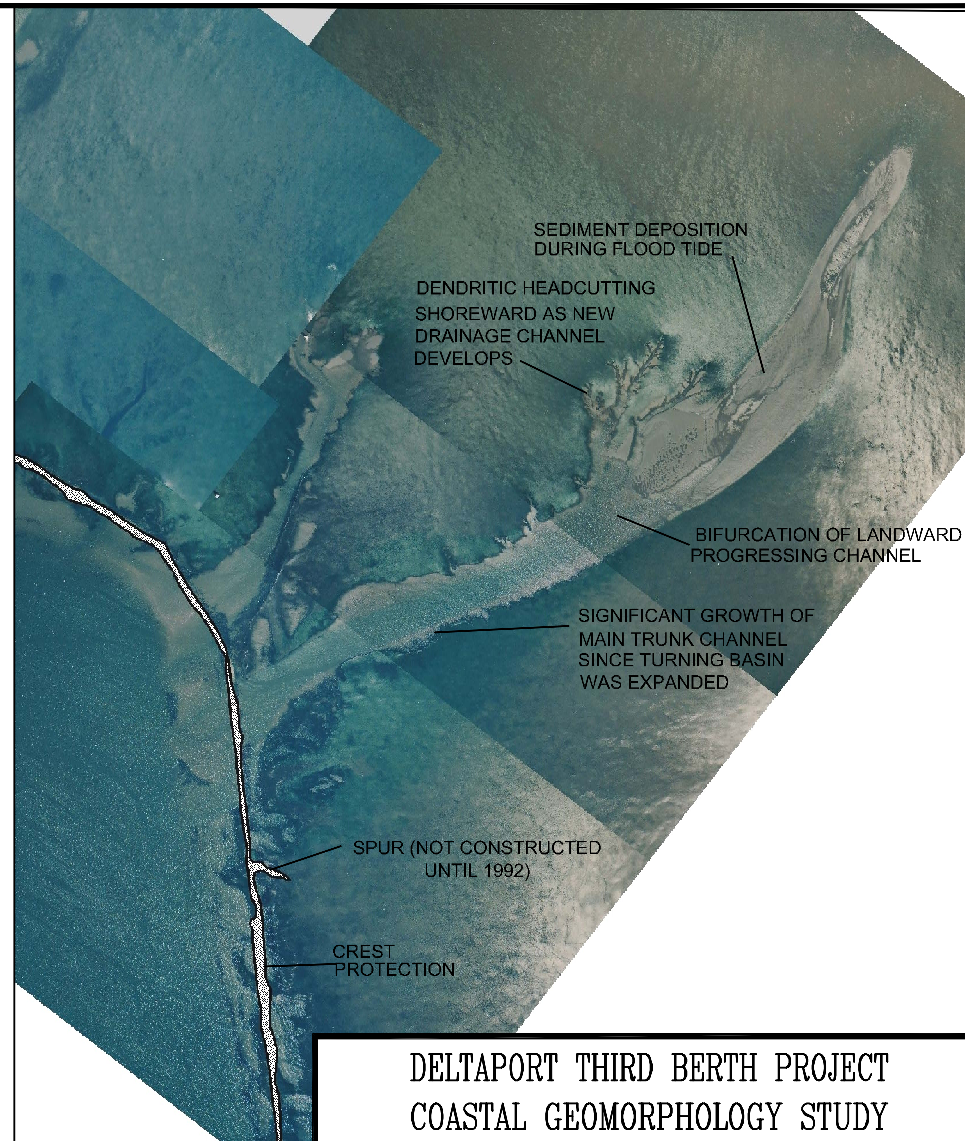
Photo 5: Viewing west towards sand bar area, September 2005

Photo 6: Viewing seaward from head of tidal flats, September 2005

FIGURES



1979



1991

Notes:

1) Orthophotos georeferenced using ArcView GIS.
2) Crest protection installed in 1981.
3) Spur constructed in 1992.
4) Crest protection outline added to photos for reference.
5) Original basin dredged in 1969.
6) Ship turning basing enlarged between 1980-1982.

