RISK ANALYSIS OF CVRD FORCEMAIN ON BALMORAL BEACH

DRAFT REPORT

Prepared for:

Comox Valley Regional District

19 September 2016

NHC Ref. N0. 3001937

nhc
northwest hydraulic consultants
water resource specialists

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Prepared for:

Comox Valley Regional District
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Prepared by:

Northwest Hydraulic Consultants Ltd.
Nanaimo, BC

19 September 2016

NHC Ref No. 3001937

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CREDITS AND ACKNOWLEDGEMENTS

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We wish to acknowledge the assistance provided by Zoe Norcross-Nu'u, Comox Valley Regional District, during the study.

EXECUTIVE SUMMARY

Northwest Hydraulic Consultants Ltd. (NHC) was retained by the Comox Valley Regional District to conduct a risk analysis of the existing forcemain on Balmoral Beach. The analysis considers hazards from scour and impacts from debris. The study estimates the magnitude and probability of the hazards, determines the potential consequences of a failure and then combines these results to characterize the overall risks. The study also provides recommendations for mitigating these risks. This study does not assess effects of corrosion or deterioration of the pipe over time. A pipeline conditions assessment should be carried out to complement the results of this study.

The forcemain was constructed in 1982 and extends over a distance of approximately 2 km along the intertidal shoreline of Balmoral Beach. The depth of cover was initially 1.5 to 2 m after it was constructed. Routine inspection in 2002 identified exposed portions of the pipe and surveys showed that a 300 m length had a depth of cover of less than 0.5 m. In 2003, emergency protection was placed over a length of 320 m on the north end of the beach. The protection consisted of two layers of gabion mattress covered by cobble and boulder blanket. Without these measures, the forcemain would have failed, causing a break in the line and a discharge of untreated wastewater onto the beach. NHC (2003) indicated that the design life of the mattress protection was *10 to 20 years.* This work was considered as an interim solution that would offer protection until the forcemain was re-located off the beach.

Monitoring surveys have been carried out annually since 2003 along the centerline of the forcemain, which provide a good basis for estimating trends in beach levels and annual scour rates. Based on this information it was concluded that there is a high probability (almost certain) that at least one section of the forcemain will become exposed in the next 5 to 10 years, and it is possible that the forcemain will be exposed at several sections in the next five years. There is a low probability (approximately 10%) that at least one section will be exposed within one year.

In order to assess the consequences of a failure of the forcemain, information is required on where the sewage will disperse to and the resulting effects on human health, socio-economic activities and the environment. The primary processes controlling the circulation and dispersion of the effluent include tides, winds, and freshwater inflows from the Courtenay River. A three-dimensional hydrodynamic model (Delft-3D) of the Strait of Georgia was developed and used to assess the dispersion and dilution of the effluent and the extent of the impact zone. The model simulations show the dispersal pattern of the plume from a 24 hour release on the beach. Freshwater outflows from Courtenay River will push the plume northwards, maintaining its extent off Balmoral Beach and Cape Lazo, while reducing its spread into Comox Harbour and Baynes Sound. Southeasterly winds, which occur frequently during storm conditions, will tend to push the plume around Goose Spit into Comox Harbour.

The risk analysis was made assuming the present level of monitoring is continued and no additional repairs or maintenance are undertaken to mitigate the hazards. Considering a time span of five years (to 2020) the following conclusions have been drawn:

- There is a high probability (90%) that maintenance will be required to prevent exposure of the forcemain during the next five years.
- There is a medium probability (approximately 50 %) that a failure (lasting 24 hours) will occur at least once over the next five years.
- There is a low probability (approximately 10 %) that multiple failures could occur along the forcemain during a storm over the next five years. The duration of the discharge could persist longer than 24 hours in this situation.

In order to reduce the risk of failure the following mitigation measures are recommended:

- Monitoring and inspection of the beach should be carried out annually over the entire length of the forcemain on the beach (at present only the southern section is surveyed). A brief condition report should be prepared interpreting the survey data and the condition of the existing protection and indicating whether repairs or other work is required.
- Emergency response plans should be reviewed to deal with a potential breakage of the forcemain. This should include identifying and obtaining critical equipment that would be needed to repair a break.
- The top layer of the existing mattress that has experienced damage should be repaired.

In order to reduce the risk further, plans should be initiated to re-locate the forcemain off the beach. If this is not possible, then plans to install a replacement line at a level below the anticipated scour level should be considered. This would require implementing a long-term shoreline management plan to ensure the level of the beach does not continue to lower over time.

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1 INTRODUCTION

1.1 Scope of Work

Northwest Hydraulic Consultants Ltd. (NHC) was retained by the Comox Valley Regional District (CVRD) to assess the risk of scour and erosion causing a failure to an existing sewer forcemain on Balmoral Beach. The CVRD identified five main components to the coastal engineering risk assessment:

1. The rate of erosion over the forcemain.
2. The probability that the forcemain will rupture from erosion.
3. The probability that the forcemain will rupture from impact.
4. The effect of rupture – where would the effluent leak and what lands and waters are likely to be impacted.
5. The range of clean-up costs associated with the rupture.

In addition, it was indicated that the study should recommend the best maintenance and inspection practices that the CVRD could employ until the forcemain has been relocated and to recommend emergency response practices. CVRD requested that NHC review the ISO 31000 risk management standard and assess whether the work plan and study approach are compatible with it. Aspects of the study that deviate from the standard would be identified and discussed with the CVRD.

The study was initiated with a kick-off meeting on 3 June 2016 with D. McLean and D. Arnold of NHC, R. Wong of Current Environmental and Z. Norcross-Nu'u of the CVRD. A site inspection was made along the beach at that time. Topographic surveys were carried out during the inspection to fill in some data gaps from the previous monitoring work.

1.2 Purpose of Report

This draft report includes the following topics:

- Observations of the beach and existing forcemain protection from a site inspection made on 3 June 2016.
- A review of historic wave and tide level data and assessment of hydraulic conditions at the forcemain.
- A description of the oceanographic hazards due to scour and wave impacts along the forcemain.
- A summary of the potential effects of a forcemain failure on water quality in the adjacent waters.
- A characterization of the consequences of a failure in terms of costs and impacts to the environment, health and safety concerns and economic losses to commercial fisheries.

- A risk analysis conducted by combining the information on hazards and consequences.
- Conclusions and recommendations for short-term and long-term measures to reduce risks.

1.3 Method of Approach

1.3.1 Terminology

In this report, a “hazard” is defined as the probability of occurrence of a potentially dangerous event (scour or exposure of the forcemain) in a fixed time frame and area of extent (Varnes, 1984). A risk assessment involves not only characterizing the hazard but also assessing the consequences of an event in terms of its human health and safety, socio-economic and environmental impact. In this context, “risk” is defined as the combination of the likelihood of the event occurring and the resulting consequences of the event (de Wrachien, 2008).

The ISO 31000 Risk Management Standard defines risk as the effect of uncertainty on objectives. In this context, risk management refers to a systematic set of activities and methods that are used to direct an organization, a particular industry or a type of project, and to better manage the many risks that can affect the ability to achieve the objectives. The approach is intended to establish the risk management policy, accountability, communication and reporting mechanisms, and how risk management integrates into the project activities. The ISO risk management process involves the following key activities:

- Communication and consultation during all stages of the risk management process.
- Establishing the objectives and scope, and defining the parameters and risk criteria.
- Risk assessment, which is the process of risk identification, risk analysis and risk evaluation.
- Risk treatment, which is the selection and implementation of alternative(s) for modifying risks.
- Monitoring and review.

Documentation is also an important component of the risk management process.

This risk management process has been adapted and applied to coastal zone management in Australia (Rollason et al., 2010). The same general principles can be applied to assessing risks of a forcemain failure on Balmoral Beach.

1.3.2 Study Approach

This study focuses on analyzing risks of scour and erosion causing a failure to the existing sewer forcemain on Balmoral Beach and providing recommendations for mitigating those risks. This information will be used by CVRD as part of their overall strategy for managing risks. The relation between the risk analysis described in this report and risk management is illustrated in Figure 1.

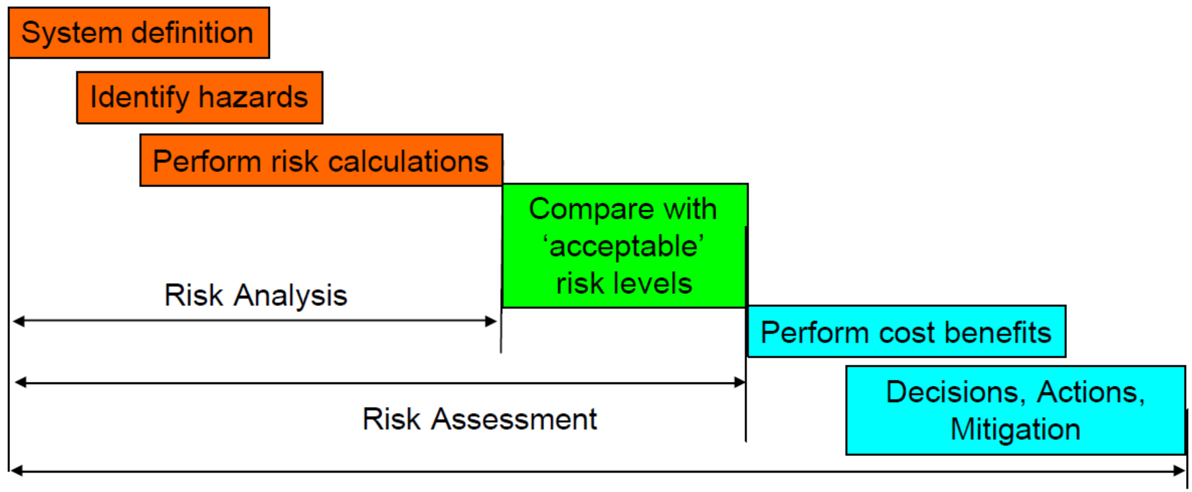

Figure 1: Levels of risk management (from Hopkins et al., 2009)

The scope of the study extends along the 1.7 km route of the forcemain on Balmoral Beach. A failure of the forcemain is defined as any loss of integrity or breakage of the pipe leading to a discharge of wastewater onto the beach. The probability of failure has been expressed in terms of annual exceedance probability. Consequences are measured in terms of potential harm to public health, socio-economic impacts and impacts to the environment. Where possible, approximate costs associated with a failure have been estimated. However, some effects have had to be expressed qualitatively.

1.3.3 Outline of Report

The context of the risk analysis includes describing the location and spatial extent of the study and the processes that generate the risk. Chapter 2, Physical Setting, Chapter 3, Environmental Setting and Chapter 4, Balmoral Beach Forcemain describe the context of the study area. Chapter 2 provides a brief overview of the shoreline characteristics and morphology as well as the tides and wave conditions at the site. Chapter 3 describes the environmental significance of the region and summarizes information on fisheries and commercial shellfish harvesting in the area. Chapter 4 describes the history of the forcemain, including the emergency protection installed in 2003/2004. This chapter also summarizes the monitoring surveys of the beach that were conducted along the centreline of the forcemain between 2003 and 2016 and the observations from the June 2016 site inspection. Chapter 5, Hazards characterizes the types of hazards to the forcemain and their probability of occurrence. Chapter 6, Effect of Forcemain Failure on Water Qualitysummarizes results from hydrodynamic modelling to simulate the dispersion and resulting dilution of a plume of effluent discharged from a rupture on the beach. Chapter 7, Risk Analysis, describes the consequences of a forcemain failure, in terms of the effects on the environment, human health and safety and commercial fisheries and shellfish industries. This chapter also provides preliminary estimates of costs for clean up and repairs. In addition, it describes a number of mitigation measures that could be implemented to reduce the risks. Chapter 8, Conclusions and recommendations summarizes the key findings from the study. This report also includes two appendices. Appendix A contains a detailed description of the water quality model.

Appendix B provides a brief description of the ISO Risk Management Standards and their application to the present study.

2 PHYSICAL SETTING

2.1 Shoreline Characteristics

Balmoral Beach extends approximately 3 km between Goose Spit and Cape Lazo and faces southeastwards into the Strait of Georgia (Figure 2).

The beach is bordered by high Pleistocene-age sand and gravel bluffs (Willemar Bluffs) along the backshore. Clauge and Bornhold (1980) described the bluffs as an important source of sediment to the beach and to Goose Spit. They indicated that eroded sediment from the bluffs accumulated at the base of the bluffs in summer forming a backshore apron (Photo 1 to Photo 3). However, during winter months the apron eroded away as a result of storm waves that entrained the sediment and cut directly into the cliffs. The entrained sediment was then transported by longshore currents and deposited in more sheltered waters at Goose Spit. Balmoral Beach was described as having a cobble-boulder pavement that formed in the winter during high energy storm events. During the summer, the coarse sediment was blanketed by sand. The finer sediments are located mainly near the base of the bluff, while the cobble and boulder material is more commonly found below the mean tide level.

Photo 1: Eroding Willemar Bluffs supplying sand and gravel sediment to Balmoral Beach, June 30, 2001

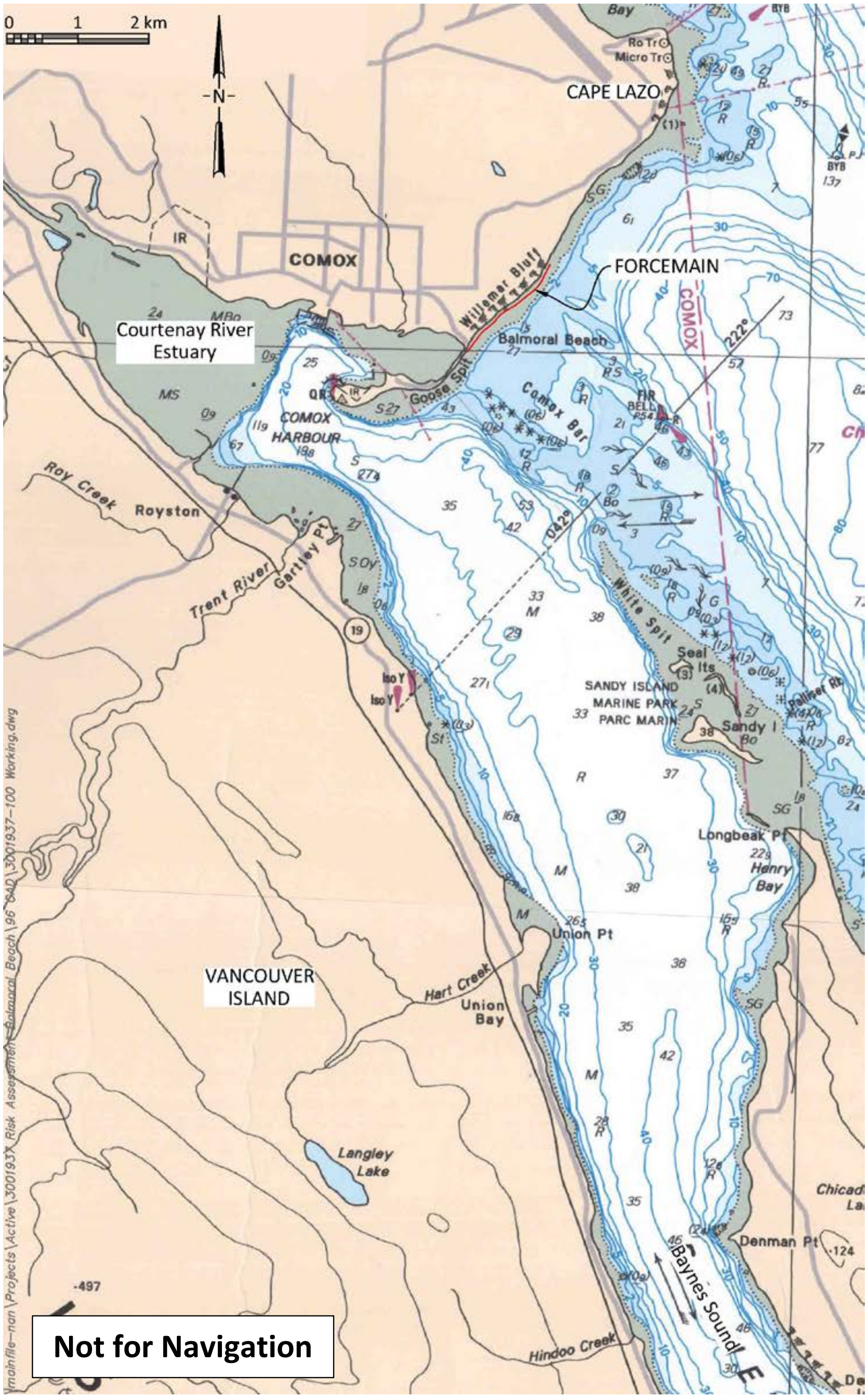

Figure 2: Study location (Canadian Hydrographic Services Chart 3513)

Figure 3 compares a low-level aerial photo of the beach in 1968 with a Google Earth image from 2005 at approximately similar tide conditions. A well-defined spit or splay of gravel is visible in 1968 and 2005 (labelled “A” on Figure 3). A tidal pool is also visible northeast of this feature (“B”) on both images. Another tide pool further to the northeast (“C”) is only visible on the 2005 image.

The main change to the beach since the study by Clague and Bornhold (1980) is that most of the bluffs are now continuously protected from wave erosion by riprap (Photo 2 through Photo 4), which has reduced the supply of sediment to the beach. It is our understanding that most of the riprap was constructed in the late 1990s and between 2001 and 2002. Groynes have also been constructed near the southern end, which reduces the sediment supply to Goose Spit.

2005

1968

Figure 3: Comparison of beach in 1968 and 2005

Photo 2: New riprap along base of Willemar Bluffs with tidal pools in background, May 2003

Photo 3: Continuous riprap along base of Willemar Bluffs, 2003

Photo 4: Groynes and riprap at southern end of Balmoral Beach, 2003

Beach profiles were surveyed by NHC in June 2003 and in 2016. The average slope of the beach is approximately 8% overall, being flatter below mean tide (typically 2 to 3%) and steeper above mean tide (9% to 10%).

2.2 Tides

Table 1 lists predicted tides levels at Comox in local chart datum (CD) and in Canadian Geodetic Vertical Datum (CGVD). All elevations in the report are in geodetic datum unless otherwise specified.

The tidal range at the site is 5.3 m. Ocean levels have been recorded in Comox Harbour by the Water Survey of Canada. The highest observed ocean level reached 2.735 m CGVD on March 10, 2016. Storm surges and set-up in the Strait of Georgia can temporarily raise ocean levels by 1 m above predicted levels.

Table 1: Predicted tide levels at Comox

Tide Condition	Abbreviation	Chart Datum (CD)	Geodetic Datum (CGVD)
Higher High Water Large Tide	HHW LT	5.4	2.1
Higher High Water Mean Tide	HHW MT	4.7	1.4
Mean Sea Level	MSL	3.3	0.0
Lower Low Water Mean Tide	LLW MT	1.3	-2.0
Lower Low Water Large Tide	LLW LT	0.0	-3.3

2.3 Winds and Waves

2.3.1 Winds

The local wind climate in the study area can be assessed by the use of a wind rose, a graphic presentation of winds for specified areas, utilizing arrows at the cardinal and inter-cardinal compass points to show the direction from which the winds blow and the magnitude and frequency for a given period of time. The wind rose derived from the nearby Atmospheric Environment Service (AES) wind station at Comox Airport (1953 – 2009) is shown in Figure 4.

The greatest frequency and the greatest wind speed in the study area occurs in the southeast/northwest orientation. The predominance of the southeasterly/northwesterly direction illustrates that the overall pattern of winds over Vancouver Island align with the orientation of the island shelf, with some variation due to local conditions.

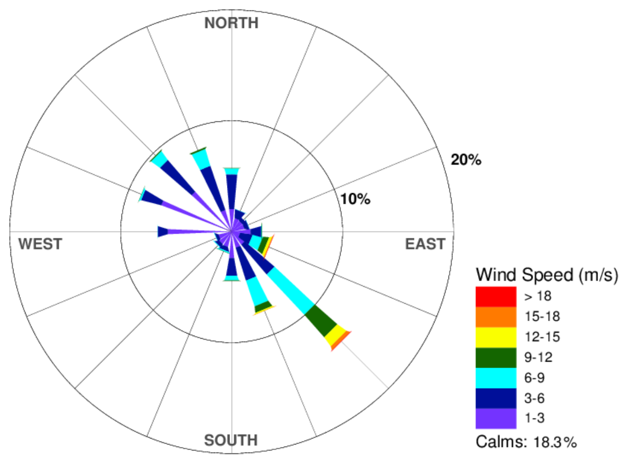

Figure 4: Comox Airport wind rose distribution (1953 to 2009)

2.3.2 Waves

The shoreline is exposed to storms from the east through the south-southeast (SSE). The maximum fetch reaches over 90 km within a narrow range of approach angles. More typically, the fetch length from the southeast varies from 35 to 50 km. Wave heights have been measured by Fisheries and Oceans Canada at Sentry Shoal situated 27 km north of Balmoral Beach in the middle of the Strait of Georgia. During the period 2003 to 2016, the significant wave height (Hs) at the buoy exceeded 3.0 m during eight storm events for a total duration of 12 hours. These events were all from the southeast direction. The southeasterly fetch at the buoy is approximately 90 km and is expected to record slightly higher waves than at Balmoral Beach.

Previous experience has shown that the most severe erosion on the east coast of Vancouver Island occurs when extreme high tides coincide with large winter southeasterly storm events. Table 2 summarizes the most severe storm events at the site since 2003. One of the highest ocean levels on record occurred on March 10, 2016 and coincided with southeast waves reaching a height of 2.6 m. Storms in December 2006, 2007 and 2012 had higher offshore waves (3.3 m and 3.4 m respectively) but lower ocean levels.

Table 2: Highest recorded storm events since 2003

Date	Hs (m) at Sentry Shoal	Ocean Level at Comox Harbour (m CGVD)
Dec 11, 2006	3.3	2.25
Nov 12, 2007	3.4	2.27
Nov 24, 2011	2.8	2.41
Dec 19, 2012	3.0	2.13
Dec 9, 2014	3.0	2.56
March 10, 2016	2.6	2.74

Hourly wind speed and direction have been measured at Comox Airport since 1953. The dominant winds come from the southeast, south-southeast and northwest directions. Table 3 summarizes a frequency analysis of extreme winds from the southeast direction.

Table 3: Frequency of hourly wind speeds at Comox Airport

Return Period (Years)	Observed Speed (m/s)	Adjusted 10 m height (m/s)
2	20.3	17.8
5	21.6	18.9
10	22.5	19.7
20	23.5	20.5
50	24.8	21.7
100	25.7	22.5
200	26.7	23.4

Deep water wave heights were estimated using JONSWAP wave hindcasting methods. The waves were generated using the wind speed data in Table 3, assuming a fetch length of 90 km (southeast storm conditions). Table 4 summarizes the estimates southeast deep water wave characteristics.

Table 4: Wave heights generated by southeast storms offshore from Balmoral Beach

Return Period (Years)	Hs (m)	Tp (sec)
2	3.5	7.9
5	3.8	8.1
10	4.0	8.3
20	4.2	8.4
50	4.5	8.6
100	4.7	8.7
200	4.9	8.9

3 ENVIRONMENTAL SETTING

3.1 Ecological Significance

The Courtenay River Estuary is known to support all five species of Pacific salmon at various stages of their life histories as well as some of the largest populations of migratory birds in the Strait of Georgia (Adams, 2000). An inventory of one part of the estuary reported 137 species of terrestrial plants, 21 species of salt marsh vascular plants, 32 species of algae and 106 species of marine fauna including 14 species of fish and 124 species of resident and migratory birds. This indicates the abundance and diversity of the region.

Baynes Sound is south of Balmoral Beach and extends between Denman Island and Vancouver Island (Figure 2). The following description of Baynes Sound is reproduced from the Association of Denman Island Marine Stewards web site.

> *Baynes Sound is ranked second only to the Fraser River Estuary for its ecological importance along BC's west coast and "the most important wetland complex on Vancouver Island" by two of the foremost conservation agencies, the Pacific Estuary Conservation Program (PECP) and the Pacific Coast Joint Venture (PCJV). It is internationally recognized as important for migratory water birds as well as providing habitat for at least six salmonid species (Jamieson et al., 2001).*
>
> *Baynes Sound is a critical feeding and overwintering area for migratory birds and is internationally recognized as an Important Bird Area (IBA)1. (Axys et al., 2000). Birds that occur within this region in numbers that are of global significance include the Pacific Loon, the Western Grebe, Brant (*Branta bernicla ssp. nigricans*), Black Turnstone (*Arenaria melanocephala*), Surf and White-winged Scoter, Harlequin Duck (*Histrionicus histrionicus*),*

*Mew Gull (*Larus canus*), Glaucous-winged Gull (*Larus glaucescens*) and Thayer's Gull (*Larus thayeri*) (Booth 2001).*

3.2 Fisheries

Baynes Sound, Lambert Channel and Comox Bar are significant herring spawning areas. In Comox Harbour and Baynes Sound adult herring aggregate in massive schools to spawn during late winter with heaviest concentrations occurring in March and lasting for approximately 4 weeks (Koke, 2008). Female herring produce an estimated 19,000 eggs, which are fertilized externally during extrusion and adhesion in dense masses to eelgrass, other algae and suitable substrate (Hart, 1973). Fertilized eggs incubate for 7 to 10 days before hatching into larvae, which typically remain in shallow nearshore water for an additional 2 months. While adult herring spawn repeatedly for several years, mortality to eggs and adults during the reproductive cycle is high as the annual concentration of food resources in and around Balmoral Beach and Goose Spit attracts an array of predators including water birds, marine mammals and fish.

3.3 Avians

The estuary is known to host overwintering migratory birds, with a high proportion of waterbirds throughout the winter (Asp and Adams, 2000), and is part of the 560.7 km^2 K'omoks Important Bird Area (IBA). The marine portion of K'omoks IBA represents a critical staging and wintering area for migratory and resident bird species in BC and is ranked second in importance after the Fraser River Estuary for migratory water bird habitat within the Strait of Georgia (Dawe et al., 1998; Butler, 2008). While the number of water birds is significant throughout winter, the highest concentration in and around Balmoral Beach and Goose Spit occurs in March and April when valuable food resources become available with the onset of peak herring spawning activity (Martell, 2008). These areas support globally significant populations of water birds including red listed Western Grebe, blue listed Surf Scoter, Pacific Loon, Harlequin Duck, White-winged Scoter, Brant, and blue listed Great Blue Heron (Martell, 2007). Table 5 outlines the timing of events that may coincide with a winter spill for various species.

3.4 Commercial Fisheries

Information on the commercial resources adjacent to Baynes Sound was described in the Baynes Sound Coastal Plan for Shellfish Aquaculture (BC Sustainable Resource Management, 2002). The Plan indicated the area around Baynes Sound produces approximately 50% of the Province's cultured shellfish, with the major commercial products being oysters, clams and scallops. It was also indicated that the Comox Indian Band has interest in shellfish aquaculture and has identified several sites in the area in Comox Harbour and the northern portion of Baynes Sound for beach culture development.

Figure 5 shows the Fisheries and Oceans (DFO) management areas near the site. Figure 6 shows the active commercial shellfish tenures. The 2002 BC Ministry of Sustainable Resource Management Plan indicated there were 110 shellfish beach and off-bottom aquaculture tenures covering 573 ha in Baynes

Sound. In 2001, an estimated 3360 tonnes of product, worth $8 million to growers, was produced. Five processing plans have operated in the area. In 2000, these plants processed $17.6 million worth of product (wholesale values). Some of this value reflects other BC product imported to the area. Shellfish aquaculture in the area generated 225 jobs on farm sites in 2000 and 165 jobs for processing. The annual wage bill was reported to be $8 million.

Figure 5: DFO Management Area 14 showing Balmoral Beach in sub-area 14-11

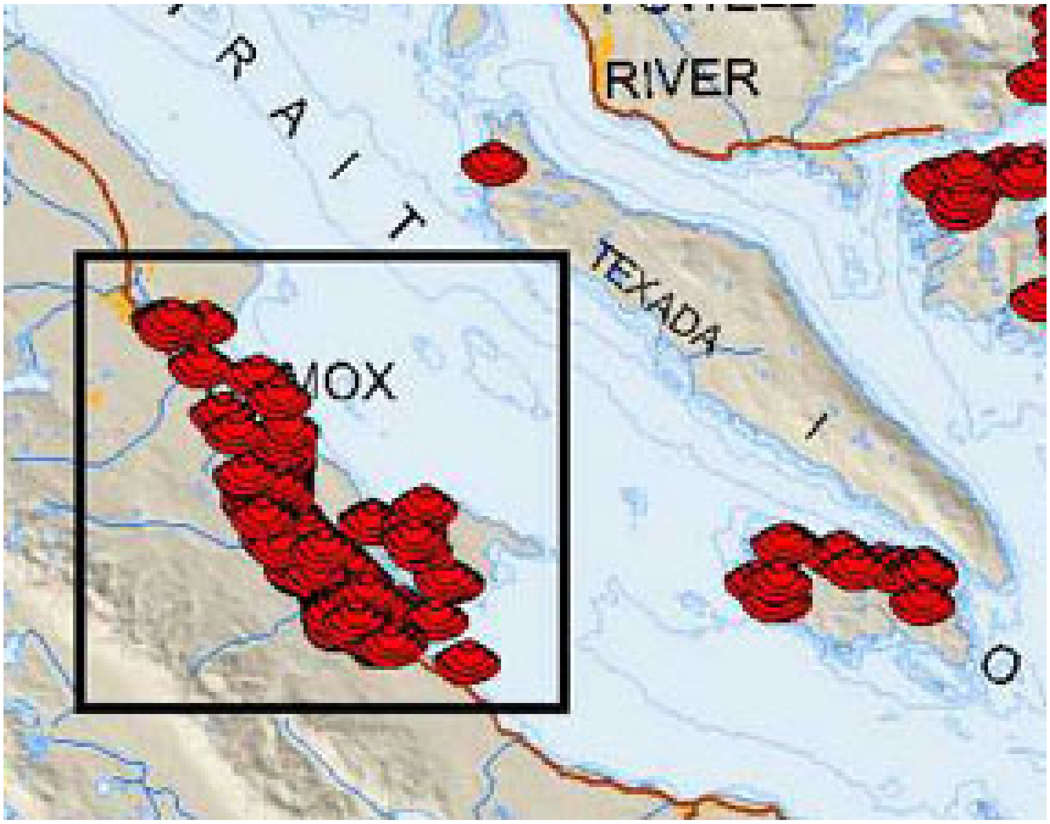

Figure 6: Overview map showing active commercial shellfish tenures located in Baynes Sound and Comox Harbour (adapted from BC Shellfish Growers Association, 2016)

The roe herring industry in Baynes Sound is extremely important to the fishing industry, with 2001 catches amounting to approximately 8,400 tonnes for the seine fleet and 400 to 1,000 tonnes for the gillnet fishery. The total landed catch value in 2001 was estimated to be $15 to $25 million (BC Ministry of Sustainable Resource Management, 2002).

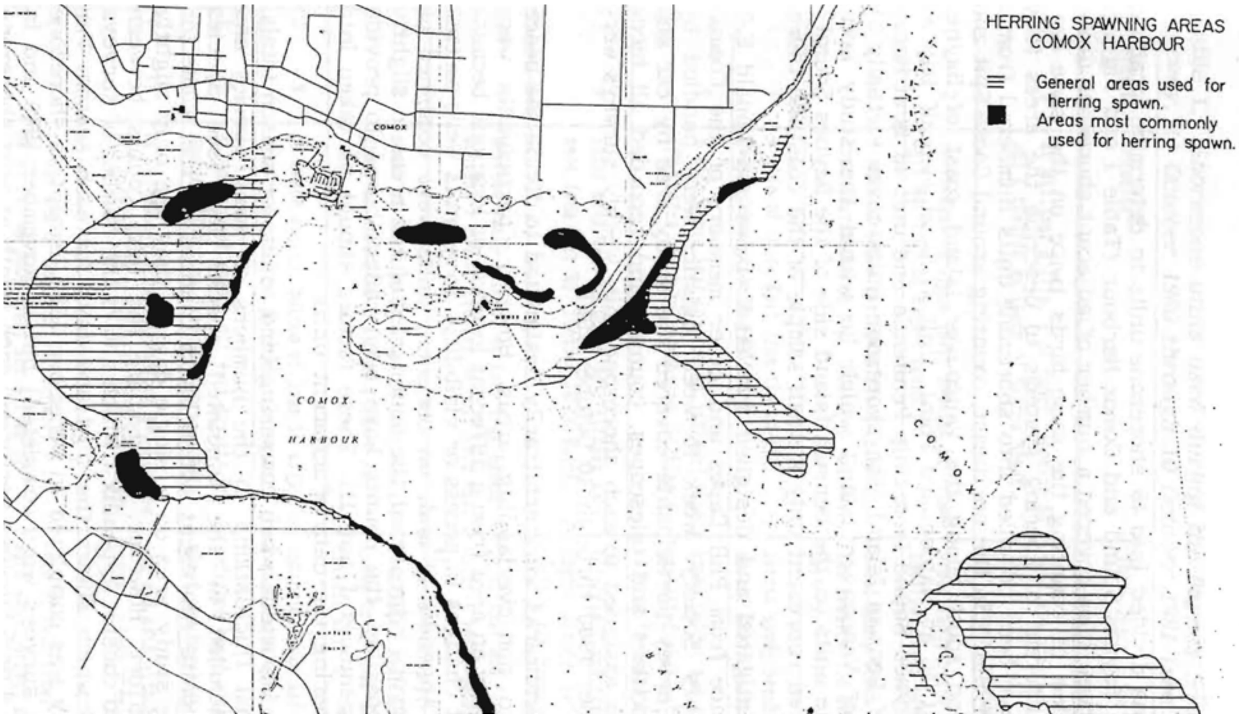

Figure 7: Known herring spawning areas in and around the study area (adapted from Dawe et al., 1998)

Table 5: Summary of fish and avian activity that may coincide with the high risk spill period

Season	Period	Organism	Event
Early winter	May - Dec	Salmon, var. spp.	Nearshore migration along Balmoral Bluffs and migration en route to estuary
Winter	Jan - Apr	Pacific herring	Spawning
Winter	Dec - Apr	Waterfowl	Overwintering, dependent on herring spawn
Winter	Nov - Feb	Sand Lance	Spawning
Spring/Summer	May - Sep	Surf Smelt	Spawning
Late winter	Mar - Jun	Juvenile salmon, var. spp.	Downstream migration to estuary

4 BALMORAL BEACH FORCEMAIN

4.1 Construction

The forcemain was constructed in 1982 and extends from near the mouth of the Courtenay River to Goose Spit and then along Balmoral Beach for 1.7 km to Curtis Road where it turns up to the wastewater treatment plant (Figure 2). The section along Balmoral beach is located in the inter-tidal zone and runs along the base of the Willemar Bluffs.

Locations along the forcemain are referenced to the stationing shown on the site plan prepared by Grant Land Surveying Inc. An orthophoto of the beach with stationing is shown in Drawing 1.

It is our understanding that the forcemain is an 860 mm diameter pre-stressed concrete cylinder pipe (brand name "Hyprescon") and was installed using a conventional cut and cover method (NHC, 2003). The as-built survey shows the top of the pipe is at approximately -1.5 m near the southern end (between Station 2+00 and 6+00) and then gradually rises up to approximately -1.0 m by Station 10+00 (Figure 8). The surveys show the forcemain had a depth of cover of approximately 1.5 to 2.0 m after construction.

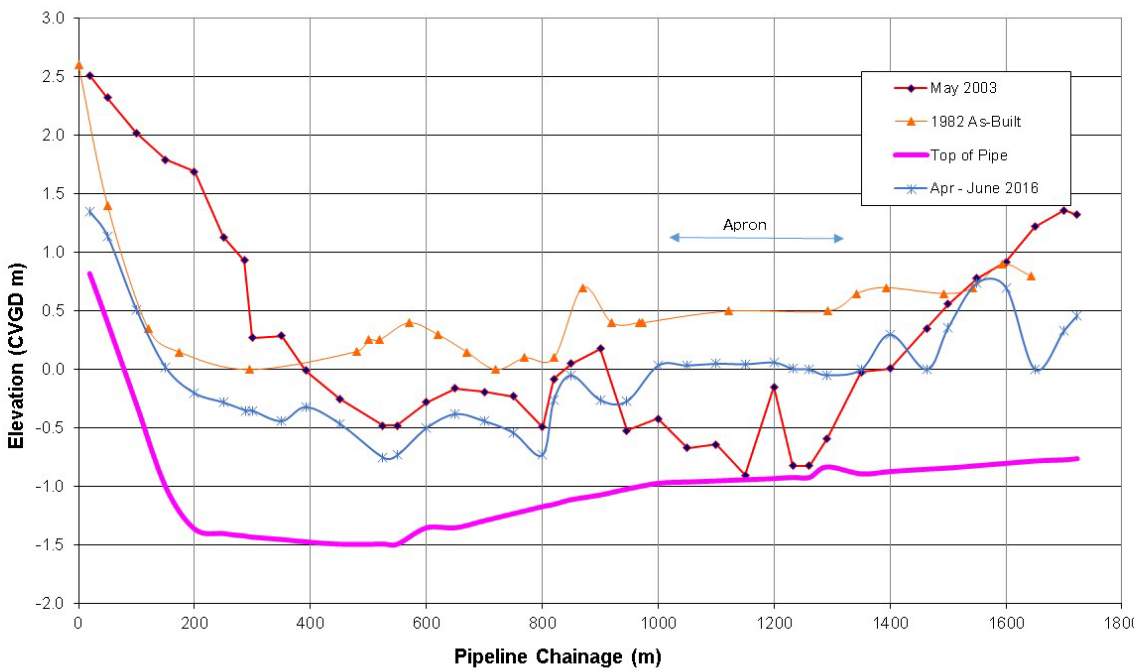

Figure 8: Profile along forcemain and beach level in 1982, 2003 and 2016 (chainage is from south to north)

4.2 2003-2004 Emergency Scour Protection

Monitoring by the CVRD in 2003 indicated that the depth of cover over the forcemain was less than 0.5 m in some locations (Figure 8). In May 2003, inspections showed that portions of the line were exposed (Photo 5). The study concluded that the forcemain was vulnerable to scour and undermining due to long-term lowering of the beach profile and identified four alternatives to prevent a failure of the forcemain:

1. Re-locate the sewer line away from the foreshore.
2. Install a parallel section of line at a lower elevation to prevent undermining.
3. Install protection over the portion of the line that is threatened by scour.
4. Place a gravel and cobble berm over the line and install a series of groynes to retain the beach material.

Photo 5: Exposed sections of forcemain near Sta. 11+00 in May 2003

It was concluded that Alternative 1 was the best long-term solution from a coastal engineering perspective. However, due to the urgent need to protect the line it was concluded that Alternative 3 should be implemented as an interim measure until plans could be formulated for implementing a permanent, long-term solution.

In August 2003 and 2004, emergency protection was placed over a portion of the forcemain:

- Phase 1 (summer 2003): 215 m over the most critical portion between Station 10+90 to 13+05.
- Phase 2 (summer 2004): additional 105 m of protection between Station 10+15 to 13+35.

The adopted protection (shown in Figure 9) consisted of:

- A 0.25 m thick (minimum) granular filter blanket over the pipe.
- Two layers of gabion mattress (0. 5 m and 0.3 m) totalling 0.8 m in thickness. The mattress extended 6 m seaward and 1.8 m below the forcemain to prevent undermining by scour.
- A cobble/boulder cover over the mattress, typically 0.3 m thick.

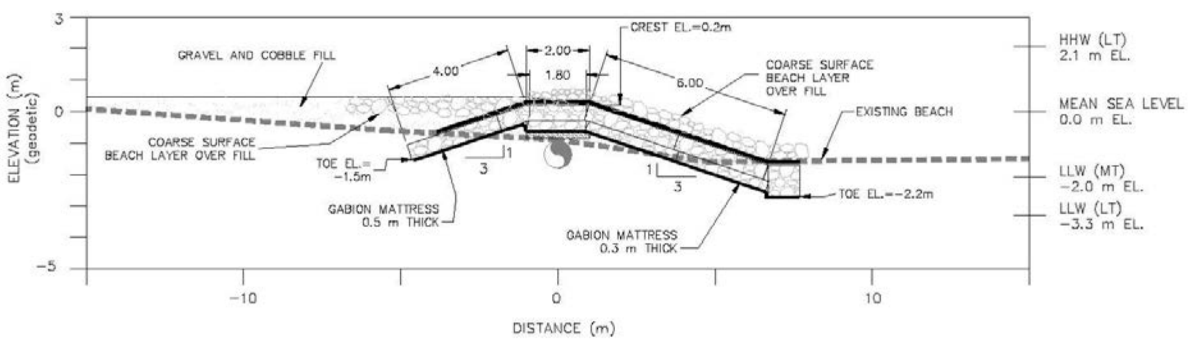

Figure 9: Cross section of erosion protection

Additional information on the condition of the forcemain at the time of the work may have been documented by Associated Engineering, the prime engineer on the project. However, NHC was not involved in this aspect of the work.

4.3 Monitoring

Observations spring 2004 after a storm season showed that storms readily mobilized and transported the cover layer (up to 400 mm diameter boulder and cobble) landward (Photo 6). The mattress remained stable and there was no evidence of scour or undermining in front of the structure.

The CVRD continued to monitor the forcemain annually by hiring Grant Land Surveying Inc. to conduct profile surveys over the pipe. The dates of the surveys varied, but were mostly conducted between March and April at the end of the winter storm season. The surveys originally extended over the entire 1700 m length. After 2005, the surveys were restricted to the unprotected section of the line between Station 0+19 and 9+46. NHC conducted an additional survey in June 2016 over the protected portion of the forcemain to compare with the information from March 2005.

The depth of cover over the forcemain was determined from each survey and was then plotted over time to identify trends. The data were grouped into three geographic sections:

- Station 0+19 to 4+50, southern unprotected section.
- Station 5+25 to 9+46, middle unprotected section.
- Station 10+50 to 13+50, northern section protected in 2003-2004.

Trends over time are plotted in Figure 10 through Figure 12. Figure 13 shows the depth of cover along the forcemain in 2016 as well as the minimum depth of cover observed between 2003 and 2016.

Photo 6: Waves have removed cobble-boulder cover and deposited material landward (April 2004)

Figure 10 shows the depth of cover over the forcemain between 2003 and 2016 at 11 stations along the southern end of Balmoral Beach close to Goose Spit. The depth of cover lowered relatively rapidly between 2003 and 2009 and has fluctuated randomly since then at most stations. The greatest changes occurred between Station 1+50 to 2+50 where the depth of cover decreased from between 2.5 and 3.0 m in 2003 to 1 m by 2016. The average rate of bed change was -0.1 to -0.15 m/year. Another area of significant beach lowering occurred at the extreme south end (Station 0+19 and 0+50) where the depth of cover has decreased from between 1.7 and 1.9 m in 2003 to less than 0.5 m by 2015. The rate of beach lowering averaged approximately -0.11 m/year in this location.

Figure 11 shows the depth of cover has remained between 0.8 m and 1.2 m at most locations along the middle section between Station 5+52 to 9+46. There appears to be a slow trend of decreasing cover over time (typically -0.015 m/year) at most locations. The lowest depth of cover occurred near Station

8+00, varying from 0.68 m in 2003 to 0.44 m in 2016. This location corresponds to a notable embayment in the shoreline.

Figure 12 shows the depth of cover over the forcemain has remained between 0.8 m and 1.0 m after the mattress protection was installed. The reduction in the cover at some stations (11+00) reflects the erosion of the cobble/boulder cover layer that was placed over the mattress (Photo 6).

The northern end of the mattress protection is at Station 13+35. North of the mattress, Station 14+00 and 17+00, the depth of cover has remained greater than 1 m.

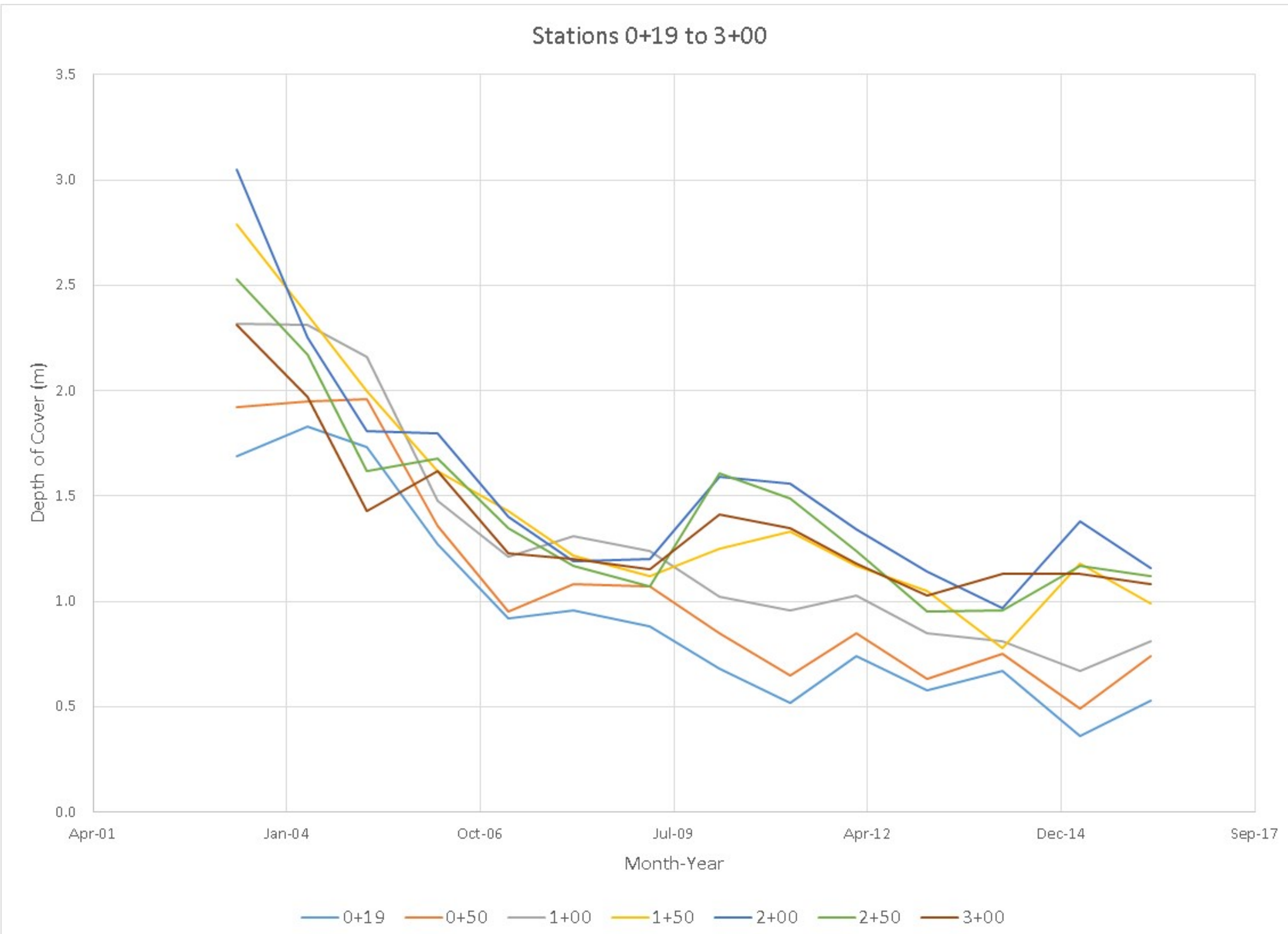

Figure 10: Depth of cover over forcemain near southern end of Balmoral Beach from 2003 to 2016

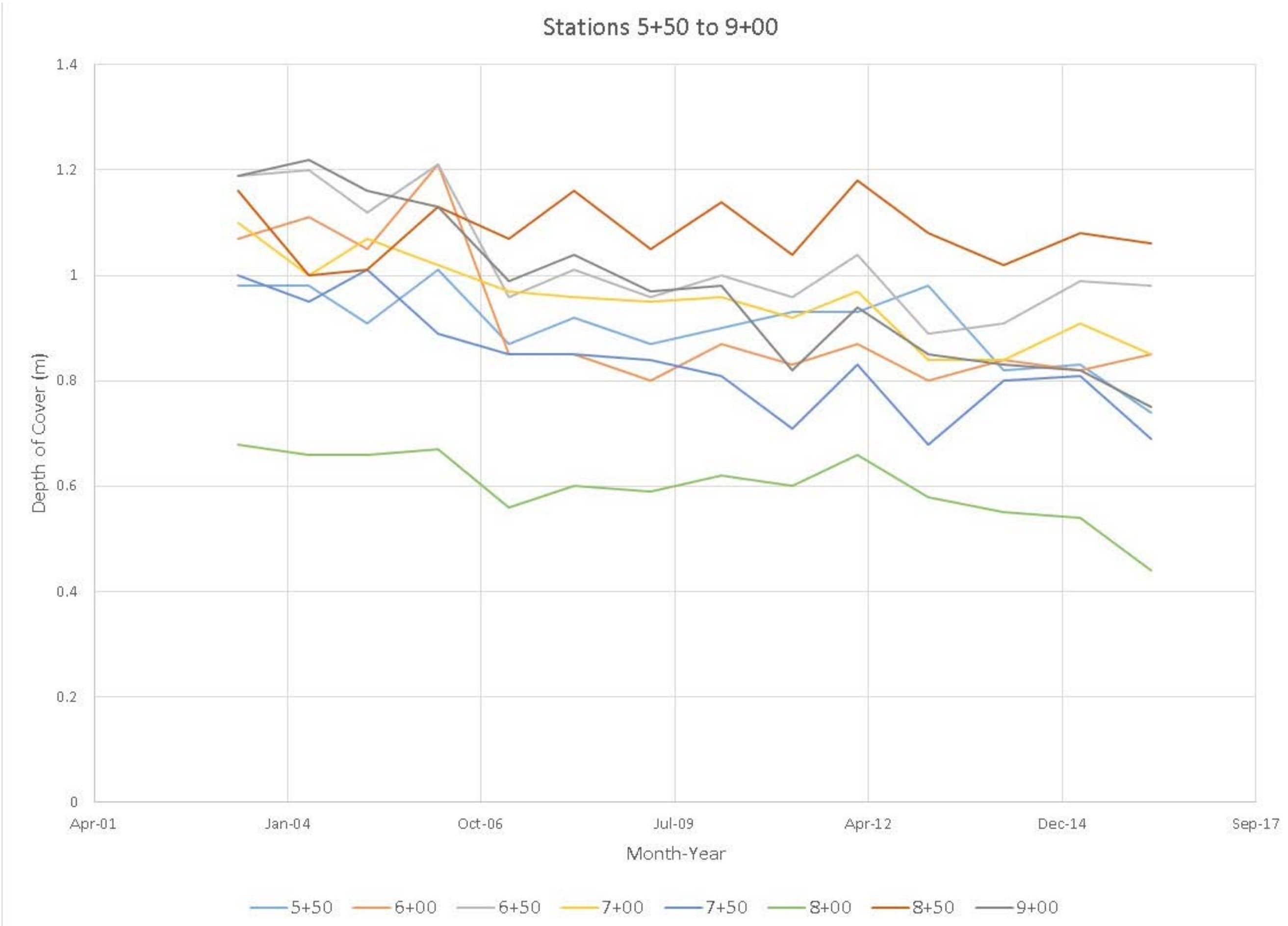

Figure 11: Depth of cover over forcemain in middle section of Balmoral Beach from 2003 to 2016