0 80 160 240 320 400

DISTANCE IN METRES

NHCV

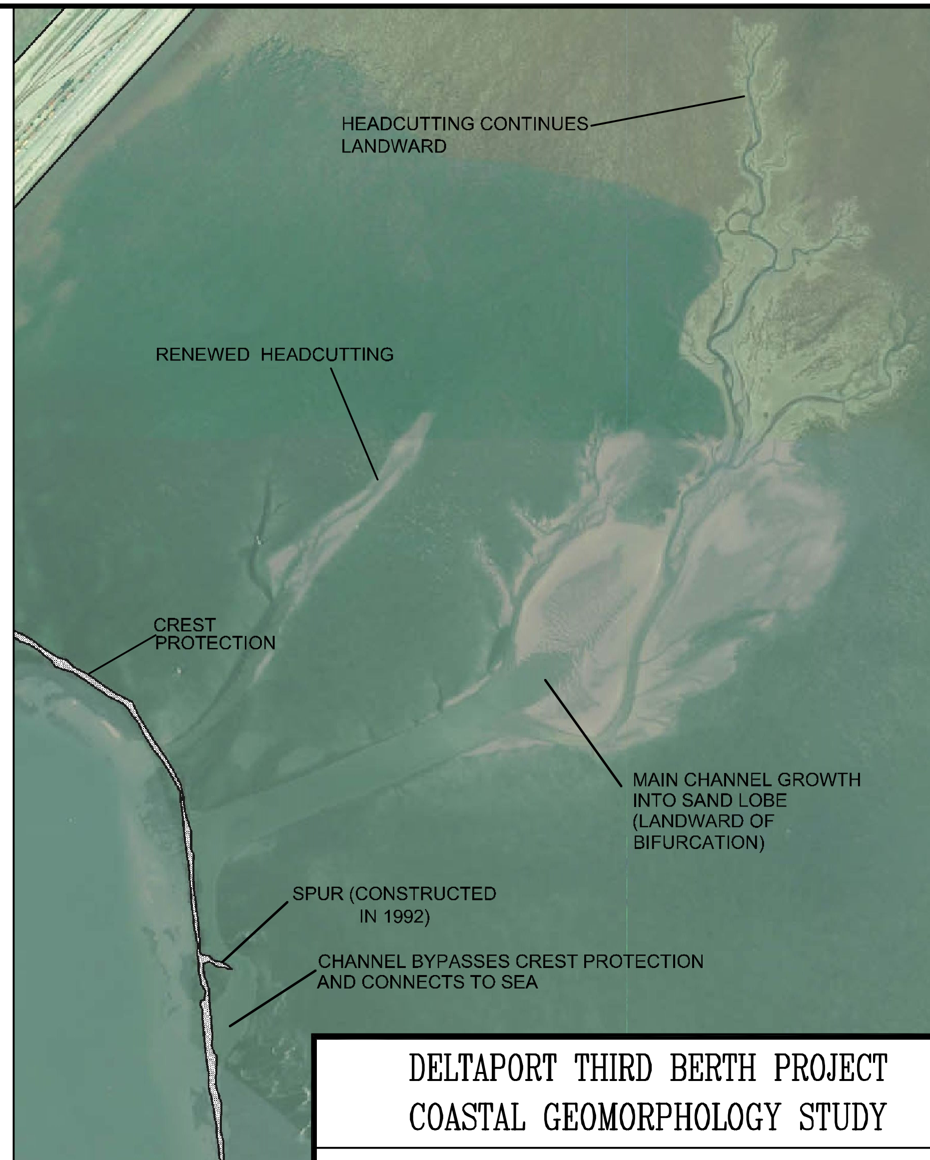
DELTAPORT THIRD BERTH PROJECT
COASTAL GEOMORPHOLOGY STUDY

Historical Development of Tidal Channels, 1979 and 1991

northwest hydraulic consultants
Triton Consultants Ltd.

FIGURE 1

1995



2002

Notes:

1) Orthophotos georeferenced using ArcView GIS.
2) Crest protection installed in 1981.
3) Spur constructed in 1992.
4) Crest protection outline added to photos for reference.
5) Original basin dredged in 1969.
6) Ship turning basing enlarged between 1980-1982.