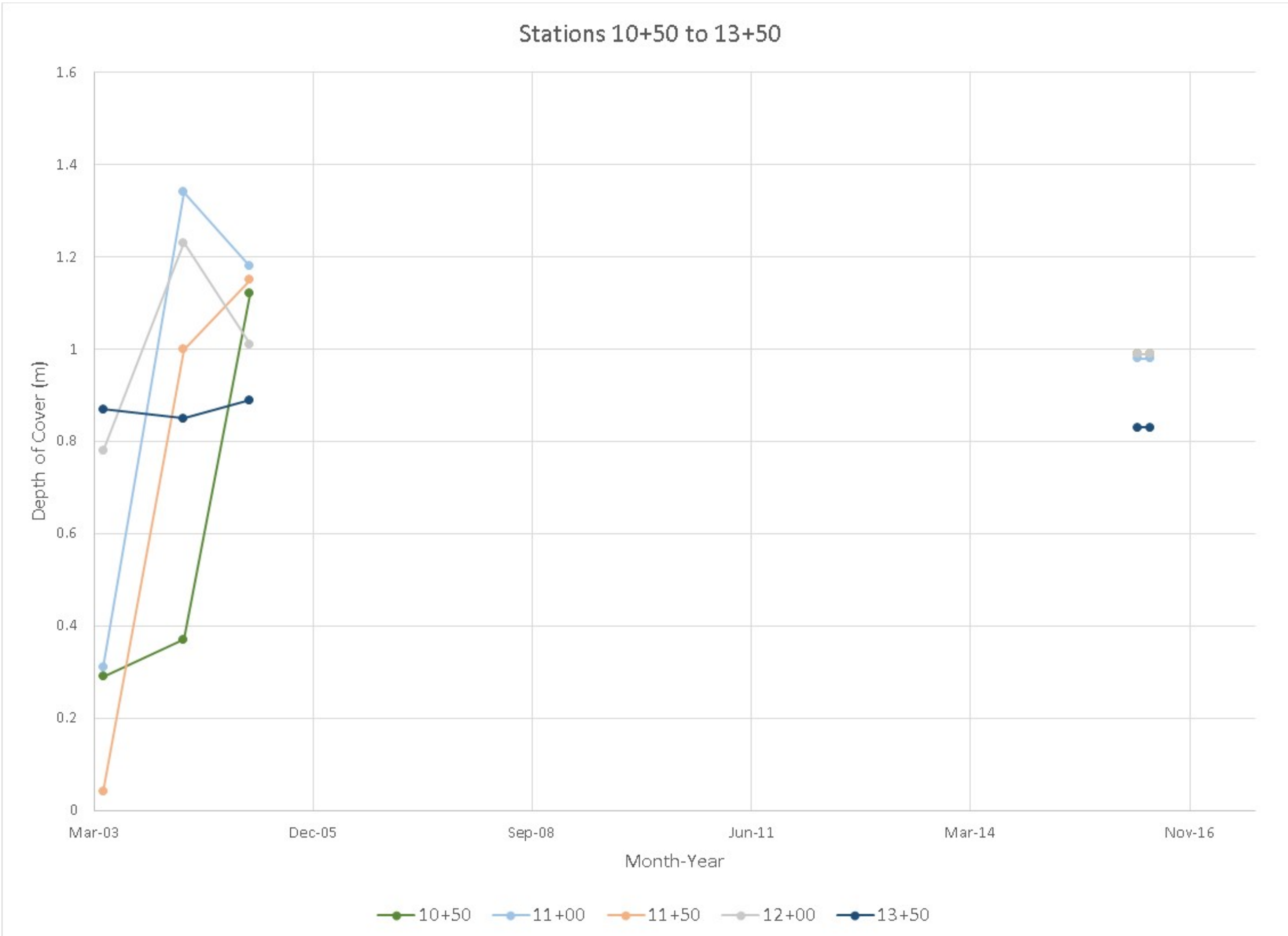

Figure 12: Depth of cover over forcemain along section covered by mattress from 2003 to 2016

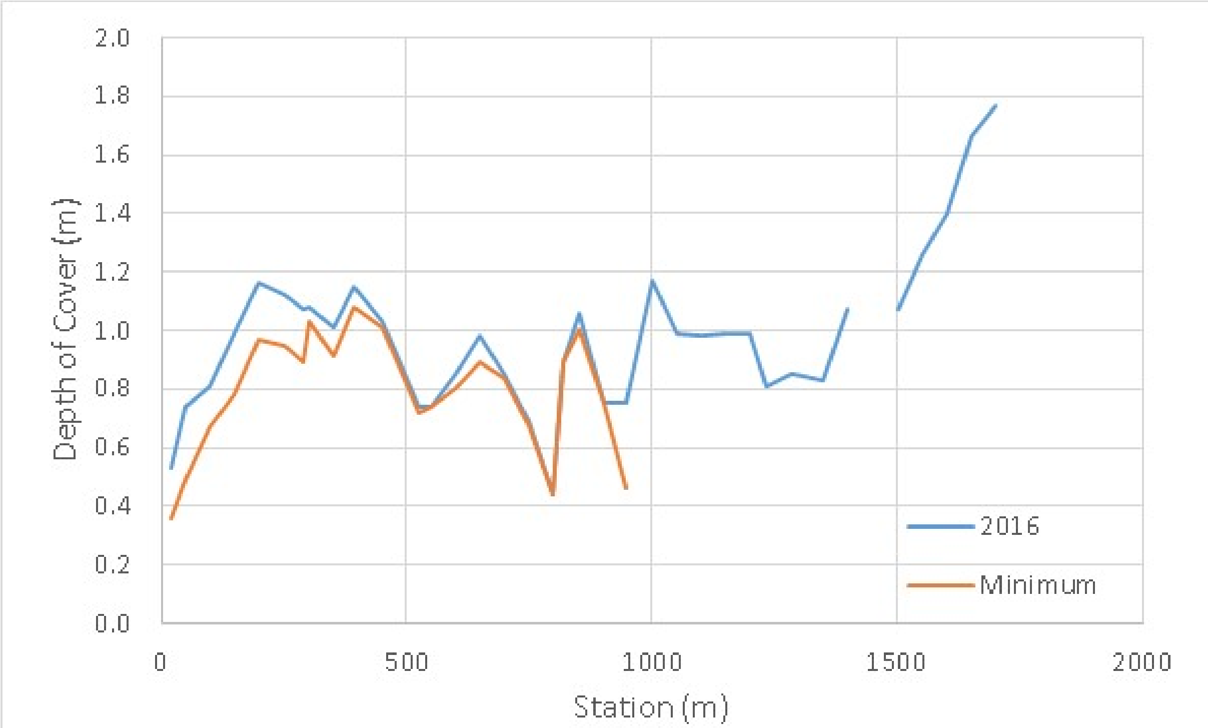

Figure 13: Depth of cover over forcemain in 2016

4.4 2016 Site Inspection

The site inspection was carried out on 3 June 2016 by D. McLean and D. Arnold of NHC, R. Wong of Current Environmental and Z. Norcross-Nu'u of CVRD. The tide level during the visit was near low tide, varying from 0.8 m to 2.0 m CD or -2.5 m to -1.3 m CGVD. Photo 7 to Photo 14 show general conditions on the beach starting near Goose Spit Park and extending up to near Curtis Road. Where possible, we have included comparable photos from 2003 and 2004 to try to illustrate the changes that have occurred.

The most noticeable recent change was seen near the south end of the beach (Station 0+20 to 4+50), where the base of the bluffs was continuously covered by large riprap between 2003 and 2016 (Photo 7). The beach material at the base of the riprap is mainly sand and gravel. Further seaward the beach coarsens and consists mainly of cobble. The repeat surveys show this section of beach has lowered by up to 2 m between 2003 and 2016, probably in response to the new riprap and reduced supply of sediment from upcoast. The depth of cover is less than 0.5 m near the south end, increasing to 1 m at Station 4+50.

There are seven groynes situated between Stations 4+75 and 6+25 (Photo 8), which date back to at least 2003. The level of the beach typically drops 0.3 to 0.6 m across each groyne, with gravel and sand sediment accumulating on the upcoast (north) side and sediment being removed on the downcoast (south) side of each structure. The depth of cover over the forcemain is presently 0.7 m in this area. The repeat surveys show that the ground remained relatively constant between 2003 and 2016.

Photo 9 shows the lower cobble and gravel beach and shallow tidal pool near Station 8+00. The depth of cover is presently only 0.44 m in this area, the lowest value recorded during the surveys. Photo 10 shows the southern limit of the boulder/cobble blanket that was placed over the forcemain in 2004. The plastic pipe corresponds to the centreline. The blanket appears to be intact. The depth of cover is 0.75 m. Photo 11 shows the exposed top of the mattress near Station 10+80. The boulder/cobble cover material has been displaced landward by waves in 2003/2004. The depth of cover here is 1 m (based on surveys by NHC in June 2016). There is no evidence of local scour seaward of the centreline and the mattress is intact. The top of the mattress is frequently exposed between Station 10+80 and 12+90, indicating this section of beach has been exposed to the most severe wave conditions. Several of the mattress lids were found to be damaged, which has allowed some of the cobble material in the top layer of mattress to be lost (Photo 12, Photo 13). The total length of mattress that has experienced this type of damage is approximately 30 m. The second (bottom) mattress remains undamaged. The depth of cover over the forcemain presently varies between 0.8 and 1.2 m along the protected section of the forcemain.

Three large tidal pools are situated on the seaward side of the forcemain in this section. It is expected that the deeper water in these pools allows larger waves to reach this section of the beach without breaking. By comparison, the northern section of the forcemain (north of Station 13+00) is protected by a wider continuous beach, which causes the waves to break further offshore. The existing boulder/cobble cover that was placed over the northern end of the mattress has remained intact (Photo 14). The depth of cover in June 2016 was greater than 1 m north of Station 14+00.

September 2003

June 2016

Photo 7: Near Station 2+00 viewing north. Shoreline has been riprapped since 2003. Riprap appears to have been displaced by waves onto beach

April 2004 June 2016

Photo 8: Near Station 4+50, viewing north. Displaced riprap and concrete blocks on groynes

April 2004 June 2016

Photo 9: Near Station 8+00 showing coarse-grained lower beach

April 2004 June 2016

Photo 10: Near Station 9+40, viewing north showing start of cobble/boulder protection over forcemain

April 2004 June 2016

Photo 11: Near Station 10+80 viewing north, showing exposed top of mattress

April 2004

June 2016

Photo 12: Near Station 12+20 viewing southwest, showing exposed mattress and shoreward displacement of boulder/cobble cover

Photo 13: Damaged top cover of mattress between Station 11+50 and Station 12+50, June 2016

Sept. 2003 June 2016

Photo 14: Near Station 13+00, viewing southwest along intact boulder/cobble cover over forcemain

5 HAZARDS

5.1 Identification of Hazards

5.1.1 Types of Hazards

The main hazards to the forcemain identified in this study include:

- Deterioration and corrosion of the concrete cylinder pipe's steel wire wrapping, leading to leakage or rupture.
- Undermining and failure of the forcemain as a result of scour processes, including local scour and general beach profile lowering.
- Failure of the forcemain due to impact from beach cobble and log debris.

5.1.2 Deterioration of the Forcemain

The forcemain is a pre-stressed concrete cylinder pipe (PCCP-Hyprescon) that is constructed of concrete but gets its strength from a high strength steel wire wrapping that is coated with concrete. With time, the wire will corrode, which can reduce the strength of the pipe to the point of failure. The age of the existing forcemain is approximately 35 years (installed around 1982). The present condition of the pipe is unknown.

The failure rate of PCCP has been documented by the US EPA (Romer and Ellison, 2008). That study reported that the highest incidence of PCCP failures has occurred for pipes constructed in the late 1970s and early 1980s, which corresponds to the date when the forcemain was installed. Based on the EPA's data, it should be recognized that leakage of effluent onto the beach could occur as a result of corrosion or deterioration of the pipe wall and joints, regardless of whether the line is exposed by scour or subject to impact forces. This mode of failure is not within our scope of work and should be investigated by other specialists with expertise in pipeline structures. The results of the assessment should then be factored in this study to update the risk analysis.

5.1.3 Undermining From Scour and Beach Profile Lowering

Unprotected Portion of the Beach

There are several types of scour processes that need to be considered:

- Long-term lowering of the beach due to interruption of the sediment supply.

  For example, there appears to be a consistent relation between the installation of riprap along the base of the Willemar Bluffs and the lowering of the beach as documented in Figure 8 and Figure 10.

- Seasonal and short-term lowering of the profile in response to storms and tides.

- Local scour in front of structures such as sea walls and revetments or exposed pipelines.

Hughes (1994) indicated that once a pipe becomes exposed, additional local scour will develop due to the local flow field generated around the pipe. In particular, once a section of pipe becomes unsupported the scour hole will expand rapidly. Hughes (1994) concluded that pipelines will be damaged if uncovered and exposed to strong waves and longshore currents. In 2003 it was noted that portions of the pipe had probably been exposed for one or two years. At that time only the crown of the pipe was visible (Photo 5). Also, it is likely that the pipe has deteriorated since 2003, making it more susceptible to failure. Therefore, for the purposes of this study we have assumed that the pipe will be subject to failure (either by undermining from scour or impacts) at unprotected sections of the forcemain if the depth of cover over the pipe is reduced to zero.

Protected Portion of the Beach

The situation is complicated by the emergency protection that was installed in 2003/2004 between Stations 10+15 and 13+35. This protection extends over approximately 20% of the length of the forcemain on Balmoral Beach. The protection consists of several components (Figure 9). From top to bottom, these consist of:

- A layer of cobble/boulder cover;
- Upper gabion mattress (0.5 m thick);
- Lower gabion mattress (0.3 m thick);
- A 0.2 m thick gravel/cobble blanket over the pipe.

The upper and lower mattresses extend over the pipe and tie in to a deeply buried gabion placed seaward of the pipe to prevent undermining by scour. The main hazards to the protection include:

- Deterioration of the steel wire mattress baskets due to corrosion and abrasion;
- Scour and beach profile lowering in front of the protection, particularly in the vicinity of the deep tidal pools adjacent to the forcemain between Stations 11+00 and 12+50.

It was anticipated that the cobble/boulder cover material would be subject to movement and transport, given the high wave energy at the site. Although this material was displaced from the top of the mattress in some sections, there has been no general scour or beach lowering in front of the protection.

NHC's 2003 report stated: "*The life span of the gabion mattress is commonly quoted to be at least 50 years. However, in marine applications, subject to waves and corrosion, a time frame of 10 to 20 years may be more realistic. Therefore, this alternative may be considered as an interim solution that would offer protection until the sewer line was re-located off the shoreline (as proposed in Alternative 1)*".

The June 2016 site inspection showed that abrasion damage has occurred to some of the lids of the top layer of mattress (about 10% of the total length). Tears or breakage of the lids will allow some of the stone material in the mattress to be washed out, reducing its effectiveness. The bottom mattress has not been affected to date. It is assumed that the forcemain will fail once the lower mattress experiences significant damage and loss of material.

Impacts from Debris

If the forcemain becomes exposed as a result of scour (as illustrated in Photo 5), it will be subject to impact forces from the cobble and boulder beach material and from debris such as driftwood. The periodic monitoring and site inspections have shown that 350 mm (75 kg) boulders are readily mobilized and transported on Balmoral Beach by waves in most storms. Furthermore, the beach has a considerable amount of large logs and driftwood that are periodically re-worked in the surf zone during storms. This debris can gouge into the beach creating additional scour. Therefore, the hazards from scour and debris impacts have been considered together.

5.2 Analysis of Hazards

5.2.1 Present Conditions

Figure 14 (top) shows the present (2016) ground profile along the forcemain and the top of the pipe (based on information from Associated Engineering 2003). The bottom plot shows the corresponding depth of cover over the pipe in 2016 as well as the recorded minimum cover over the period between May 2003 (prior to conducting the emergency repairs) and June 2016. The vulnerability of the forcemain to scour varies along the beach and is governed by several factors including:

- Elevation of the pipe;
- Ground elevation over pipe;
- Local beach characteristics (profile slope, sediment size);
- Local wave conditions at the site.

The depth of cover over the line in 2016 ranges as follows:

- 0.5 m to 1.1 m near the south end (Station 0+00 to 5+00);
- 0.8 m in the middle section (Station 5+00 to 10+00);
- 0.8 to 1.0 m in the section by the mattress (between Station 10+00 and 13+50) and
- Greater than 1 m at the northern section (north of Station 13+50).

The low depth of cover near the south end reflects the rise in the level of the pipe as it approaches the manhole in Goose Spit Park. The depth of cover has remained near 1 m between Station 2+00 and 4+50 where the pipe is at its lowest level (El. -1.5 m CGVD). The depth of cover decreases north of Station 4+50 where the pipe starts to rise and the level of the beach drops off. The minimum cover in 2016 was 0.4 m near Station 8+00. The mattress protection between Station 10+00 and 13+50 has maintained the depth of cover at approximately 0.8 to 1.0 m since 2003.

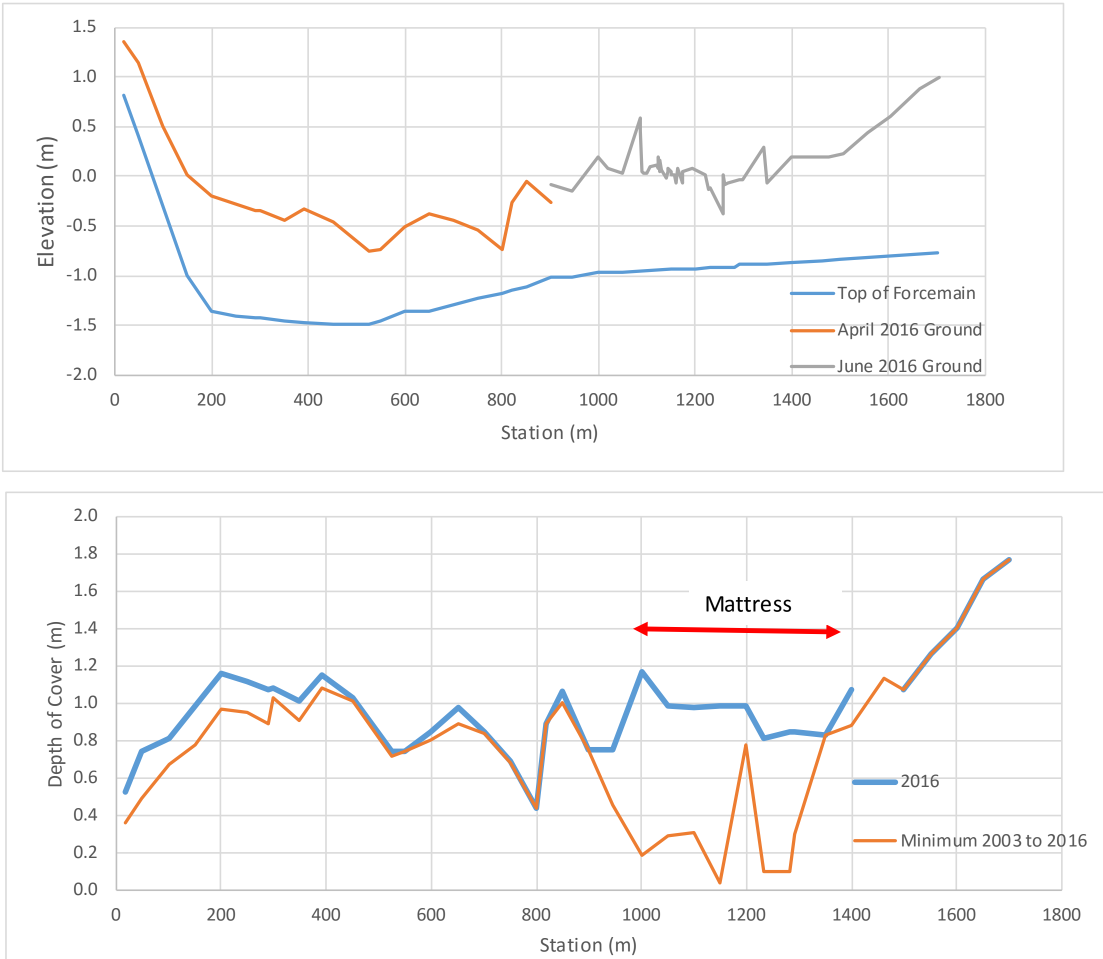

Figure 14: Beach topography along forcemain (top) and present depth of cover (bottom)

Figure 15 shows the variation in breaker height along the forcemain for the December 2012 storm and March 2016 storm. The incident deep water wave heights were 3.0 m for the 2012 event and 2.6 m for the 2016 event (Table 2). The variation in wave height over the forcemain is governed mainly by the variation in water depth and offshore beach slope, which affect the maximum breaker height (H_b). This plot shows that the most severe wave conditions occurred between Station 9+00 and 12+00, which corresponds to the section, that became exposed in 2002 and the site of the 2003 emergency protection works. This section has the highest breaking wave conditions because the ground level is generally lower (water depth is greater) and the offshore beach slope is steeper than at other sections.

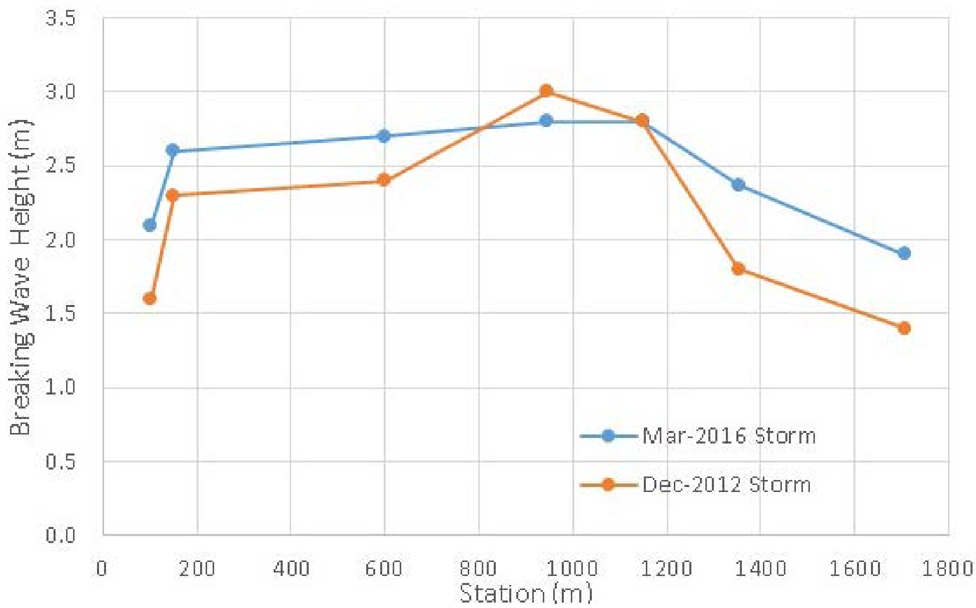

Figure 15: Variation in breaking wave height over forcemain along Balmoral Beach for two storm events

5.2.2 Estimation of Future Scour

Future scour and beach lowering will depend on a number of factors, including:

- Storm intensity and coinciding ocean levels;
- Sediment supply to the beach;
- Effects of human-induced changes such as construction of new shoreline structures and encroachments.

The magnitude of beach lowering has a short-term probabilistic component (the annual year-to-year variation in beach levels due to scour from storms) and a long-term deterministic component (due to systematic degradation). For the purposes of this study, we have assumed that the trends observed since 2003 will continue and that no new structures or interventions will be carried out.

There are no reliable analytical methods to predict beach profile scour (Hughes, 1999). However, the 2003 to 2016 monitoring surveys provide useful information to assess the magnitude and frequency of beach level changes at the site. The survey data were analyzed two ways:

- To estimate the magnitude and frequency of annual scour (S_a).
- To estimate trends in average beach levels over time to account for long-term profile degradation (S_l).

The magnitude and frequency of annual scour was estimated as follows:

- The annual beach change (scour or infill) was computed between successive survey years for all profile stations (typically 22 points between Station 0+19 and 9+46).
- The annual maximum bed change (scour) was then compiled from this data, resulting in 13 values of annual maximum scour within the unprotected length of the forcemain.
- The scour values were then ranked from highest to lowest and assigned a frequency of occurrence of r/(n+1), where r is the rank and n is the total number of years of observations.
- The points were then plotted as a cumulative frequency distribution and a smooth curve was plotted by eye through the data (Figure 16).

The plot in Figure 16 shows the return period (1/probability) of the scour equaling or exceeding a given magnitude in any one year. Some representative statistics are summarized in Table 6.

Table 6: Annual probability of scour at unprotected section of forcemain

Return Period (years)	Annual Probability of Exceedance (%)	Scour (m)
2	50	0.3
5	20	0.5
10	10	0.7
20	5	1.0

The main limitations of this analysis include:

- The surveys were not always made at the same time of the year. The dates varied from March to June.
- The surveys may not have measured the maximum beach lowering (some recovery may have happened after the storm).
- The surveys measure only the ground level over the forcemain. Greater profile changes may have taken place in other sections of the beach. The data are not strictly homogeneous or stationary in a statistical sense since impacts of riprap placement and the reduction in sediment supply have induced systematic changes over time.

In spite of these limitations, the data from these surveys provides more information than is commonly available to assess scour processes in coastal environments and to our knowledge is unique on Vancouver Island.

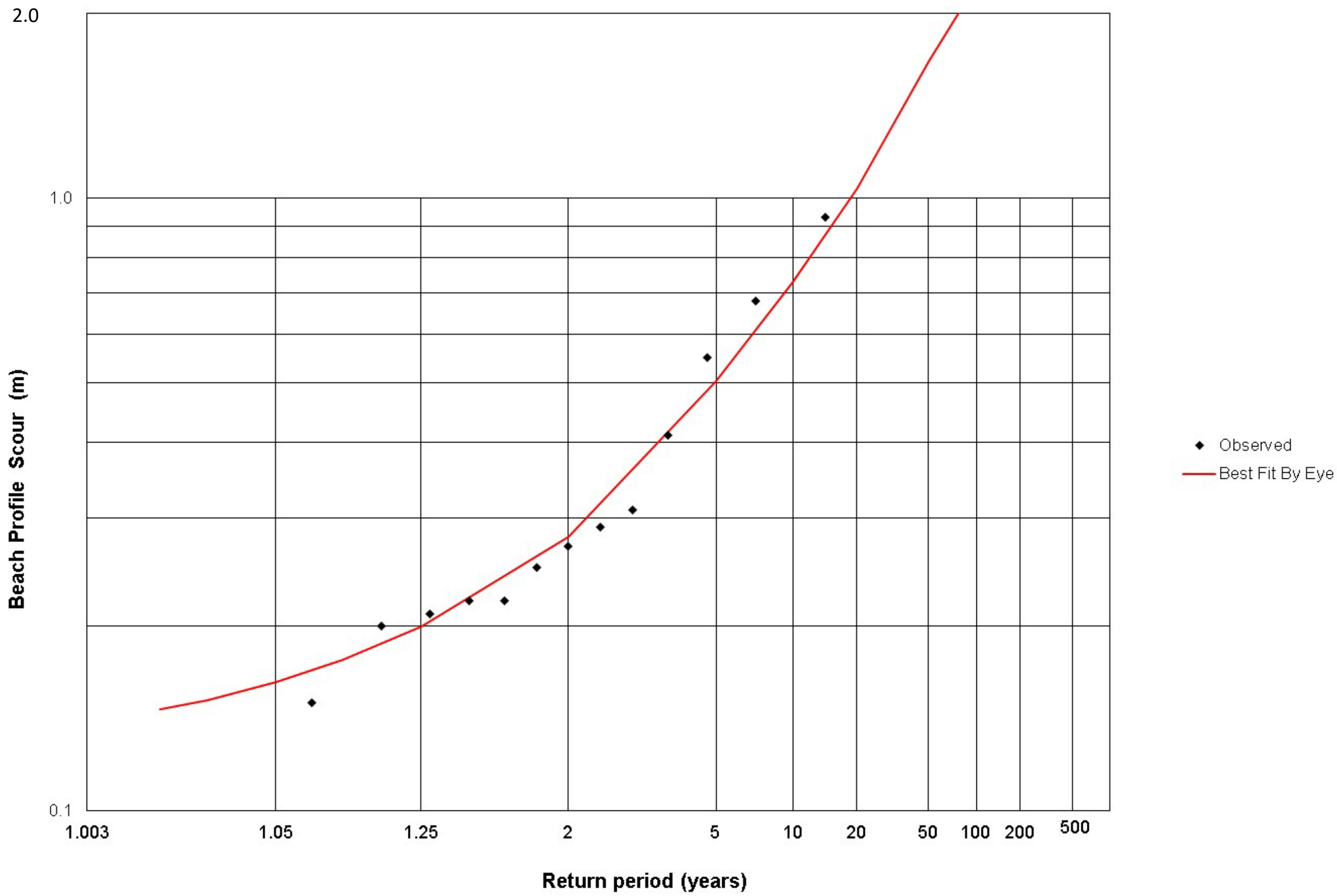

Figure 16: Empirical estimation of probability of scour on Balmoral Beach at forcemain based on observed annual maximum beach level change from 2003 to 2016

The second analysis used the data to define the rate of average bed lowering over time (S_l). This rate of lowering has been highest along the section between Stations 0+19 and 4+50, although the rate appears to be slowing down over time (Figure 10). For future conditions, we assumed an average rate of -0.08 m/year between Stations 0+19 and 4+50 and a rate of -0.02 m/year between Stations 5+25 and 9+46. However, the rate of lowering is subject to considerable variation from year to year. For this analysis, yearly changes in beach elevation rates were binned from all surveyed points and a frequency histogram of profile changes was generated. Using these probabilities, a Monte Carlo simulation was performed to estimate the number of years before the beach level lowered to the point where the depth of cover was reduced to zero. It was assumed that the present depth of cover was 0.9 m along the forcemain. This analysis showed that the time for the forcemain to become exposed averaged 13 years under past trends in beach lowering. Note that future trends may differ from past trends, causing a longer or shorter time to pipe exposure. Also, this projection does not account for the effect of short-term fluctuations (year-to-year scour) due to storms.

The potential total scour (S_t) in any year is computed as the sum of the annual scour (S_a) and the long-term lowering (S_l). The total scour is measured relative to 2016 profile conditions. Including the long-term trend with the annual scour illustrates how the probability of exposure will increase over time if the beach continues to lower due to the reduced sediment supply. For example, the depth of cover at Station 8+00 is presently 0.4 m. At present, the probability of the bed scouring greater than 0.4 m in any year is approximately 30%. If the beach lowered progressively -0.02 m/year the depth of cover will be reduced to 0.2 m in roughly 10 years. The probability of scour exceeding 0.2 m in any one year is 80% (return period of 1.25 years). Using this approach the probability of scour relative to present ground levels was estimated for 1-year, 5-years and 10 years (Table 7).

For the purposes of this study, the probability scales have been assigned qualitative terms such as "high", "medium", "low" and "very low". The relation between these qualitative terms and the annual exceedance probability are listed below:

- A high probability event represents a condition that is expected to be exceeded in most years (90% or 1.1 year return period).
- A medium probability event represents a frequently occurring event that is exceeded 50% of the time (2-year return period).
- A low probability event has an annual probability of exceedance of 10% (10-year return period).
- A very low probability event has an annual probability of exceedance of 1% (100-year return period).

The use of these terms is subjective but is intended to assist in interpreting the analysis.

Table 7: Probability of beach scour at unprotected section of forcemain, Station 0+19 to 9+60

Probability	Total Scour Relative to Present Conditions (m)		
	1 year	**5 years**	**10 years**
High	0.3	0.4 to 0.7	0.5 to 1.1
Medium	0.5	0.6 to 0.9	0.7 to 1.3
Low	0.7	0.8 to 1.1	0.9 to 1.5
Very Low	1.0	1.1 to 1.4	1.2 to 1.8

5.2.3 Discussion of Results

Comparing the potential scour in Table 7 to the present depth of cover over the forcemain indicates that there is a high probability (almost certain) that at least one section of the forcemain will become exposed in the next 10 years, and that it is possible that the forcemain will be exposed at several sections in the next five years. There is a low probability (approximately 10%) that at least one section will be exposed within one year.

It is assumed that if the forcemain becomes exposed as a result of scour or beach lowering it will experience a break or major leak (fail). The breakage may occur either due to undermining from scour or by impacts from cobbles and driftwood. This assumption is based on the experience reported by the US Army Corps of Engineers (Hughes, 1990) as well as from the available information on the general condition of the pipe and susceptibility to damage (Romer et al., 2008). Therefore, under these assumptions the forcemain is expected to experience at least one failure in less than 10 years.

The top layer of the existing erosion protection mattress has experienced some damage since it was installed in 2003. The lifespan of this emergency protection was estimated to be 10 to 20 years (NHC, 2003). It is assumed that the bottom layer of the mattress will become seriously damaged by 2023. Once the stone in the mattress is winnowed away by the waves, the underlying forcemain will be subjected to breaking waves and impact forces from debris and will break. The life of the protection could be extended by carrying out periodic inspections, maintenance and repairs. At present, the routine monitoring surveys do not include the portion of the beach covered by the mattress.

5.3 Mitigating Hazards

The analysis presented in Table 7 assumes no new mitigation is carried out. Three types of mitigation could be carried out to reduce the threat of exposure. Additional measures to reduce the overall risk of a failure are discussed in Section 7.6.

5.3.1 Improved Monitoring

The present annual profile survey could be expanded to include an inspection of the beach and the existing protection after major storms. At present, the surveys do not cover the protected portion of the pipe. The survey data should be interpreted to decide whether further action is warranted.

5.3.2 Short Term Protection

In the short term, two methods or options are considered feasible for protecting the forcemain:

- Option 1: Install additional mattress (or possibly articulated concrete mattress) with a cobble cover, similar to the 2003 design.
- Option 2: Install a temporary gravel blanket over the forcemain acting as coarse beach nourishment.

Selecting the most appropriate option will depend on the specific location of the site, environmental permitting requirements and the time available to implement the work. Option 1 is likely to require more time for receiving permit approvals than Option 2.

Due to the relatively high longshore transport rates along the beach, a decision to adopt Option 2 would mean conducting relatively frequent applications of the gravel (say every 1 to 3 years). On the other hand, this approach could become integrated into a long-term plan to improve the overall stability of the shoreline. Using beach nourishment to protect the forcemain is more feasible along the southern end of the beach (south of Station 6+00) where the wave energy is reduced and the general level of the beach is higher. It is not clear if this option is practical on the more exposed northern section of the beach.

5.3.3 Long-Term Measures

Re-locating the forcemain off the beach is the best long-term strategy in terms of addressing coastal hazards, particularly given the uncertainties added by sea level rise (as sea level rises the increased water depths over the forcemain will result in higher breaking wave heights and higher wave energy). Other alternatives could involve re-constructing the forcemain on the beach at a lower elevation. This alternative would need to incorporate a long-term shoreline management strategy to ensure the beach will not continue to lower in the future. This strategy could involve examining a range of measures to restore natural shoreline processes and to manage the stability of key features such as Balmoral Beach, the Willemar Bluffs, Goose Spit and Cape Lazo. The strategy would need to consider the effects of future sea level change. Strategies for restoring the historic sediment supply and longshore transport rates along the beach would probably require large-scale beach nourishment, which is beyond the scale of any local forcemain maintenance operations.

6 EFFECT OF FORCEMAIN FAILURE ON WATER QUALITY

6.1 Method of Assessment

In order to assess the consequences of a forcemain failure, information is required on where the wastewater will disperse to and the duration that water quality will be adversely impacted. The primary processes controlling the circulation and dispersion include tides, winds, and freshwater inflows from the Courtenay River. A three-dimensional hydrodynamic model of the northern Strait of Georgia was developed and used to assess the dispersion and dilution of the effluent. The model was developed using Delft-3D, a 3D hydrodynamic model that calculates non-steady flow and transport phenomena from tidal and river flow forcing. Delft-3D uses a finite difference scheme that numerically solves the horizontal momentum equation and includes discharge sources. The equations and model description are provided in Lesser et al. (2004). Additional details on the model development and simulation results are described in Appendix A.

The model output describes the dilution of the initial discharge from the forcemain over a period of time and space. By specifying the initial composition of the wastewater in the forcemain, the concentration of key water quality parameters in the diluted effluent can be determined. This information was then reviewed by the project's biologist to provide a preliminary assessment of the effects on the environment.

6.2 Assumptions

6.2.1 Timing

A failure of the forcemain is most likely to occur during a severe winter storm event. Given there is no way to by-pass a break in the forcemain, a temporary collar or replacement section of pipe would have to be installed at the point of breakage. Due to the low elevation of the beach, the work window for carrying out repairs is very limited and if the break occurs in winter, this work would have to be carried out at night, when low tides occur. This situation makes access and repairs very difficult. It was assumed that leakage from a single break would continue for a period of 24 hours before emergency repairs were carried out.

6.2.2 Discharge Volume and Waste Water Characteristics

Table 8 summarizes the range in flow rates in the forcemain between 2009 and 2014 (from CVRD). The average daily flow between 2009 and 2014 was 14,200 m^3/day. The flow rate is substantially higher during winter months, exceeding 30,000 m^3/day. The prescribed flow rate during a discharge was 64,800 m^3/day.

Table 9 summarizes some of the physical and chemical characteristics of the wastewater (from CVRD). For the purposes of the modelling, the contaminants were assumed to be conservative and to not decay with time.

Table 8: Flow rate in forcemain (from CVRD)

Year	Permit Exceedances (>18,500m^3/day)	Average Daily Flow (m^3/day)	Max Daily Flow (m^3/day)	Min Daily Flow (m^3/day)
2014	31	14,220	38,462	10,965
2013	4	13,258	21,225	10,379
2012	40	14,809	35,126	11,302
2011	30	14,171	31,173	10,818
2010	41	15,345	49,254	11,450
2009	27	13,243	39,300	11,663

Table 9: Comox influent wastewater characteristics (2014)

Parameter	Mean	Minimum	Maximum
Temp (°C)	17.3	10.7	23.5
pH	7.6	7.1	8.0
BOD (mg/l)	228.9	145	454
TSS (mg/l)	213	42	726
TKN (mg/l)	47.6	37.1	164
Alkalinity (mg/l)	298	111	505
Fecal Coliform	53,400,300	2400	>160,000,000
E-Coli	27,311,500	230,000	>160,000,000

6.3 Water Quality Modelling

6.3.1 Model Development

The model grid covers the northern Strait of Georgia (Figure 17) and extends from Campbell River at the north boundary to Ballenas Islands at the south boundary. The model consists of three 2-way coupled curvilinear domains with progressively finer resolution, with the finest grid resolution in the vicinity of the Balmoral Beach, where it is 100 m. In the vertical direction, the model grid consists of 20 fixed z-layers that are thinner near the surface (top 2 m) and thicker at depth. The difference in horizontal and vertical geometry is required because of the large aspect ratio characterizing the marine environment, and because much of the variability (density stratification, vertical shear in horizontal flow) is concentrated near the surface, which requires a finer vertical resolution. The bathymetry for the model is derived using datasets from CHS hydrographic charts.

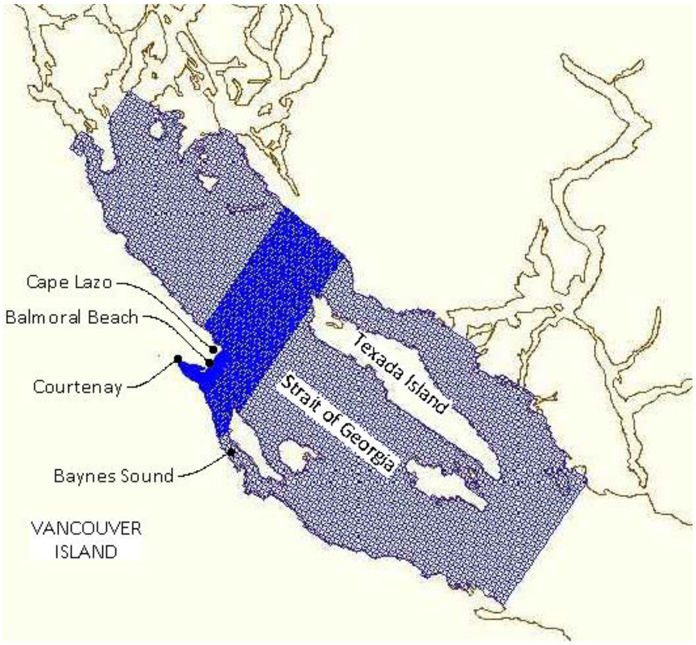

Figure 17: Coarse model grid of the northern Strait of Georgia and fine grid near the Balmoral Beach

6.3.2 Selected Model Results

Five model simulations (Table 10) were conducted to assess the dispersion and dilution of the effluent and the extent of the impact zone. The initial concentration of the wastewater released from the pipe is prescribed to be 1.0, with a background concentration of 0.0 in the ocean. The actual concentration of any contaminant can be computed from the model results by multiplying the predicted dilution value by the actual concentration discharged from the plant (Table 9). For example, if the fecal coliform levels in the wastewater discharge is 53,400,300 counts per 100 ml and the dilution at a particular location after 24 hours is predicted to be 10,000, then the resulting concentration of the effluent is 5,340 counts per 100 ml.

The model simulations include a range of environmental conditions, including varying tides, inflows from the Courtenay River, varying winds as well as the duration of the wastewater discharge. These parameters all have a significant effect on the dispersion and dilution of the effluent plume. Dilution is reduced when the daily tidal range is small (neap tide conditions). This is because the smaller tidal range generates lower tidal currents and lower dispersion rates. Freshwater outflows from the Courtenay River will push the plume northwards, limiting its movement into the Courtenay River Estuary and Comox Harbour but reducing dilution rates off Balmoral Beach and Cape Lazo. Southeasterly winds counteract the effect of the river, pushing the plume around Goose Spit into Comox harbour.

The model simulations were initially limited to a duration of one week, which included a period of 96 hours after the end of the wastewater release. Later on, two simulations were extended to cover a duration of 30 days to assess the longer term dispersion processes.

Table 10: Model Runs

Run	Tide	Wind	Courtenay R. (m^3/s)
1	Spring	Calm	0
2	Neap	Calm	0
3	Neap	Calm	52
4	Neap	Southeasterly, varying between 10 and 15 m/s	0
5	Neap	Southeasterly, varying between 10 and 15 m/s	52

A worst-case scenario in terms of conditions in the Courtenay River Estuary and Baynes Sound is the situation of a forcemain break during calm winds and low inflows from the Courtenay River (Run 2). Figure 18, Figure 19 and Figure 20 show the extent of the effluent plume at an elevation of -2 m CGVD 24 hours, 48 hours and 96 hours after discharging on the beach.

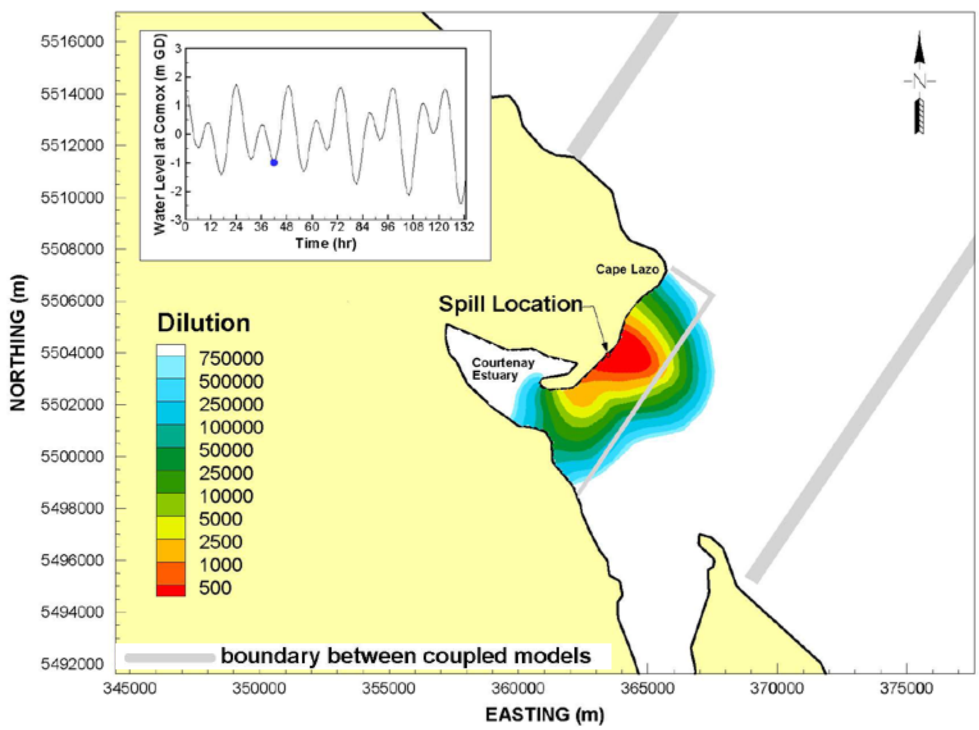

Figure 18: Run 2 – Dilution map 24 hours after discharge, calm winds, low Courtenay River inflow

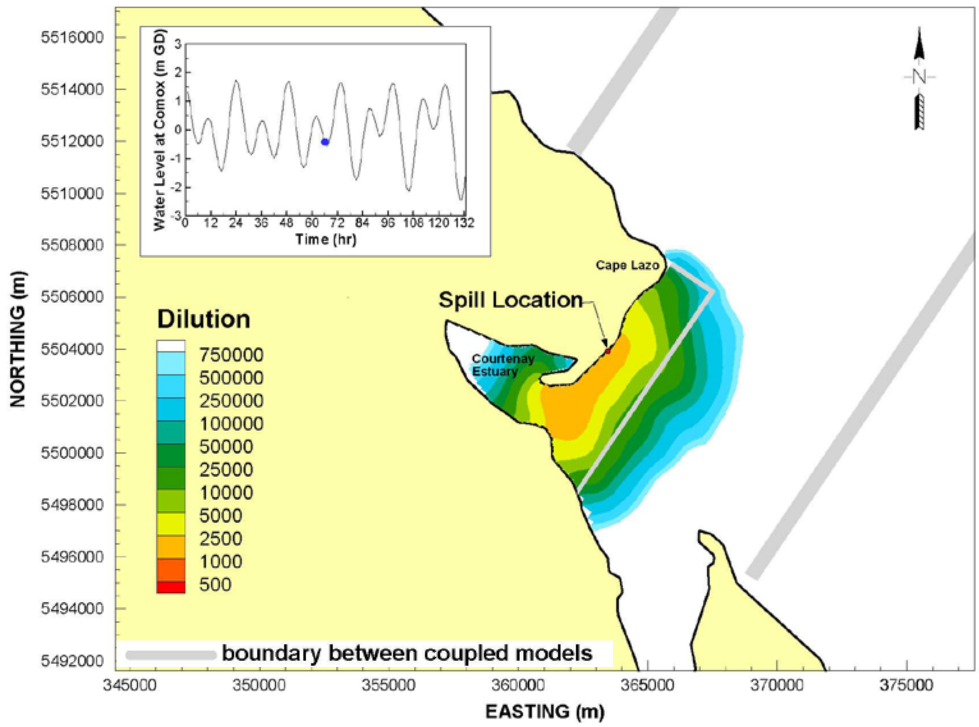

Figure 19: Run 2 – Dilution map 48 hours after discharge, calm winds, low Courtenay River inflow

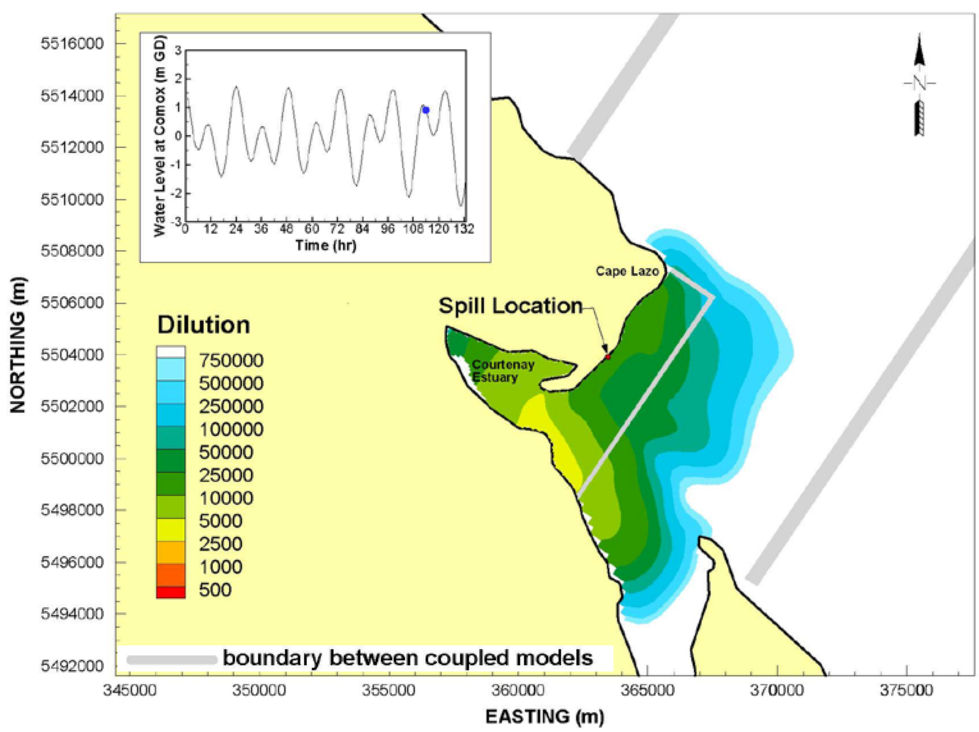

Figure 20: Run 2 – Dilution map 96 hours after discharge, calm winds, low Courtenay River inflow

After 24 hours, the discharge from the forcemain will be diluted by a factor of between 100 and 500 along most of Balmoral Beach. Dilution rates inside the Courtenay River Estuary-Comox Harbour were in the range of 4,000 to 5,000 after 48 hours. At this time, the plume will extend over a 2 km wide, 8 km long band that covers the tip of Cape Lazo to the northern end of Baynes Sound. After 96 hours, the effluent will be diluted by a factor of approximately 100,000 at the north end of Baynes Sound. However, coliform counts will still be in the range of 300 to 1,600 counts per 100 ml. It should be noted that threshold coliform levels for shellfish in coastal BC waters is presently in the range of 14 to 40 counts per 100 ml. Therefore, the potential impact zone shown on Figure 20 is expected to be much greater.