0 100 200 300 400 500
DISTANCE IN METRES

NHCV

DELTAPORT THIRD BERTH PROJECT
COASTAL GEOMORPHOLOGY STUDY

Historical Development of Tidal Channels, 1995 and 2002

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Triton Consultants Ltd.

FIGURE 2

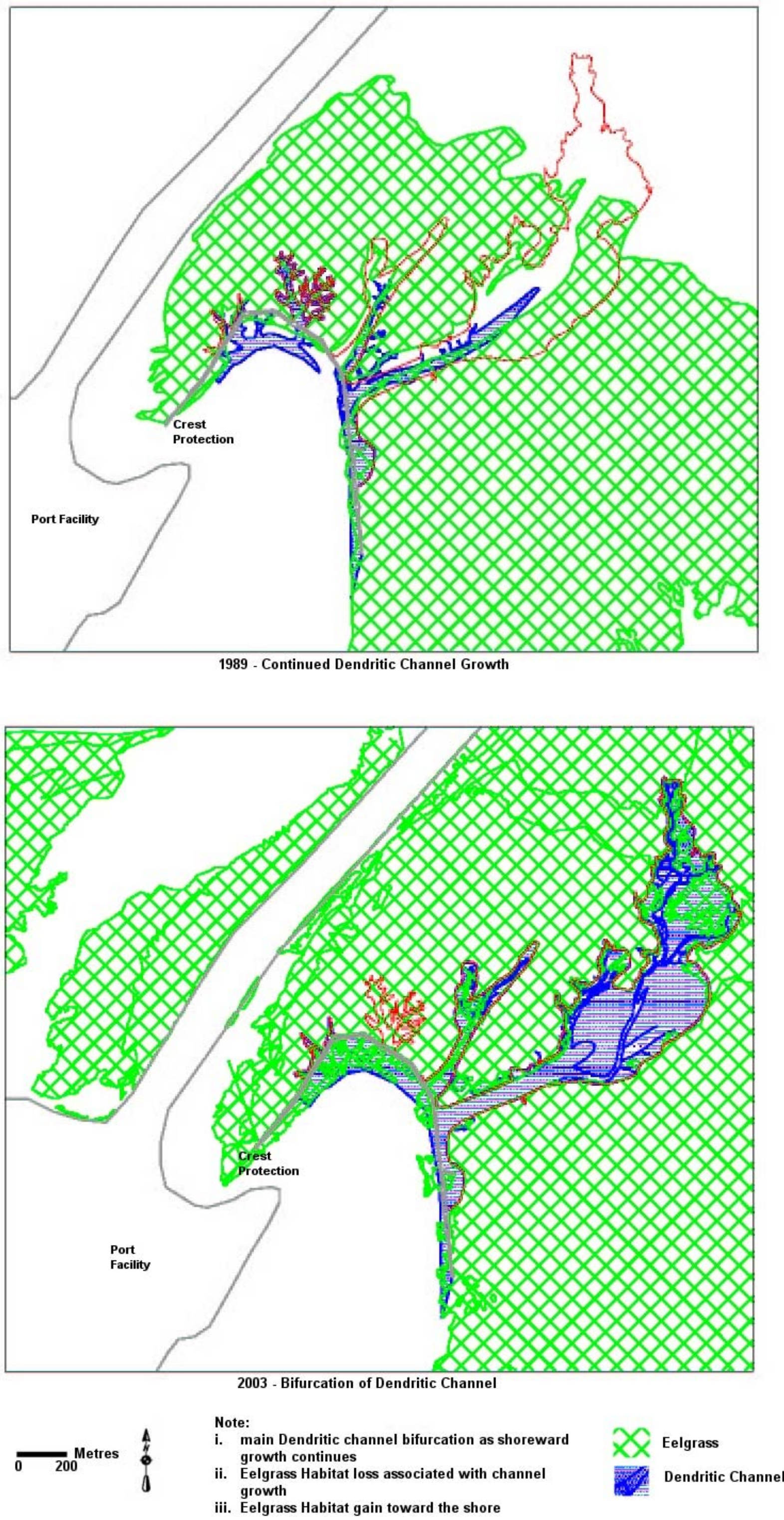

Figure 3: Evolution of Tidal Channels and Eelgrass

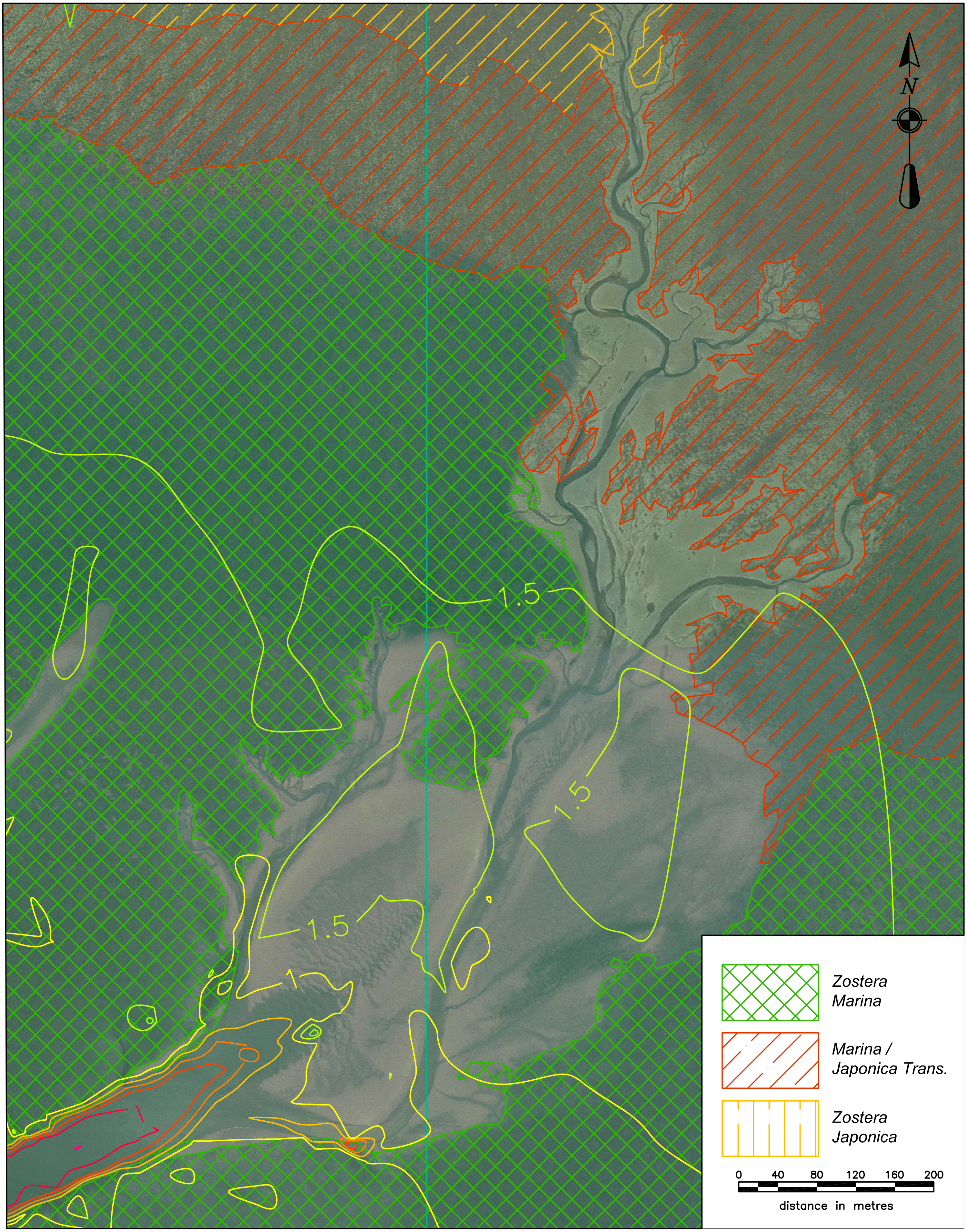

Figure 4. Relation between sand bar elevation and eelgreass extent.