Figure 21 shows the extent of the effluent plume at an elevation of -2 m CGVD 30 days after the release for Run 2 (calm winds and low Courtenay River inflow). This plot shows that the effluent would persist in the region for a long period under these conditions. The dispersion process in the system is limited by Comox Bar and minimal dilution of about 50,000 was predicted in the Courtenay estuary and in the Bayne Sounds region. The coliform counts would still be in the range of 600 to 3,200 counts per 100 ml.

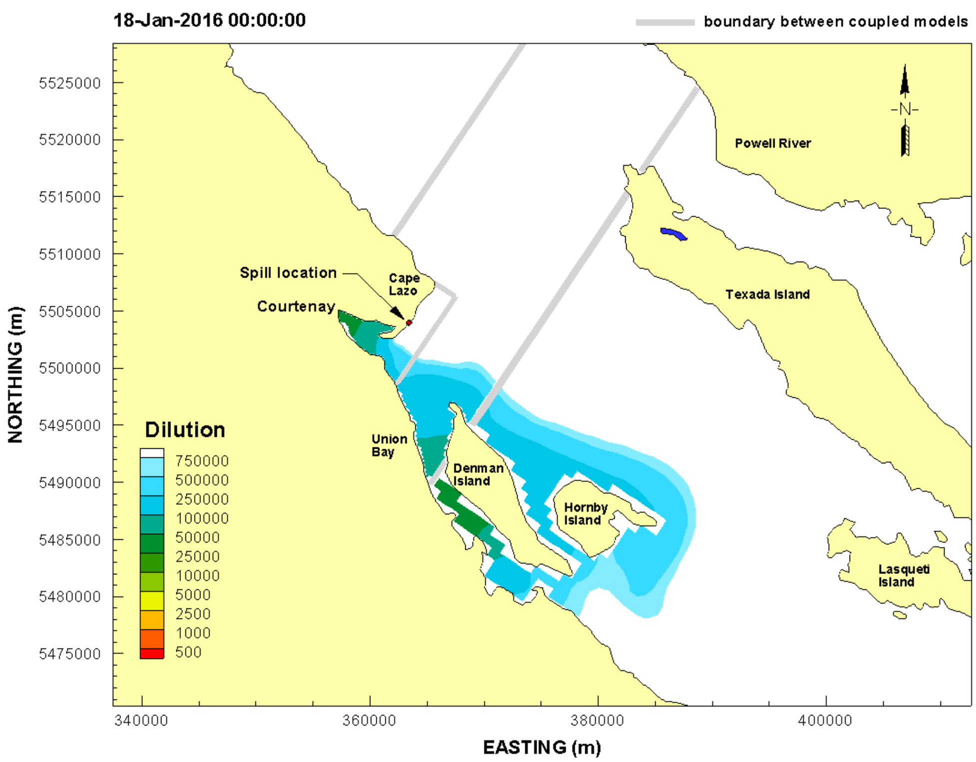

Figure 21: Run 2 – Dilution map 30 days after discharge, calm winds, low Courtenay River inflow

Figure 22 shows the effect of winter Courtenay River discharge on the effluent dispersion process under calm winds. The plot represents the extent of the effluent plume at an elevation of -2 m CGVD 30 days after the release. In this scenario, the freshwater from the Courtenay River impedes the amount of saline-effluent mixture from crossing Comox Bar. Subsequently a portion of the effluent was kept to the east of Comox Bar where the tidal currents are faster. The figure shows the freshwater input from the Courtenay River to the region resulted in greater dilution in the Courtenay River Estuary (>750,000) and the minimal dilution in Bayne Sounds is about 240,000 after 30 days. The coliform counts would still be in the range of 220 to 650 counts per 100 ml after 30 days.

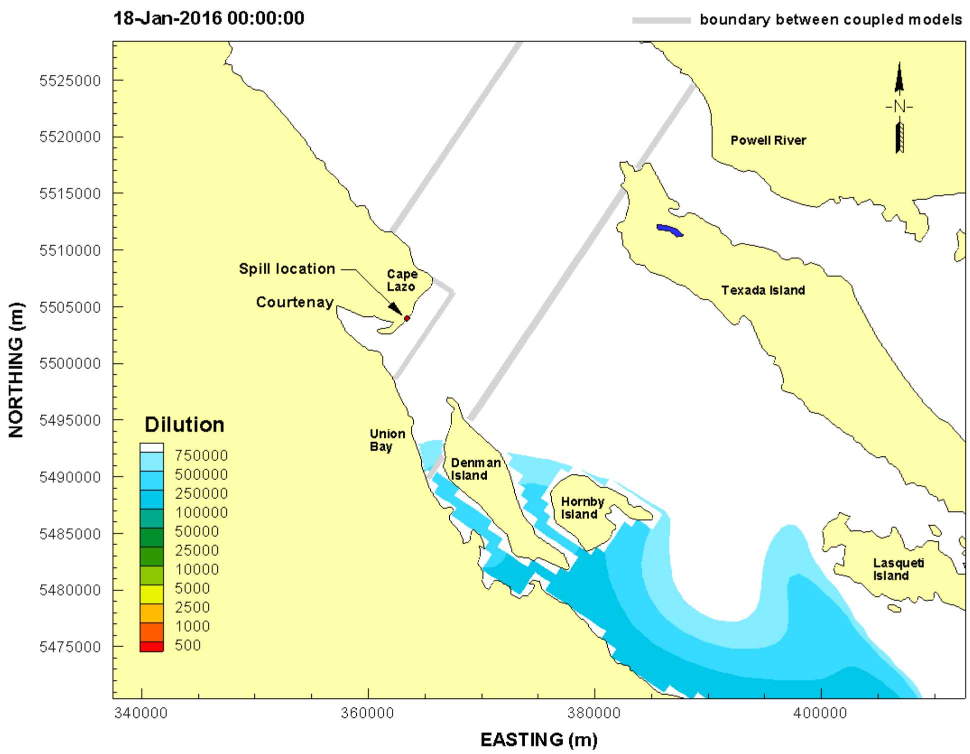

Figure 22: Run 3 – Dilution map 30 days after discharge, calm winds, typical Courtenay River inflow

As stated earlier, the contaminants were assumed to be conservative and do not decay with time. Different factors affect the growth and decay of fecal coliforms including exposure to sunlight and temperature. The cool water temperature during the winter period when the hypothetical spill event occurred would likely resulted in a die-off, resulting in lower values than predicted.

7 RISK ANALYSIS

This section combines the information on hazards from Section 7.1 and the information on consequences from Section 7.2 to assess the risks associated with the forcemain on Balmoral Beach.

7.1 Summary of Hazards

Table 11 summarizes the hazards from scour and debris impacts along the unprotected portion of the forcemain, based on the analysis of scour probabilities presented in Section 5.2.2. It is assumed that the pipe will fail if the crown becomes exposed during the winter. Therefore, entries labelled as "crown exposed" in Table 11 correspond to a failure of the forcemain. The probability scales have been defined qualitatively, but can be approximately related to annual exceedance probability (Section 5.2.2). A high probability event represents a condition that is expected to be exceeded in most years. A medium probability event represents a frequently occurring event that may be exceeded approximately 50% of the time (2-year return period). A low probability event has a probability of exceedance of approximately 10% (10-year return period).

Table 11: Probability of forcemain becoming exposed at unprotected section, Station 0+19 to 9+60

Probability	Degree of Exposure for 3 Time Periods		
	1 year	**5 years**	**10 years**
High	Depth of cover < 0.5 m	Depth of cover < 0.3 m	Crown exposed at least 1 site
Medium	Depth of cover < 0.3 m	Crown exposed	Crown exposed, several sites
Low	Crown exposed	Crown exposed, several sites	Crown exposed, several sites
Very Low	Crown exposed, several sites	Crown exposed, several sites	Crown exposed, several sites

Note: assumes no scour mitigation is carried out during the indicated time period.

Table 12 summarizes the hazard probabilities along the section of the forcemain that is covered by the gabion mattress protection. The top mattress has experienced damage by abrasion over the last 13 years and it is expected that further deterioration will occur over time. If the second underlying mattress is also damaged, there is a high probability that sections of mattress will be displaced and will directly impact the pipe during extreme storms. It is expected that this would cause the pipe to break. Therefore, entries labelled as "High impact forces on pipe" in Table 12 correspond to a failure of the forcemain.

Table 12: Probability of forcemain being damaged at protected section, Station 10+00 to 13+00

Probability	Degree of Exposure for 3 Time Periods		
	1 year	**5 years**	**10 years**
High	No significant change	Lower mattress damaged	Lower mattress damaged
Medium	No significant change	Lower mattress damaged	High impact forces on pipe
Low	Lower mattress damaged	High impact forces on pipe	High impact forces on pipe
Very Low	Lower mattress damaged	High impact forces on pipe	High impact forces on pipe

Note: assumes no mitigation is carried out during the indicated time period.

7.2 Consequence Scenarios

For preliminary planning purposes, we have prepared two scenarios (Table 13) for assessing consequences:

- Low consequence event: depth of cover reduced to minimal levels, emergency mitigation carried out, no break or discharge onto beach.
- High consequence event: forcemain breaks, wastewater discharge lasts 24 hours, effluent persists in region for at least 30 days as described in Section 6.3.

Table 13: Adopted consequence scenarios

Scenario	Consequence	Description of Scenario
Scenario 1	Low	Depth of cover reduced, repairs carried out to avoid failure
Scenario 2	High	Forcemain breaks; emergency repairs completed after24 hours

7.3 Scenario 1: Depth of Cover Reduced Below Acceptable Threshold

7.3.1 Description

In this case, it is assumed that routine monitoring surveys detect the depth of cover over the forcemain is less than 0.3 m over a length of approximately 200 m. It is also assumed that no leakage is detected. Given the likelihood of exposure in the near future, it is assumed measures are carried out to protect the forcemain. Based on Section 5.3.2, two options are considered feasible:

- Option 1: Install additional mattress with a cobble cover, similar to the 2003 design.
- Option 2: Install a temporary gravel blanket over the forcemain.

The decision on whether to use Option 1 or Option 2 would depend on the local site conditions, environmental permitting requirements and time available to complete the work.

7.3.2 Cost of Repairs

Gabion Mattress

In 2003, the cost for installing the gabion mattress averaged $1,880 per metre, for a 320 m length of protection. Accounting for inflation and allowing for a 20% contingency factor, the unit cost today is approximately $2,900 per metre. The capital cost for installing a 200-metre length of mattress protection is approximately $600,000. Additional costs may be incurred for environmental compensation requirements and maintenance. The cost represents a single application of the protection.

Beach Nourishment

Using beach nourishment to protect the forcemain is more feasible along the southern end of the beach (south of Station 6+00) where the wave energy is reduced and the general level of the beach is higher. It is unlikely this option is practical on the more exposed northern section of the beach without other structural measures to limit longshore transport. For preliminary planning, it is assumed that a gravel fill will be placed in a 20 m wide, 250 m length to an average thickness of 1 m. Preliminary costs for beach nourishment are based on recent project experience at Rathtrevor Provincial Park near Parksville. Including a 20% contingency, the cost of supplying and placing the fill is $265,000. It is assumed that the nourishment would need to be repeated every two to three years on average, and possibly after any large storm such as the March 2016 event. Therefore, in addition to the capital cost there would be an annual maintenance cost in the order of $130,000 per year. This represents the cost required for a single site.

7.4 Scenario 2: Forcemain Failure Due to Scour or Impacts

7.4.1 Description

The clean-up required for a wastewater discharge on the beach would probably involve monitoring and sampling of water and shellfish and waiting for the sewage to be diluted by the ocean. The time period for this would be in the range of several weeks. A complicating issue is the fecal contamination of the underlying sediment. Fecal bacteria survives well in sediments as it is mostly protected from UV radiation, which is what kills or deactivates it in the open water. Sediments also contain carbon, nitrogen and phosphorus, which are ingredients for the survival and growth of the fecal bacteria (Mallin et al., 2007). The fecal bacteria levels in the sediment will eventually lower as it gets stirred up when the tide comes in and when there is heavy rainfall. At each of these events, a fresh plume of fecal contamination will be released into the ocean, raising levels that may have appeared to be diluted to acceptable levels previously. Because of the propensity of the fecal bacteria to remain in the sediments, it is expected that it would take 4 to 8 weeks for the appropriate level of dilution to be reached. However, it could be longer depending on the tides, currents, wind, and amount of rainfall.

7.4.2 Effects of a Forcemain Failure

Effect on Environment

The main concerns are changes in dissolved oxygen (DO) and the associated impacts on fish and avians, acute toxicity effects caused by ammonia and elevated fecal coliform levels.

The high biochemical oxygen demand (BOD) level associated with effluent would consume DO resulting in a lower level. Salmonids, herring and other forage fish, which utilize the area, are sensitive to low DO (BC MoE, 2016). Assuming the spill occurred in winter, the most likely effects would be on juvenile and adult salmonids and forage fish (Asp and Adams, 2000). Salmonids may avoid acute physiological effects of depleted DO, however avoidance behaviour (i.e. avoiding entering areas of low DO) may obstruct the migratory pathway and impair spawning (BC MoE, 2016). Herring and other forage fish are an important part of the food web in the area as larvae provide feed for fish and invertebrates, while juveniles and adults are consumed by salmon and birds. A spill during the herring breeding period would have potentially negative effects as known herring spawning areas shown in Figure 7 occur within the predicated spill area (DFO, 2016).

In Comox Harbour and Baynes Sound adult herring aggregate in massive schools to spawn during late winter with heaviest concentrations occurring in March and lasting for approximately four weeks (Koke, 2008). Female herring produce an estimated 19,000 eggs, which are fertilized externally during extrusion and adhesion in dense masses to eelgrass, other algae and suitable substrate (Hart, 1973). Fertilized eggs incubate for 7 – 10 days before hatching into larvae, which typically remain in shallow near shore water for an additional 2 months. While adult herring spawn repeatedly for several years mortality to eggs and adults during the reproductive cycle is high as the annual concentration of food resource in and around Balmoral Beach and Goose Spit attracts an array of predators including water birds, marine mammals and fish.

Ammonia content in raw sewage as total Kjeldahl nitrogen (TKN) can be toxic to fish. Salmonids in particular are sensitive to elevated ammonia levels. Exposure to ammonia can cause erratic behaviour, convulsion, and other distress symptoms. These symptoms quickly escalate and lead to fish mortality (Haywood, 1983).

Health and Safety

The two main concerns to health and safety of the public in the case of a raw sewage discharge are:

1. Direct human contact, and
2. Consumption of contaminated shellfish.

Both concerns are related to the level of fecal coliforms in the water and sediments at the beach and in the shellfish harvesting areas. Swimming in waters with high fecal coliform levels and contact with contaminated sand on the beach can cause rashes and infections, and has been related to gastrointestinal and respiratory illness (GC, 2012). According to the BC Municipal Wastewater Regulations (MWR), when discharging sewage to recreational waters the fecal coliforms levels should be less than 200 MPN/100 mL, requiring a dilution of the raw sewage in the range of 270,000 to 800,000, depending on the initial concentration in the sewage at the time of the discharge.

Human illness associated with consumption of contaminated shellfish includes typhoid, salmonellosis, gastroenteritis, infectious hepatitis, paralytic shellfish poisoning, and amnesic shellfish poisoning (CFIA, 2016). The MWR requires that any sewage being discharged to shellfish-bearing waters should have fecal coliform levels less than 14 MPN/100 mL, requiring a dilution in the range of 3.8 million to 11.4 million based on the wastewater properties listed in Table 9. This is also the required level in order for a shellfish area to be classified as approved or conditionally approved. Any shellfish growing areas with levels exceeding 14 MPN/100 mL will be classified as restricted, conditionally restricted, or prohibited, limiting or halting any shellfish harvesting (CFIA, 2016).

Effect on Commercial Fishery and Shellfish

According to established protocols, a failure of the forcemain on Balmoral Beach would result in an emergency closure of the shellfish growing area. In an emergency closure, the boundaries of the closure and other specifications will be recommended by Environment Canada (EC) and/or the Canada Food Inspection Agency (CFIA) to the Department of Fisheries and Oceans Canada (DFO). DFO will then place the affected shellfish growing area in the closed status and specify the closure boundaries.

Closure of affected shellfish growing areas will be in place for a minimum of 7 days, at which point the situation would be reevaluated by EC and CFIA. This will generally be done through sampling of water and the shellstock.

When an emergency closure is in response to the discharge of untreated sewage, the affected area can be re-opened upon recommendation from EC and CFIA after the minimum 7 days based on representative sampling of water and shellstock or, without sampling, after 21 days following the cessation of the discharge event (CFIA, 2016).

Effect on Recreation

If a break occurred in the summer months, a number of recreational activities could be temporarily affected. The safe level of fecal coliforms in swimming waters is limited to 200 MPN/100 mL. Based on the wastewater properties listed in Table 9, dilution values of approximately 800,000 would be required to achieve a safe level. Any waters and sediments exceeding this limit would have to be closed to the public until sampling results indicate that the area is deemed safe to the public again. The extents of the closure would depend on a number of factors including wind speed, the level of discharge from Courtenay River and the state of the tides, but could extend further north than Cape Lazo, enter Comox Harbour, and extend south into Baynes Sound. The closure would be estimated to be 4 to 8 weeks but could be longer depending on how much fecal contamination is stored in the sediments and how effectively it is removed by the tides and any rainfall runoff.

7.4.3 Cost of a Failure

Forcemain Repairs

Using published data from AWWA (2007), Pure (2015) reported that the cost of a forcemain failure in the USA has typically ranged between $500,000 and $1,700,000 per failure (in US $). The equivalent costs in Canadian dollars ranges from $650,000 to $2,200,000. The cost of capital replacement was reported to average $8,750/linear metre (converted to Canadian dollars). These figures are indicative of average conditions in North America, but are not necessarily representative of local conditions near Comox. Also, the costs do not include provision for installing additional protective measures to prevent a future recurrence of the failure. Any repair of the line would require installing either of the measures prescribed in Section 7.3.2. The cost of installing new protection over the pipe was $580,000 for Option 2 (gabion mattress). Therefore, the repair cost of a single forcemain failure is expected to be in the order of $1,000,000 to $2,000,000.

Additional Economic Losses

In addition to costs for direct repair, the discharge of wastewater is likely to adversely impact the commercial herring fisheries and shellfish industries (Section 3.4). The extent of the impacts will be highly dependent on the time of year and hydro-meteorological conditions around the time of the breakage.

DFO statistical data from 2011 to 2013 for oysters, clams, and scallops (Pattern, 2016) were used to estimate the monetary value of the yearly shellfish catch in areas affected by a 24 hour discharge of wastewater from the forcemain. Table 14 summarizes the average yearly production values over a five year period. The management areas are shown on Figure 5. The extent of the affected water quality was based on the 7 day simulation described in Section 6.3.2). In addition to these affected sub-areas, Sub-areas 14(1) through 14(8) could also be impacted from the effluent plume if coliform levels persist over a duration of 30 days after a spill event.

Table 14: Average annual monetary value from 2011-2013 for oysters, clam, and scallop fisheries in areas potentially affected by a 24 hour spill

DFO Area	Oyster Value ($)	Clam Value ($)	Scallop Value ($)	Total Value ($)
14(9) to 14(15)	$680,100	$355,500	$200,900	$1,236,500

The values in the above table represent average annual production in the area that is likely to be impacted by the spill. This represents approximately 12% of the total shellfish harvest in Baynes Sound (Section 3.4). A single closure may not result in a loss of an entire year's production. However, given the uncertainties in the scale of the spill and environmental conditions at the time of the event, such as wind and precipitation, it is very difficult to determine a precise value of shellfish harvest that would be lost. However, the data demonstrate the scale of the industry in the area that would suffer negative consequences from a spill. It should be noted that Table 14 does not include production from the commercial herring or salmon fishery.

7.5 Risk Analysis

Figure 23 shows a generalized representation of the relation between hazard probability, consequence and the resulting risk. The plot represents the following situations:

- Scenarios where the hazard probability is high and the consequence of the event are high are shaded red and correspond to the highest risk.
- Scenarios where the hazard probability is low and the consequences are low are shaded green and correspond to the lowest risk.

- Various intermediate scenarios are classified as high, medium or low risk, depending on the combination of probabilities and consequences. For example, if the consequences are high, a low probability event may still result in a high overall risk.

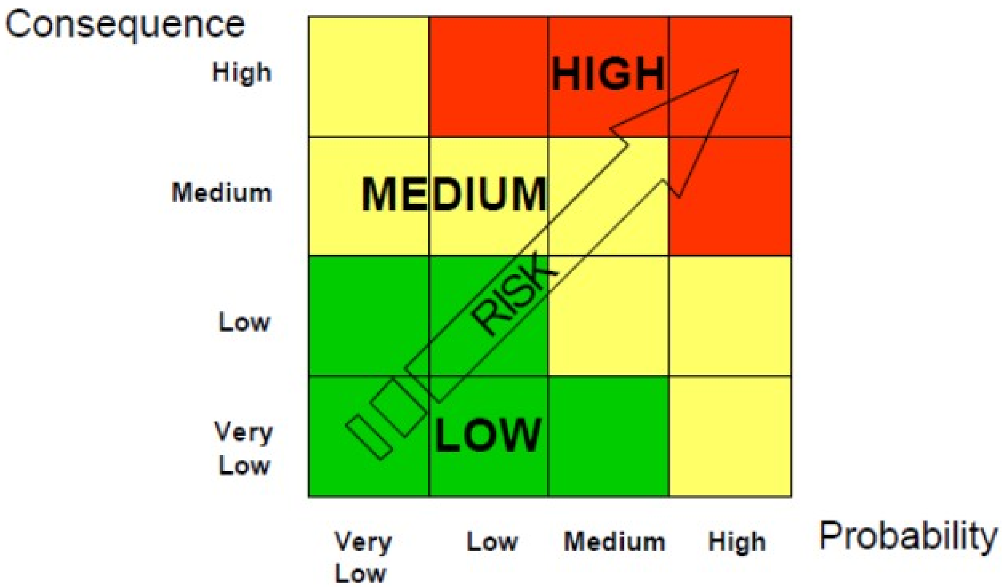

Figure 23: Comparison of consequences and hazard probability to define risks

This representation is qualitative in nature and is mainly intended to illustrate the inter-relationship of these parameters. The information on hazards and consequences described in Sections 7.1, 7.3and 7.4 provide quantitative and semi-quantitative information for evaluating the risks associated with the forcemain. Based on these results, the following conclusions have been drawn:

- There is a high probability (approximately 90%) that the depth of cover over the unprotected portion of the forcemain will be reduced to unacceptable levels (less than 0.3 m) during the next five years. Assuming emergency repairs are carried out in a timely manner this would be a low consequence event (Scenario 1), resulting in a cost of approximately $600,000 per event. It is expected that these types of events will be recurring. This situation is classified in Figure 23 as a “medium” risk.
- There is a medium probability (roughly 50 %) that a high consequence event (Scenario 2 involving a failure and a discharge on the beach lasting 24 hours) will occur at least once over the next 5 years. The approximate costs associated with this event are expected to be in the order of $2 to 3 million per event. This situation is classified in Figure 23 as a “high” risk.

- There is a low probability (approximately 10 %) that a more severe consequence event (multiple failures along the forcemain and a wastewater discharge duration lasting more than 24 hours) will occur at least once during the next five years. This situation is also classified in Figure 23 as a "high" risk situation.

This analysis assumes the present level of monitoring is continued and no additional repairs or maintenance are undertaken to mitigate the hazards. There are a number of measures that could be carried out to reduce the risks.

7.6 Risk Reduction Measures

7.6.1 Short-term

Short-term measures can be implemented to reduce the risk of a failure on the beach. These measures are listed below:

Improved Monitoring

At present, the annual beach surveys cover only the unprotected portion of the forcemain. The surveys should be expanded to include the 320 m section of the beach protected by the mattress. The survey information should be reviewed each year to assess changes in the depth of cover at critical sections. The general condition of the existing mattress should be inspected each year and reports of damage should be assessed. This should include repeat photography at selected locations and documenting any evidence of damage or displacement of the protection.

In addition to surveying a centerline profile, cross sections should be surveyed at intervals of approximately 200 m spacing along the beach. These cross sections should extend from the base of the bluffs to approximately low tide.

Prepare Emergency Response Plan

This involves developing and testing contingency plans to deal with a potential break in the forcemain in order to minimize the duration of the discharge on the beach. This would include reviewing response plans under winter storm conditions, including how to repair a breakage at night during low tides. Equipment necessary for undertaking repairs (such as portable lighting equipment, pipe collars) should be identified and obtained, if not already available. Personnel should be trained on how to deal with a spill, review communication plans to relevant affected groups and communities and develop clean up plans after the repairs are completed.

Repair of Existing Mattress

The 2016 site inspection showed that portions of the 2003 gabion mattress have been damaged. The damage was confined to the top layer of the mattress. In some sections, tears were noted in the lids of the mattress top. In some sections, the lids have been abraded to the point that some gravel fill has been lost from the top mattress. Repairs should be carried out as soon as possible. This could include adding new lids to the baskets and replacing some of the lost stone where necessary.

Ongoing Maintenance

Maintenance should be carried out to protect the forcemain when the depth of cover over the pipe is inadequate. Based on the past monitoring surveys, it would be reasonable to initiate measures when the depth of cover is less than 0.5 m. Other values may also be appropriate, depending on the level of risk that is considered acceptable.

Maintenance could include either installing an additional gabion mattress over the line or by using beach nourishment to build up the level of the beach by placing a gravel fill. These two options were described previously in Section 5.3 and preliminary costs were presented in Section 7.3.2.

The cost for installing a 200 m length of gabion mattress was estimated to be $580,000 or $2,900 per metre. The life span of the gabion mattress is approximately 15 to 20 years. The cost for installing an equivalent section of gravel fill over the forcemain was estimated to be $265,000. Due to the strong longshore transport rates, it is expected the beach fill would need to be replenished repeatedly (say every two years or after a large storm event similar to the March 2016 event).

7.6.2 Long-term Risk Reduction Measures

Lower the Forcemain

This would involve replacing the existing forcemain with a new line set well below the anticipated future scour level. The scour level is difficult to predict, particularly if the sediment supply to the beach is not restored. A preliminary estimate of the safe level is in the range of elevation -2.0 to -2.5 m. This would require setting the new line between 1.0 and 1.5 m below the existing level. Given the uncertainty in future developments along the shoreline and future climate change effects, there is still a significant risk that the line could be exposed to new hazards after a period of 20 to 30 years. Therefore, over the long term, conditions return to the present undesirable situation, with the line being exposed to a high risk of failure.

Re-locate the Forcemain

Relocating the forcemain off the beach would be the most effective method for reducing the risk of a failure. This alternative was recommended in NHC (2003).

8 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are preliminary since some of the environmental effects investigations are still underway. This section will be updated when the information comes available.

8.1 Conclusions

There is a high probability that maintenance will be required in the next 5 years (period ending in 2020) to prevent a failure of the forcemain.

There is a medium probability (approximately 50 %) that a failure could occur at least once during the next five years, resulting in a discharge onto the beach lasting 24 hours. This assumes that that monitoring and maintenance operations are not upgraded.

There is a low probability (approximately 10 %) that multiple failures, with a discharge duration exceeding 24 hours could occur at least once during the next five years. This assumes that that monitoring and maintenance operations are not upgraded.

The northern section of Balmoral Beach lowered by up to 1.5 m between 1982 and 2003, which exposed portions of the forcemain. Emergency measures were implemented in 2003 over a 320 m length of beach (between Station 10+15 to 13+35) by placing a gabion mattress over exposed portions of the forcemain. The forcemain would have failed either from undermining or debris impacts without this emergency work.

The monitoring surveys indicate that beach lowering has continued to occur towards the south end of Balmoral Beach. It is believed that this general lowering reflects a reduction in sediment supply from the Willemar Bluffs.

The most likely timing for a failure of the forcemain is during winter storms that coincide with high tides and storm surges. Under these conditions, emergency repairs to the forcemain would probably need to occur at night during low tides. It was assumed that the discharge of wastewater on the beach could last 24 hours before repairs were carried out.

Water quality modelling using the program Delft-3D showed the spatial extent of the plume from a discharge of wastewater on Balmoral Beach will depend on the local tides, winds and freshwater outflow from the Courtenay River. The worst situation occurs during times of lower tidal amplitude, low river outflow and calm winds. Under these conditions the spill could potentially affect a wide area, including Comox Harbour, the estuary, portions of Baynes Sound, Cape Lazo and Comox Bar.

It is expected that a failure of the forcemain would adversely affect the environment, commercial fisheries and shellfish industries in the surrounding area.

8.2 Recommendations

A pipeline conditions assessment should be carried out to complement the results of this study. Depending on the outcome, the assumptions made in this study may have to be revised, which could modify the study's findings.

In order to reduce the risk of failure, plans should be initiated to re-locate the forcemain off the beach as soon as possible. This recommendation was made previously in NHC (2003).

Another alternative to reduce risks would be to re-build the forcemain on the beach, below the anticipated future scour level. However, given the uncertainties in future developments along the beach and the uncertainties in future environmental conditions, the risk of exposure could increase over time.

Until a long-term solution is achieved, additional monitoring and inspections should be carried out along the forcemain. This should include inspecting the condition of the mattress and extending the topographic surveys over the length of the mattress. Details are described in Section 5.3.

Emergency plans should be reviewed and updated to conduct emergency repairs on the beach in the event of a break. The emergency plans should assume that a break is most likely to occur during a winter storm and that the work would need to be carried out at night time.

The top layer of the existing mattress has experienced damage and should be repaired. It would be relatively simple to replace the lids of the damaged mattress to prevent the loss of stone.

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APPENDIX A: HYDRODYNAMIC MODEL RESULTS

1 MODEL DEVELOPMENT

The model grid covers the northern Strait of Georgia (Figure A- 1) and extends from Campbell River at the north boundary to Ballenas Islands at the south boundary. The model consists of three 2-way coupled curvilinear domains with progressively fining resolution, with the finest grid resolution in the vicinity of the Balmoral Beach, where it is 100 m. In the vertical direction, the model grid consists of 20 fixed z-layers that are thinner near the surface (top 2 m) and thicker at depth. The difference in horizontal and vertical geometry is required because of the large aspect ratio characterizing the marine environment, and because much of the variability (density stratification, vertical shear in horizontal flow) is concentrated near the surface, which requires a finer vertical resolution. The bathymetry for the model is derived using datasets from CHS hydrographic charts.

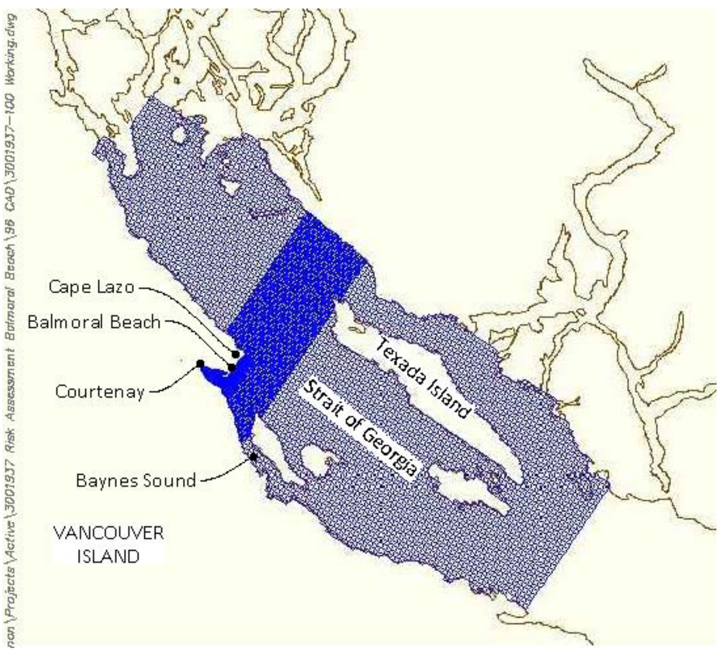


Figure A- 1: Coarse model grid of the northern Strait of Georgia and fine grid near the Balmoral Beach.

It is expected that the pipe rupture event would occur during the winter months. Freshwater runoff from the Fraser River (the most significant freshwater source in the model domain) is mostly confined to a region well south of Texada and Lasqueti Islands during winter. The overall range of salinity is consistently small in winter within northern Strait of Georgia and near uniform salinity conditions always prevail (Thomson 1981); therefore the initial salinity value of 31 psu was applied for all grid cells.

1.1 Boundary Conditions

Tides are simulated with amplitudes and phases of locally dominant tidal constituents along the open ocean boundaries (Ballenas Island and Campbell River). Two months of predicted hourly tidal elevations at Comox Harbour are shown in Figure A- 2, illustrating the daily and biweekly tidal variability.

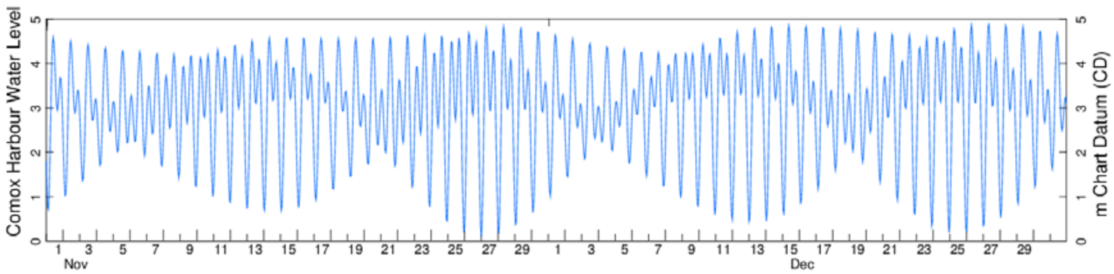


Figure A- 2: Predicted tides at Comox Harbour from November 1 to December 31, 2015.

In addition to tidal forcing, wind forcing can be a dominant factor affecting current circulation within the surface layer of the water. As a rough rule of thumb, maximum speed of surface water under a steady wind along the strait is about 3% of the wind speed (Thomson 1981). Model simulations were made initially assuming no winds. Later on, a southeast wind was applied over the ocean, with the speed varying between 10 and 15 m/s.

River runoff can be a major factor affecting current circulation at the mouths of major rivers. Most of the freshwater inflow in the study area comes from the Courtenay River, which is located approximately 6 km west of Balmoral Beach. The mean discharge for the Courtenay River is approximately 52.6 m^3/s (MELP 1996). This flow was used to set the upstream discharge boundary in the estuary.

1.2 Wastewater Properties

Water quality parameters from the Balmoral Wastewater Treatment plant are summarized in Table A- 1.

Table A- 1: Wastewater Properties

Parameter	Mean	Minimum	Maximum
Temp (C)	17.3	10.7	23.5
pH	7.6	7.1	8.0
BOD (mg/l)	228.9	145	454
TSS (mg/l)	213	42	726
TKN (mg/l)	47.6	37.1	164
Alkalinity (mg/l)	298	111	505
Fecal Coliform	53,400,300	2400	>160,000,000
E-Coli	27,311,500	230,000	>160,000,000

2 MODEL VALIDATION

The Balmoral Beach model was first validated against water level at Comox Harbour. Predicted water levels based on tidal constituents and modelled hourly water levels from December 2015 at Comox Harbour are compared in Figure A- 3. Results indicate good agreement between predicted and modelled water levels. The tidal range variability from spring to neap tidal cycles and the daily high and low water level elevations are well reproduced. The maximum root-mean-squared error (RMS) values between observed and predicted water levels is 0.17 m and compared to mean tidal range of 3.4 m at Comox Harbour, these errors are within 5%.

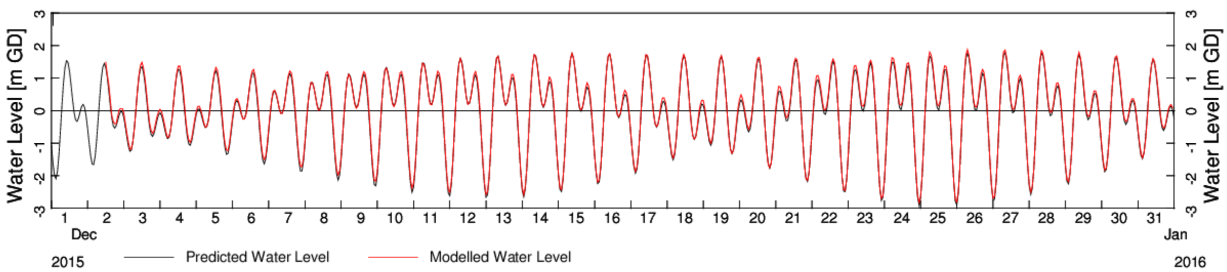


Figure A- 3: Comparison between predicted (black line) and modelled (red line) water levels.

In addition to the water level comparison, the Balmoral Beach model result was validated against tidal current maps published in Juan de Fuca Strait to Strait of Georgia Current Atlas (JDEF/SOG Current Atlas).

Figure A- 4 and Figure A- 5 show the surface current distribution during flood tide two hours before turning to ebb from JDEF/SOG Current Atlas and from the Balmoral Beach Model respectively. The model reproduced the weak northerly flood current in most of the northern Strait of Georgia and the southerly flood current from the Discovery Passage. In the vicinity of the study area, the model shows that during the flood tide surface current flows westerly across Comox Bar, and with a portion of the flow heads northward into Comox Harbour and the rest heads southward into Baynes Sound. This pattern matches the flood tide circulation (left panel on Figure A- 8) information from the Oceanographic Characteristic of Comox Harbour and Approaches in Relation to Sea Disposal of Sewage - Fisheries Research Board of Canada, 1962.

Figure A- 6 and Figure A- 7 show the surface current distribution during ebb tide two hours before turning to flood from JDEF/SOG Current Atlas and from the Balmoral Beach Model respectively. The model reproduced the weak southerly ebb current in most of the northern Strait of Georgia and the northerly ebb current near the Discovery Passage. In the vicinity of the study area, the model shows that during the ebb tide surface current flows eastward across Comox Bar, and southward into Baynes Sound. This is also similar to the circulation pattern (right panel on Figure A- 8) presented in Oceanographic Characteristic of Comox Harbour and Approaches in Relation to Sea Disposal of Sewage - Fisheries Research Board of Canada, 1962.

The results show that the model is capable of reproducing water levels and reproducing similar velocity magnitude and pattern against JDEF/SOG Current Atlas.

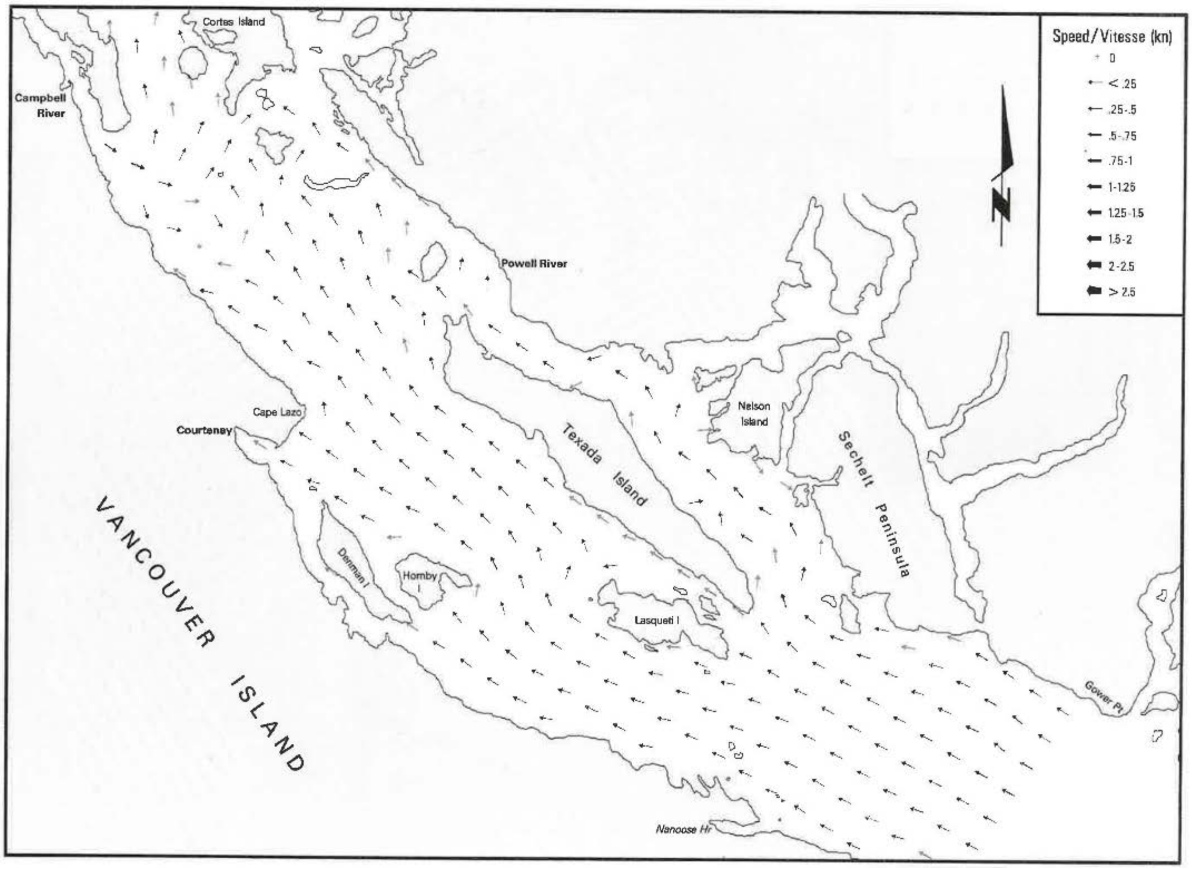


Figure A- 4: Two hours before turn to ebb – reproduced from JDEF/SOG Current Atlas Page 6.

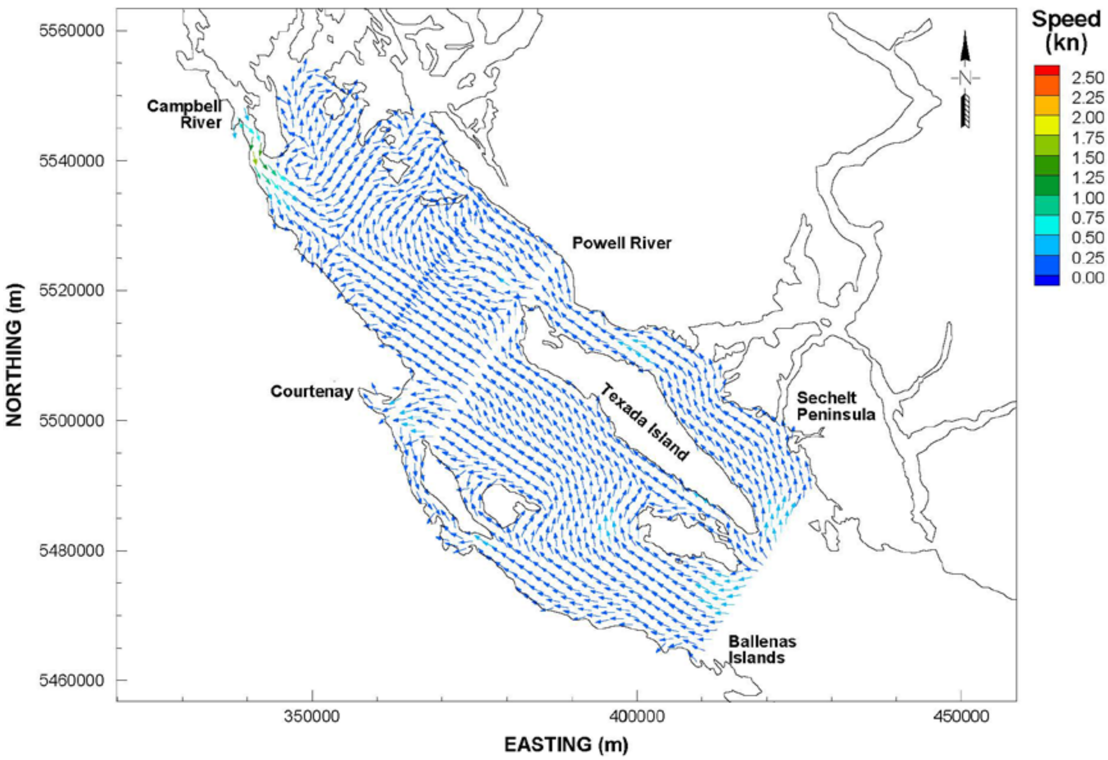


Figure A- 5: Two hours before turn to ebb – Balmoral Beach Model.

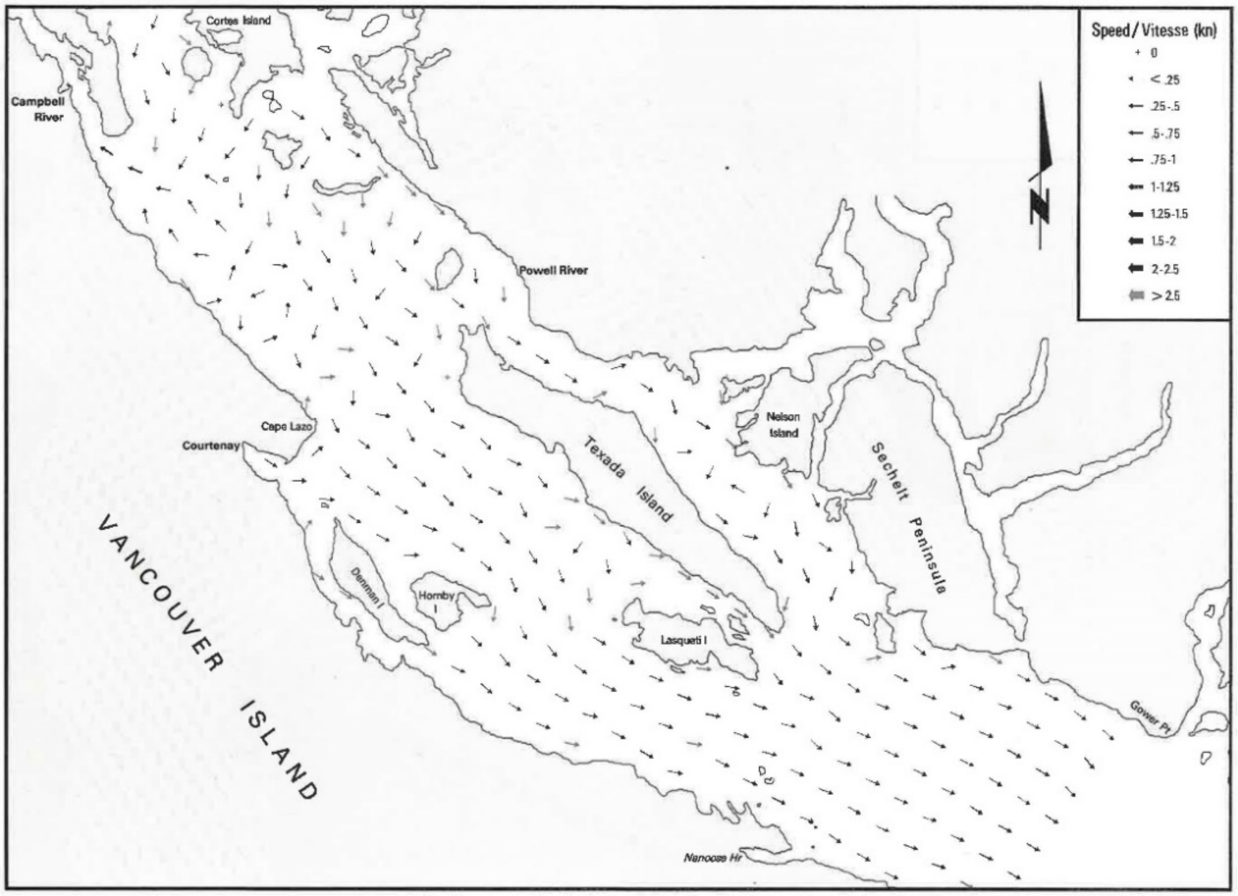


Figure A- 6: Two hours before turn to flood – reproduced from JDEF/SOG Current Atlas Page 27.