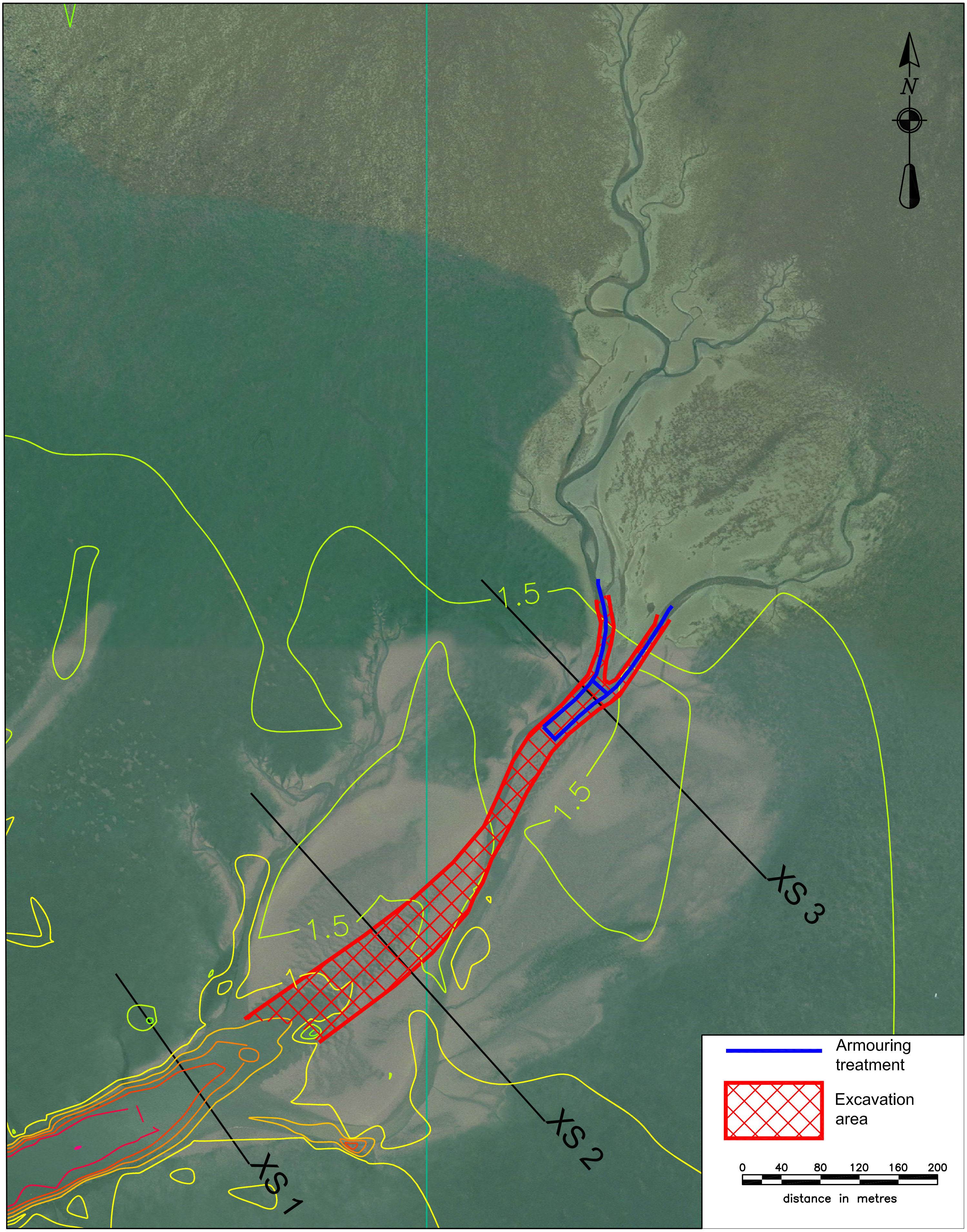

Figure 5. Proposed Phase 1 channel excavation.