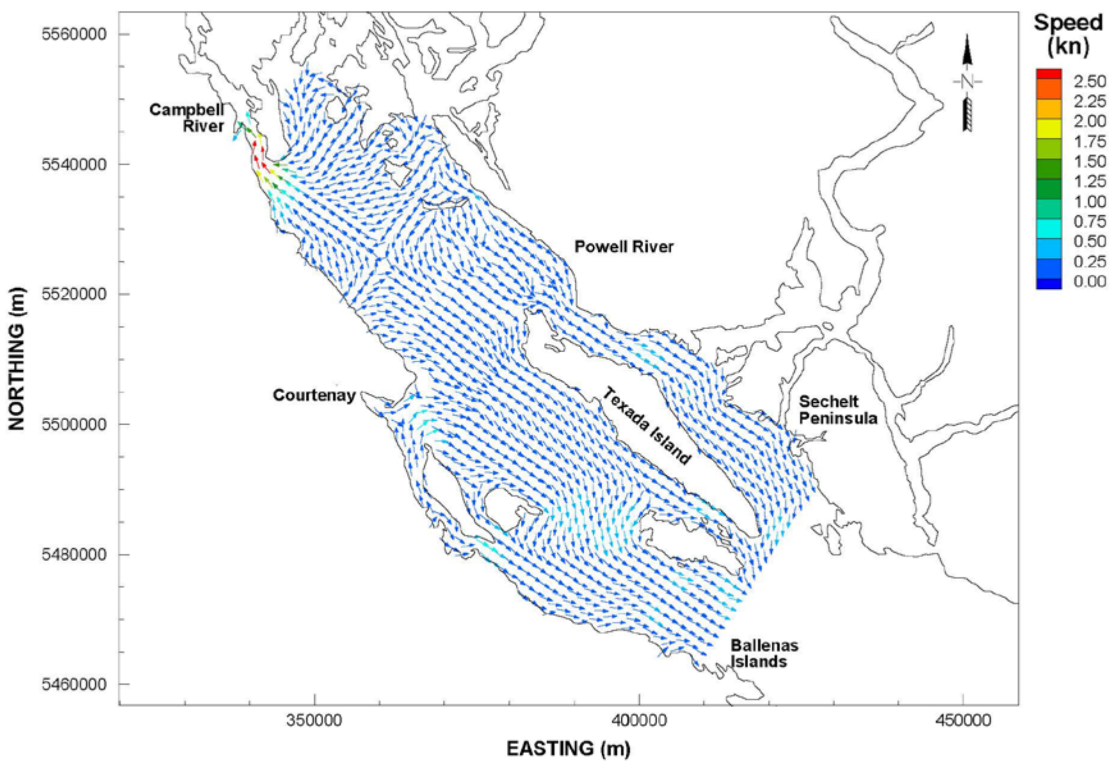
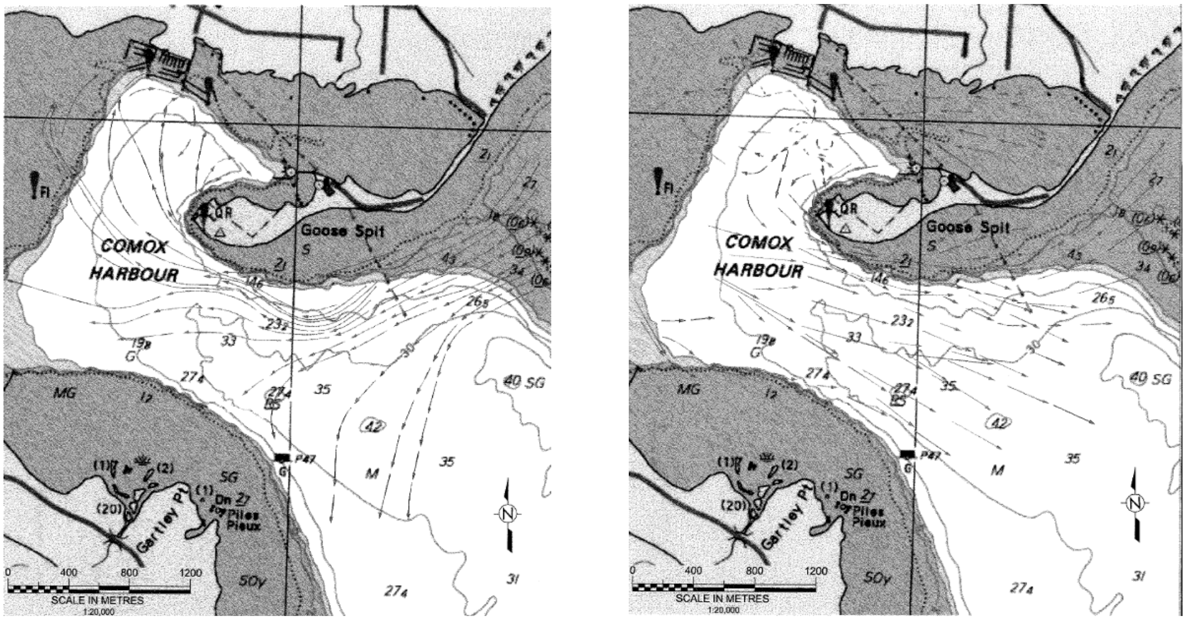


Figure A- 7: Two hours before turn to flood – Balmoral Beach Model.



Flood tides | Ebb tides

Circulation information adapted from Oceanographic Characteristics of Comox Harbour and Approaches in Relation to Sea Disposal of Sewage – Fisheries Research Board of Canada (1962)

Figure A- 8: Surface circulation during flood and ebb tides (Komex Environmental & Water Resource Engineering 2004).

3 MODEL RESULTS

3.1 Model Runs

Five scenarios (Table A- 2) were conducted to assess the dispersion and dilution of the effluent and the extent of the impact zone in the event of a pipe rupture under a range of environmental conditions.

Table A- 2: Modelled Scenarios

Run	Tide	Wind	Courtenay R. (m^3/s)
1	Spring	Calm	0
2	Neap	Calm	0
3	Neap	Calm	52
4	Neap	Southeasterly, varying between 10 and 15 m/s)	0
5	Neap	Southeasterly, varying between 10 and 15 m/s)	52

The initial concentration of the wastewater discharged from the pipe is prescribed to be 1.0, with a background concentration of 0.0 in the ocean. The actual concentration of any contaminant can be computed from the model results by multiplying the model prediction by the actual concentration discharged from the plant (Table A- 1).

3.2 Run 1: Spring Tide and Calm Winds

This run represents the case of a large tidal range, with no significant wind effects or freshwater river inflows. Time series of the water level and effluent discharge history modelled are shown in Figure A- 9. Effluent dilution maps at -2 m GD 12 hours, 24 hours, 2 days and 4 days after the initial discharge are shown in Figure A- 10.

Nearshore tidal currents during the discharge are relatively small, with maximum speeds reaching 0.25 m/s. Tidal currents further offshore by Comox Bar are stronger with maximum speeds reaching 0.5 m/s. During the flood tide surface current flows westerly across Comox Bar, and with a portion of the flow heads northward into Comox Harbour and the rest heads southward into Baynes Sound. During the ebb tide, this pattern reverses and the surface current generally flows eastward across Comox Bar, and southward into Baynes Sound. As a result, the plume of effluent remains relatively close to the shoreline between Cape Lazo and Comox harbour. After 24 hours from the start of the discharge the effluent is diluted by a factor of 100 to 500 within a zone extending approximately 2 km from the shoreline. The effluent plume is deflected into the estuary of the Courtenay River 48 hours after the discharge.

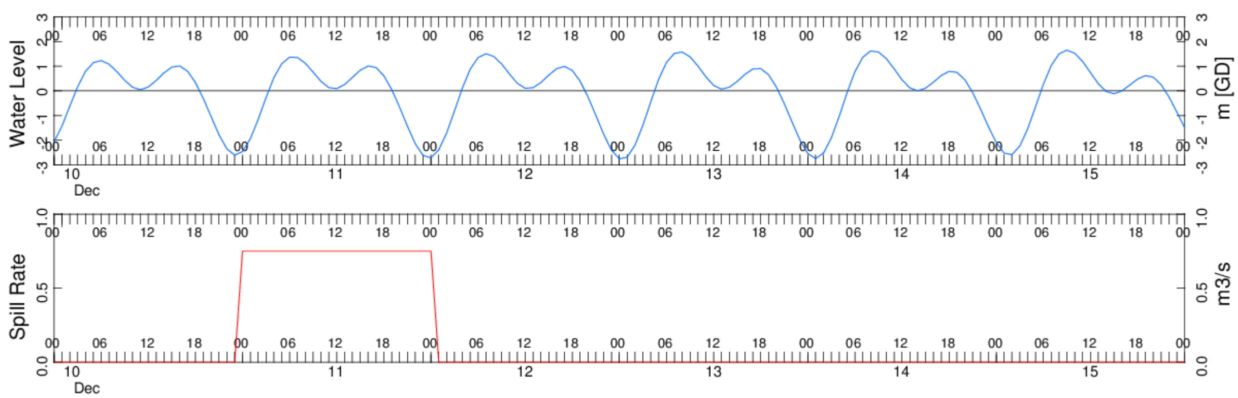


Figure A- 9: Run 1 – Water level and discharge history time series.

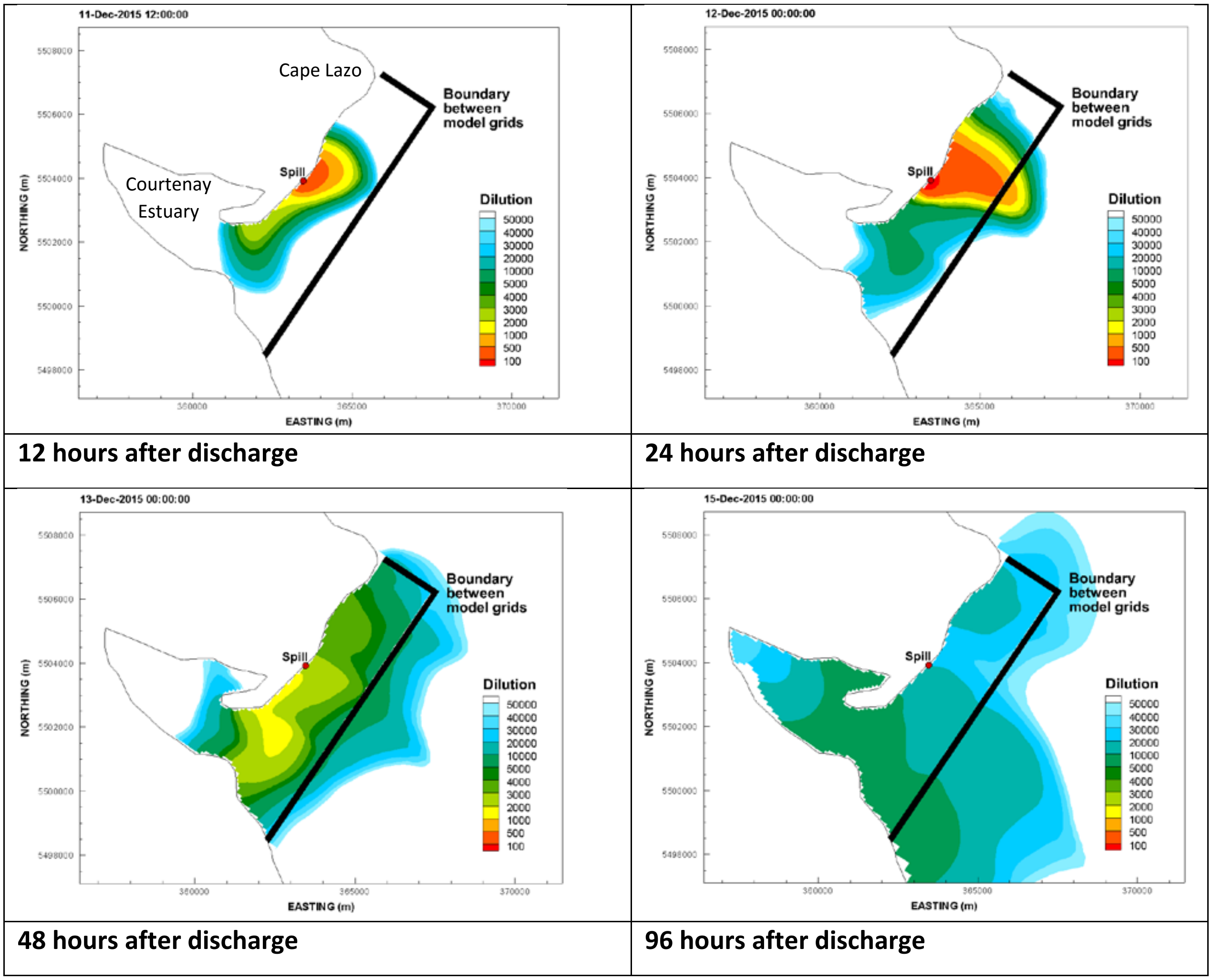


Figure A- 10: Run 1 – Dilution maps for effluent discharged into Strait of Georgia.

3.3 Run 2: Neap Tide and Calm Winds

This simulation represents the case of a discharge during a relatively small tidal range with no effect from winds or significant freshwater inflows from the Courtenay River. Time series of the water level and effluent discharge history modelled for Run 2 are shown in Figure A- 11. Effluent dilution maps at -2 m GD 12 hours, 24 hours, 2 days and 4 days after the initial discharge are shown in Figure A- 12. After 24 hours, the discharge from the forcemain will be diluted by a factor of between 100 and 500 along most of Balmoral Beach. Dilution rates inside the Courtenay estuary-Comox harbour were in the range of 4000 to 5000 after 48 hours. At this time, the plume extends over a 2 km wide, 8 km long band that covers the tip of Cape Lazo to the northern end of Baynes Sound. Figure A- 13 shows the extent of the plume after 96 hours at an expanded spatial scale and using a larger dilution scale. This plot shows that the effluent would be diluted by a factor of approximately 100,000 at the north end of Baynes Sound. Based on the data from Table A- 1, coliform counts would still be in the range of 300 to 1600.

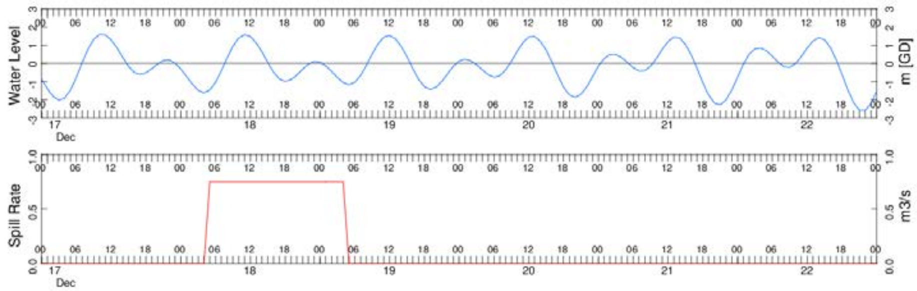


Figure A- 11: Run 2 – Water level and discharge history time series.

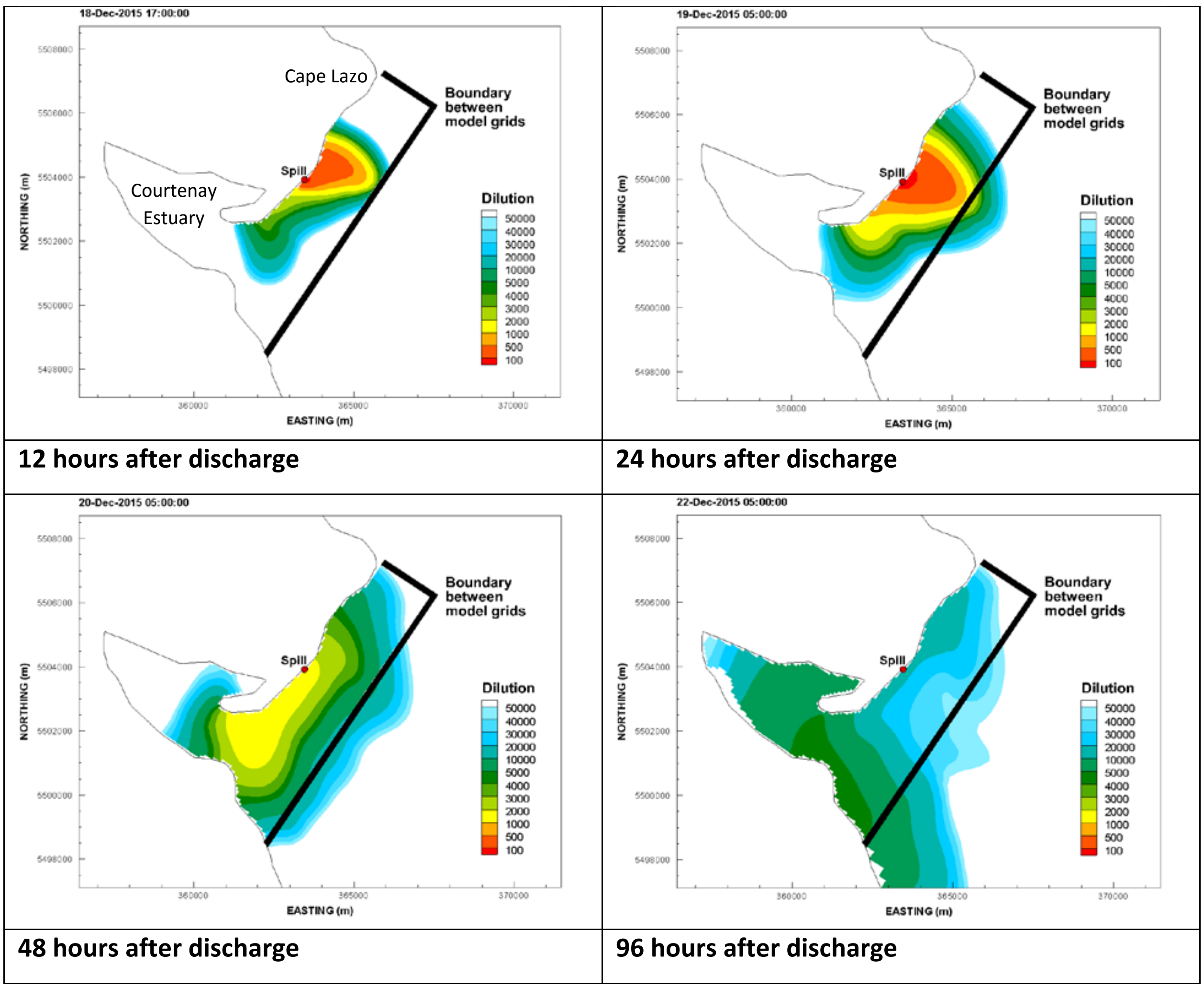


Figure A- 12: Run 2 – Dilution maps for effluent discharged into Strait of Georgia.

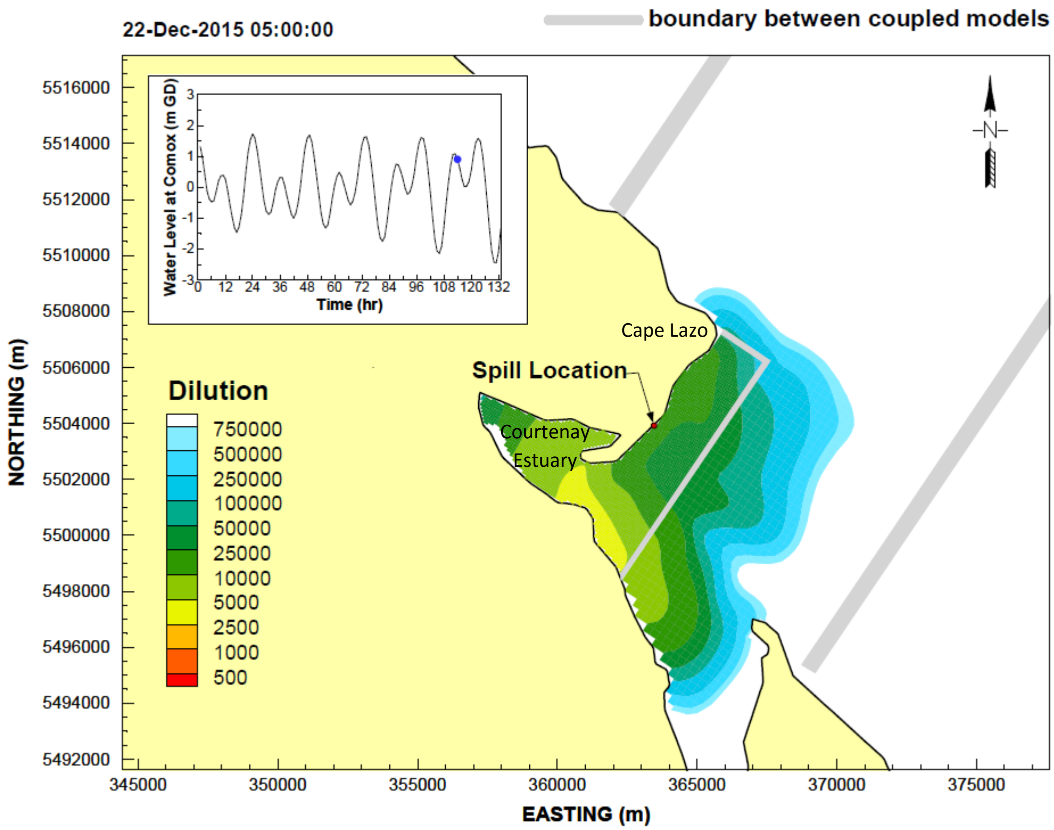


Figure A- 13: Run 2 – Dilution map 96 hours after discharge, expanded scale.

3.4 Run 3: Neap Tide with Courtenay River Inflow and Calm Winds

This run represents the same tidal conditions as Run 2 but with a constant inflow of fresh water from the Courtenay River. The effect of winds was not accounted for. Effluent dilution maps at -2 m GD 12 hours, 24 hours, 2 days and 4 days after the initial discharge are shown in Figure A- 14.

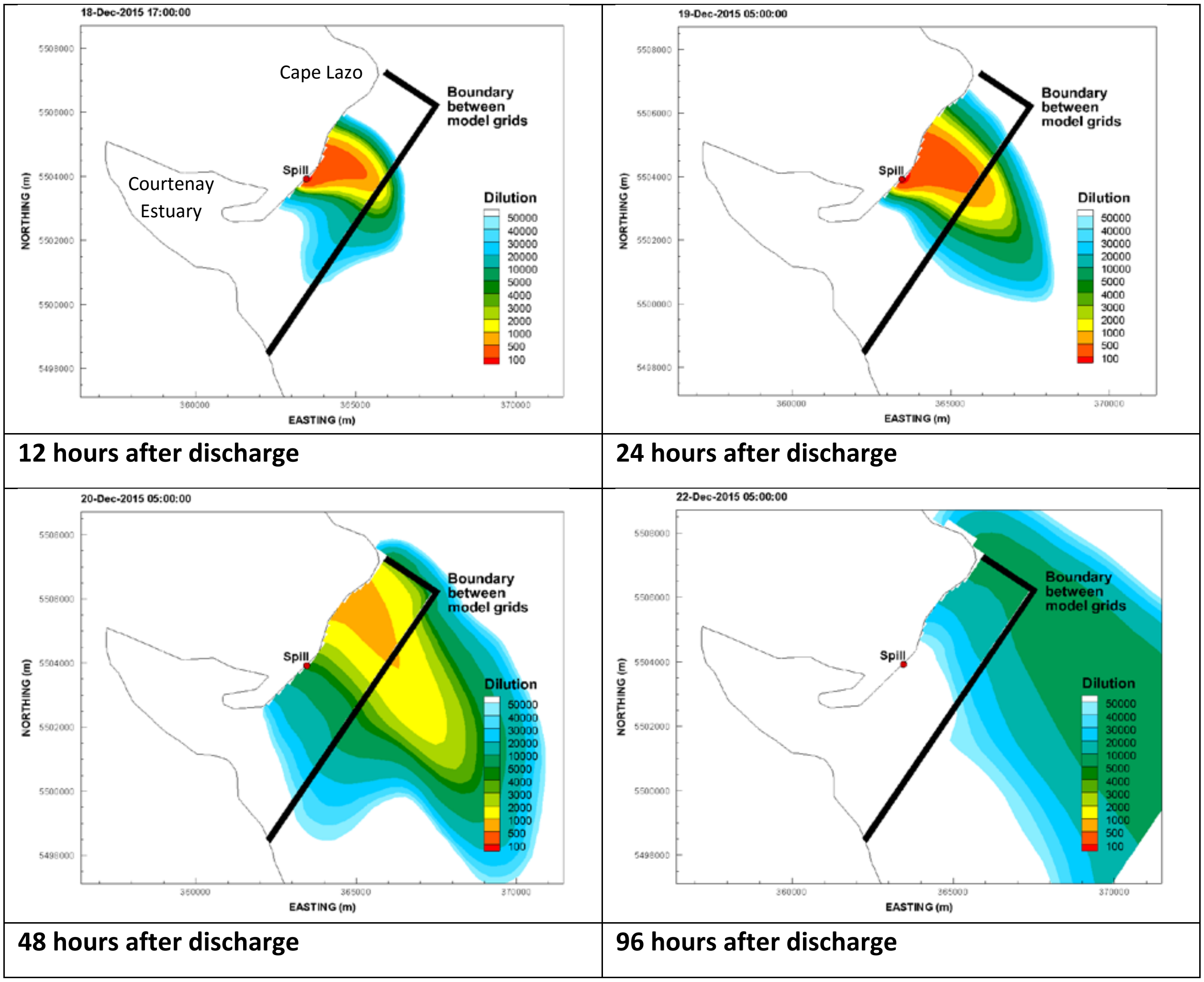


Figure A- 14: Run 3 – Dilution maps for effluent discharged into Strait of Georgia.

The flow from the Courtenay River tends to keep the plume from entering the estuary and deflects it towards the north, increasing effluent concentrations near Cape Lazo in comparison to Run 2.

3.5 Run 4: Neap Tide with Southeasterly Wind

This simulation is the same as in Run 2 but includes superimposing a southeasterly wind field over the model domain. The freshwater inflow from the Courtenay River during the event was assumed to be negligible. Time series of the water level, discharge history and wind climate modelled for Run 4 are shown in Figure A- 15.

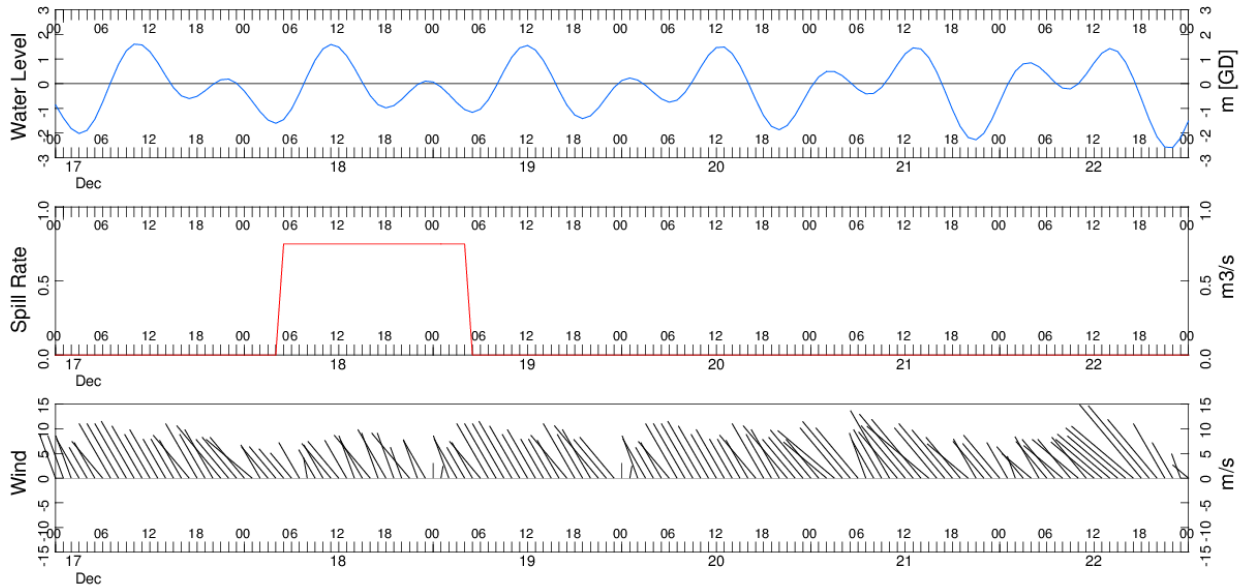
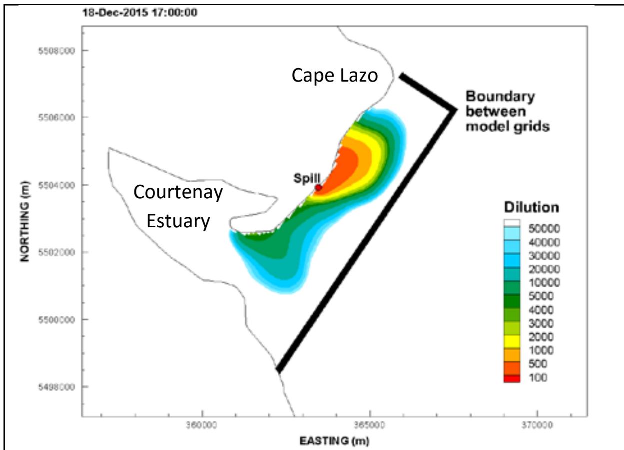
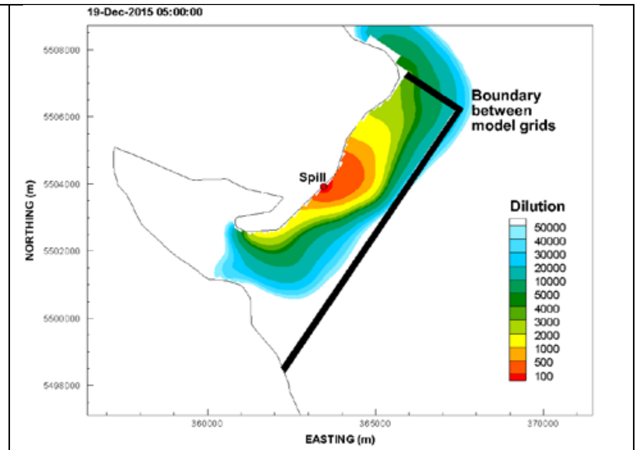


Figure A- 15: Run 4 – Water level, discharge history and wind time series.

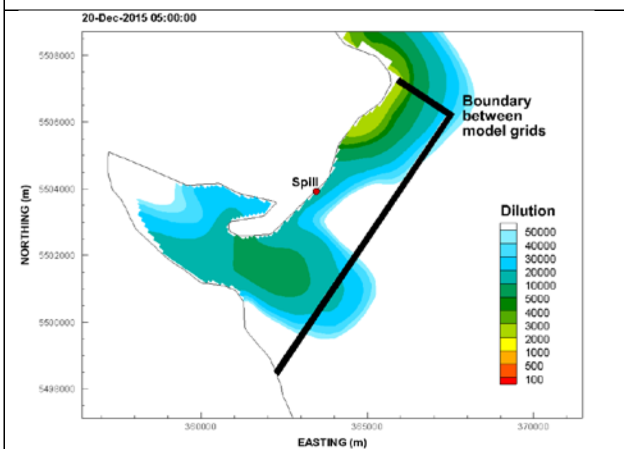
Effluent dilution maps at -2 m GD 12 hours, 24 hours, 2 days and 4 days after the initial discharge are shown in Figure A- 16. The southeasterly winds have a significant influence on the dispersal path of the plume, forcing it towards Goose Spit and into Comox Harbour and the estuary. After 24 hours, the dilution rate offshore from Balmoral Beach remained between 100 and 500. After 48 hours, dilution rates remained between 2000 and 3000 at the northern end of the beach and near Cape Lazo and were between 5000 and 10,000 inside Comox Harbour. Unlike Run 2, the plume did not extend significantly into Baynes Sound.



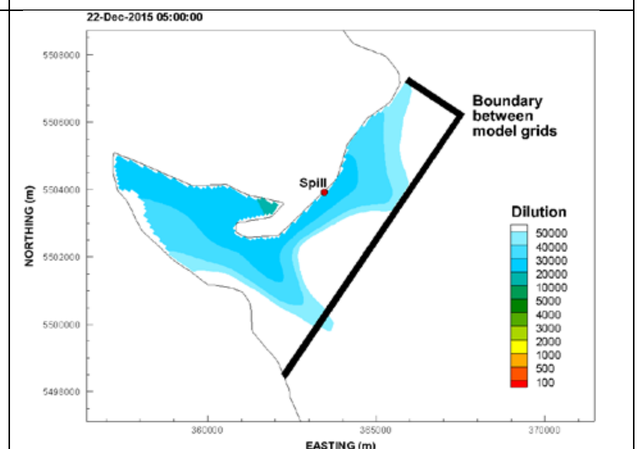
12 hours after discharge



24 hours after discharge



48 hours after discharge



96 hours after discharge

Figure A- 16: Run 4 – dilution maps for effluent discharged into Strait of Georgia.

3.6 Discussion of Model Results

The model simulations show that the dispersal pattern of the plume from a relatively short-term discharge (24 hour duration) will be governed by the magnitude of the tidal currents, winds and freshwater inflows during the event. Dilution is reduced when the daily tidal range is small (neap tide conditions). This is because the smaller tidal range results in lower tidal currents and lower dispersion rates of the effluent plume. Consequently, a rupture of the forcemain during a neap tide is expected to have greater dispersion, a greater effect in Comox harbour and greater effect in the north end of Baynes Sound than spring tide conditions.

Freshwater outflows from the Courtenay River will push the plume northwards, maintaining its extent off Balmoral Beach and Cape Lazo, but reducing its excursion into Comox Harbour and Baynes Sound. Southeasterly winds will push the plume around Goose Spit into Comox Harbour.

APPENDIX B: COMPARISON OF NHC WORK PLAN TO ISO 31000 RISK MANAGEMENT STANDARD

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nhc
northwest hydraulic consultants

NHC Ref. No. 3001937

22 August 2016

Comox Valley Regional District
600 Comox Road
Courtenay, BC
V9N 3P6

Attention: **Marc Rutten, P.Eng.**
General Manager of Engineering Services Branch

Copy to:

Via email: mrutten@comoxvalleyrd.ca

Re: **Coastal Engineering Services - Risk Assessment of CVRD Forcemain on Balmoral Beach**
Comparison of NHC Work Plan to ISO 31000 Risk Management Standard
Summary Letter

Dear Mr. Rutten

Northwest Hydraulic Consultants Ltd. (NHC) is pleased to provide this summary of NHC's comparison of the proposed work plan for coastal engineering services to assess the risk of scour and erosion causing a failure to the Comox Valley Regional District (CVRD) existing sewer forcemain on Balmoral Beach to the ISO 31000 Risk Management Standard[1]. This document outlines where the work plan conforms to the standard, and where it deviates. The project background and the scope of work were provided in NHC's proposal submitted by Dave McLean (NHC) to you on April 28, 2016[2].

1 ISO 31000 RISK MANAGEMENT STANDARD

The ISO 31000 Risk Management Standard[1], referred to herein as 'the Standard,' outlines key principles and guidelines that can be applied to a variety of activities for effective risk management. The Standard provides a systematic approach to managing any type of risk and is not specific to a particular industry, association or type of project. The Standard defines risk as: "effect of uncertainty on objectives", which is typically described in terms of consequences of an event and likelihood of occurrence.

[1] ISO 31000:2009. "Risk Management – Principles and Guidelines" International Standard, ISO 31000:2009(E). International Organization for Standardization. Prepared by ISO Technical Management Board Working Group on risk management. First Edition. 2009-11-15.
[2] Northwest Hydraulic Consultants Ltd., 2016. "Risk Assessment, CVRD Sewer Forcemain along Balmoral Beach Proposal". April 28, 2016.

The approach is structured according to principles, framework and process. The principles outlined in the Standard declare that risk management should: create value, be part of organizational processes and decision making, clearly address uncertainty, be systematic, structured and timely, be based on the best available information, be adapted to the specific context, account for human and cultural factors, be transparent and inclusive, have appropriate and timely involvement of stakeholders and decision makers, be responsive to change, and facilitate continual improvement.

The risk management framework aligns the risk management activities with the principles and is comprised of the design of the framework for managing risk, implementation of the risk management process, monitoring and review of the framework, and the continual improvement of the framework. The framework is intended to establish the risk management policy, accountability, communication and reporting mechanisms, and how risk management integrates into the project activities. Planning and commitment to risk management is a vital component of the framework.

The key activities included within the risk management process as outlined in the Standard are:

- Communication and consultation during all stages of the risk management process.
- Establishing the objectives and scope, and defining the parameters and risk criteria.
- Risk assessment, which is the process of risk identification, risk analysis and risk evaluation.
- Risk treatment, which is the selection and implementation of alternative(s) for modifying risks.
- Monitoring and review.

Documentation is also an important component of the risk management process.

The ISO 31000 Risk Management Standard has been adapted and applied to coastal zone management in Australia (Rollason et al, 2010). [3] Many of the same general principles can be applied to assessing risks of a forcemain failure on Balmoral Beach. Rollason et al (2010) found that application of the Standard helped to prioritize the risk treatment and gain acceptance when a risk treatment may not be required.

2 COMPARISON OF WORK PLAN TO ISO 31000 RISK MANAGEMENT PROCESS

2.1 Communication and Consultation

NHC's management principles include establishing and upholding effective communications amongst all staff members, our sub-consultants and our clients, maintaining close liaison with the client during execution of the project and after submission of deliverables, and maintaining an appropriate level of documentation and records pursuant to the engineering profession.

The NHC / Current Environmental team will draw on the combined experience of the two firms and collaborate closely with CVRD to provide a thorough and practical approach to completing the study. We feel working closely with CVRD through all phases of the risk management process will be critical to

[3] Rollason, V., G. Fisk, and P. Haines. "Applying the ISO 31000 Risk Assessment Framework to Coastal Zone Management." Proceedings of the 19th NSW Coastal Conference. New South Wales, Australia. 2010.

the overall success of the project. It is vital that stakeholders and those accountable for implementing the risk management process have a clear understanding of the reasons for required actions.

The work plan includes various communication and reporting activities such as:

- A kick-off meeting with CVRD staff as part of the site inspection to clarify the scope of work and study objectives, and review the schedule and available information that can be provided to support the study. In terms of the recommended guidelines in the Standard, this is an initial step toward ensuring that the interests of stakeholders are understood and considered.
- The letter herein, which summarizes the comparison of the work plan to the Standard, to review and communicate the framework of the risk assessment and identify improvements to the framework.
- A presentation of the interim study results to provide the CVRD with a preliminary summary of potential risks, causes, consequences, and preventative measures, and provides CVRD the opportunity to comment and provide input to the study.
- A draft report to summarize the technical information and recommendations to the CVRD for review and comments.
- A final report that addresses the CVRD's review comments.
- A final presentation to the CVRD that summarizes NHC's analysis and the key findings.

NHC's policies and procedures for communication and consultation is in compliance with the recommendations for recording the risk management process that is provided in Section 5.2 of ISO 31000:2009(E).

2.2 Establishing the Context

Establishing the context involves outlining the objectives and scope, and defining the parameters and risk criteria. The overall objective is to assess the likelihood and consequence of failure of the sewer forcemain at Balmoral beach due to erosion and/or impact caused by natural coastal processes. The specific objectives of the study include:

- Estimate the rate of erosion over the forcemain due to long-term degradation or beach lowering.
- Provide an indication of the likelihood that the forcemain will rupture due to scour during storm events.
- Provide an indication of the likelihood that impacts from debris during storm events could damage exposed sections of the forcemain.
- Predict the extent of effluent dispersion in the event the forcemain ruptures and the associated clean-up costs.
- Develop recommendations for maintenance and inspection practices.
- Provide technical input to assist in defining the emergency response plans in the event of failure.

The scope has been outlined in the work plan and will be reviewed and refined based on a preliminary assessment of available information, the site visit, the kick-off meeting with CVRD staff, and this comparison to the ISO 31000 Standard. The extent of the study area will be established and the key coastal processes, which are both specific to the area and generate risk, will be identified. In addition, the economic (eg. coastline development, commercial shellfish industry), social (eg. recreational demand), ecological (eg. fish and wildlife), and other values associated with the study area will be identified. The predicted consequences of failure of the forcemain will be identified using numerical modelling to estimate the extent of effluent dispersion in the event that the forcemain ruptures, and estimation of the associated clean-up costs. The consequence analysis will consider whether the impacts are likely reversible or irreversible, long-term or short-term.

A key preliminary task that will be required for the risk assessment to conform to the Standard will be to define the risk criteria or metrics that will be used to evaluate the significance of risk. The risk criteria should reflect the objectives of the risk assessment, the available information and resources, and the economic, social, ecological, and other values relevant to the study. This allows for both technical and non-technical criteria to be included in the analysis and will facilitate setting priorities for risk treatment. The risk criteria scale will relate to how significant each risk is in terms of likelihood (hazard probability from very low to high), and consequence (from very low to severe) as shown in Figure 2.1. The risk will be rated according to timeframes of 1 year, 5 years, and 10 years. The consequences will be based on actions such as: no action, repairs, emergency response within 24 hours, and emergency response within 72 hours. The risk metrics may be amended based on stakeholder input and the study findings.

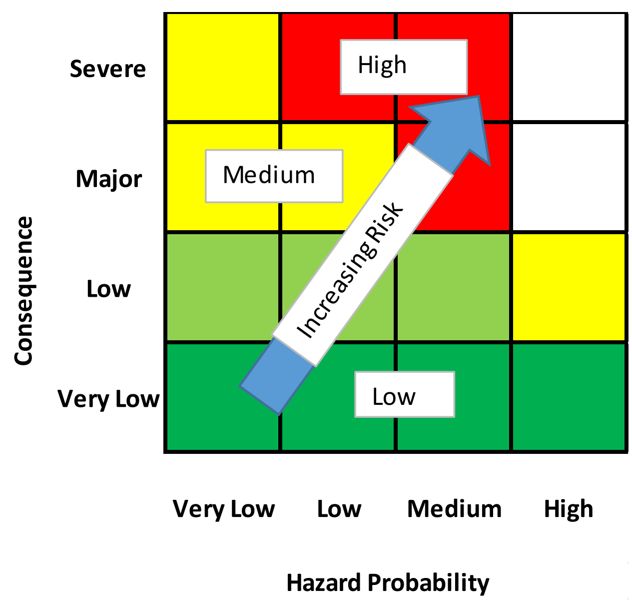

Figure 1: Risk matrix

NHC's work plan is generally consistent with the recommendations for establishing the context that is provided in Section 5.3 of ISO 31000:2009(E), but would be improved through active participation by CVRD in establishing and accepting the metrics that will be used to evaluate the significance of risk, near the beginning of the analysis. This will provide an opportunity for all parties to contribute to the analysis and ensure that the outcome of the analysis is accepted by the project stakeholders.

2.3 Risk Assessment

Risk assessment involves the process of risk identification, risk analysis and risk evaluation. The objective of risk identification is to develop a comprehensive list of the processes or events that have the potential of causing, preventing, accelerating, delaying or enhancing failure of the forcemain. During this phase of the study, key sources of risk, causes, potential consequences and possible interdependence or cumulative effects will be noted.

The NHC / Current Environmental team will then conduct the risk analysis by exploring the likelihood that the sewer forcemain will rupture from those potential causes such as natural coastal processes like erosion and/or impact. The consequence of a forcemain failure will also be evaluated. The analysis will include investigating the potential rate of erosion, and estimating what lands and waters are likely to be impacted in the event of an effluent leak. As part of the consequence evaluation, the range of clean-up costs associated with a rupture will be appraised. An overview environmental assessment will be conducted to assess the potential effects of a rupture on salmonids, forage fish and shellfish, including both recreational and commercial resources. This study will also include providing a high level assessment of the short-term clean up and mitigation costs associated with a breach. The findings of the analysis may be quantitative and/or qualitative in nature. The goal of the analysis is to provide the input for decisions regarding priorities and appropriate risk treatment. The team will identify factors that give rise to uncertainty such as where information used in the analysis may be lacking, when assumptions need to be made, when there is divergence of expert opinions, and note the limitations of the tools being used for the analysis.

The purpose of risk evaluation is to facilitate decisions that are based on the results of the risk analysis. The risk evaluation is conducted by comparing results of the analysis to the established risk criteria, thereby prioritizing the need for a risk treatment. The evaluation may also result in a recommendation to conduct additional analysis or an informed decision not to seek a risk treatment. NHC's proposed work plan for the risk assessment is in compliance with the recommendations provided in Section 5.4 of ISO 31000:2009(E).

2.4 Risk Treatment

Selection of a risk treatment to mitigate risk or a decision to not take action should involve balancing priorities and benefits with costs and effort. The Standard emphasizes that stakeholders should be involved in the decision. This will provide an opportunity for all parties to contribute to the analysis and ensure that the outcome of the analysis is technically sound, achievable, and accepted by the project stakeholders. All decisions should comply with legal and regulatory requirements and take into account social responsibility and environmental protection. The treatment option should be analyzed in terms of effectiveness, potential residual effects, and how the likelihood or consequences of risk may be altered by the treatment. A risk treatment plan should be prepared, and should include direction for how the treatment plan should be implemented, the responsibilities of those involved in approvals and implementation, required timing, the anticipated outcomes, monitoring requirements, and performance metrics. The reasons for selecting the plan should be clear within the documentation of the plan. NHC's proposed work plan is in compliance with the recommendations provided in Section 5.5 (risk treatment) of ISO 31000:2009(E).

2.5 Monitoring and Review

Monitoring and review should be planned with responsibilities clearly defined. Monitoring can provide new information that improves the risk assessment. The work plan includes development of recommendations for inspection practices that the CVRD should employ until the forcemain has been relocated. The recommendations for the types and frequency of checks and reviews will be based on the assessed risk.

The monitoring and review process is strengthened by establishing performance indicators or triggers for management responses. Action plans should be developed to respond to these triggers. For example, the work plan includes provision of technical input by NHC to assist in defining emergency response plans that would be triggered by a rupture of the forcemain. Action plans should be documented and communicated appropriately.

In addition, analysis of the monitoring results is required to detect changes over time and identify trends or emerging risks. Evaluations should be conducted to update the assessment based on the new information, and to determine whether performance indicators are being met and whether modifications to the action plans are required.

NHC's proposed work plan for monitoring and review is generally in compliance with the recommendations provided in Section 5.6 of ISO 31000:2009(E). However, the scope of the work plan does not currently include implementation of the monitoring nor evaluation of the surveys.

2.6 Documentation of Risk Management Process

The policies and procedures for project documents and records control that are being implemented within NHC's BC-based offices are summarized for our staff in NHC's Organizational Quality Manual. This manual was prepared to meet the requirements for professional practice quality management set out in the Association of Professional Engineers and Geoscientists of British Columbia (APEGBC) Organizational Quality Management (OQM) Program. The procedures outlined in the manual are in compliance with all regulatory and statutory requirements, including APEGBC's Professional Practice Guidelines.

NHC's policies and procedures for project documents and records control is also in compliance with the recommendations for recording the risk management process that is provided in Section 5.7 of ISO 31000:2009(E). Improvements to the documentation process for better consistency with the guidelines in the Standard would be to more clearly outline how the need for continuous learning is taken into account, and the benefits of re-using information for the management process. This is, however, more effectively implemented when the Standard is applied to a company's organizational processes as a whole rather than to specific project tasks.

3 CONCLUSIONS

The Standard provides general guidelines that can be applied to a particular industry, association, and/or type of project to manage any form of risk in a systematic and transparent manner. In the context of the risk assessment of the CVRD forcemain on Balmoral Beach, application of the Standard is being compared to the approach to a specific project work plan. NHC's work plan is generally in compliance with the recommendations provided in ISO 31000:2009(E). However, better consistency with the guidelines in the Standard would be attained through:

- Active participation by CVRD in establishing and accepting the metrics that will be used to evaluate the significance of risk near the beginning of the analysis, and participation in the selection of the risk treatment.
- Inclusion of the implementation of monitoring, and reviews of the monitoring within the scope of the project.
- Application of the Standard to CVRD's organizational processes as a whole in addition to its application to these specific project tasks, which would help to better implement the guidelines and the principle of continual improvement.

4 CLOSURE

We appreciate the opportunity to help with the study. Please do not hesitate to contact me (khurtig@nhcweb.com) directly by phone (604-980-6011) or email if you have any questions or require additional information.

Sincerely,

Northwest Hydraulic Consultants Ltd.

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DISCLAIMER

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