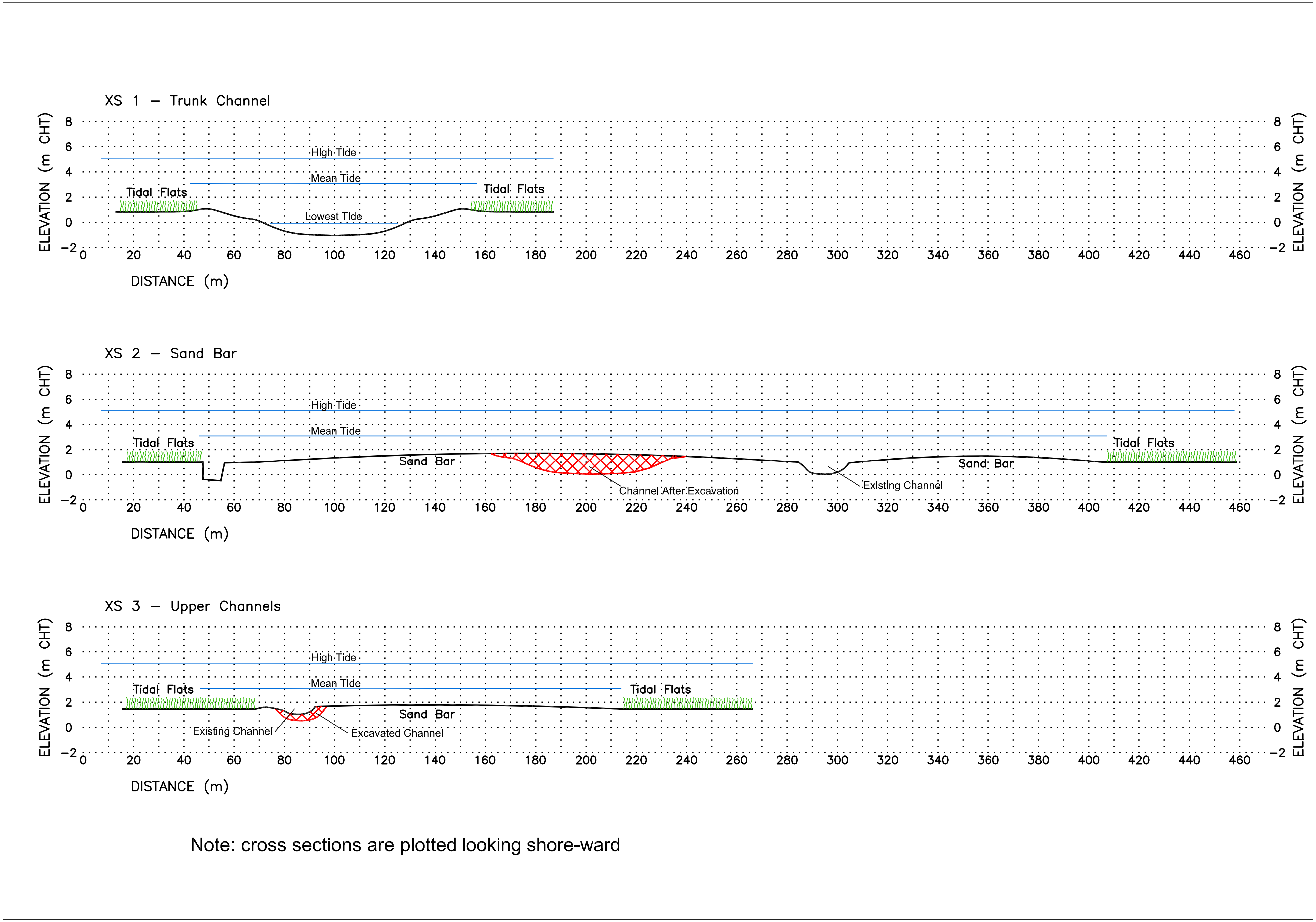

Figure 6. Idealised cross-sections showing proposed channel excavation.