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Vulnerability of Vancouver Sewerage Area Infrastructure to Climate Change

Final Report
March 2008

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CONSULTING ENGINEERS

Associated Engineering

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EXECUTIVE SUMMARY

INTRODUCTION

It is widely accepted in the scientific community that climate is changing. Climate data is used to design infrastructure and under climate change, historical climate data as the basis of operational design may not be appropriate.

Engineers Canada established the Public Infrastructure Engineering Vulnerability Committee (PIEVC) to oversee a national engineering assessment of the vulnerability of Canadian public infrastructure to changing climate conditions. PIEVC has developed a protocol to guide vulnerability assessments. The Protocol is a procedure to gather and examine available data in order to develop an understanding of the relevant climate effects and their interactions with infrastructure.

Metro Vancouver and PIEVC are cooperating in the jointly-funded Vancouver Sewerage Area (VSA) vulnerability assessment. The vulnerability assessment includes all Metro Vancouver infrastructure and operations within the VSA. The catchment encompasses the City of Vancouver, University of British Columbia (UBC) campus, UBC Endowment Lands, part of the City of Burnaby and part of the City of Richmond. The VSA is approximately 13,000 hectares.

Years 2020 and 2050 were selected for analysis of climate change effects. Much of the combined sewer system that makes up the VSA dates to the 1960s or earlier. 2020 represents an early design life boundary for much of the oldest piping and appurtenances. A key operational target is Metro Vancouver's commitment to elimination of combined sewer overflows (CSOs) in the VSA by 2050. Since the single largest impact of climate change on the VSA was expected to be increased rainfall (and therefore wastewater flow), a 2050 assessment of climate change was considered crucial for Metro Vancouver's sewer separation planning.

Addressing climate change requires two complementary actions: mitigation and adaptation. In Metro Vancouver, minimizing the region's contribution to global climate change is one of the primary goals of the current Air Quality Management Plan. And through a new Energy Planning Program, Metro Vancouver is also actively pursuing opportunities to recover energy within its own operations, often with related benefits of overall reduction in GHG emissions. The degree to which a municipality is able to deal with the impacts of climate change is often referred to as adaptive capacity.

CLIMATE CHANGE

According to the Intergovernmental Panel on Climate Change (a global scientific body set up by the World Meteorological Organization and the United Nations Environment

Program), the warming that has been experienced over the last half century is likely without precedent in at least the past 1,300 years. For the purposes of this project, climate change modelling was performed by Ouranos (a Quebec-based climatology research consortium) using the Canadian Regional Climate Model to quantify expected changes to various climate factors.

In general, all precipitation indices suggest that there will be an increase in total rainfall amount, and in the frequency and magnitude of rainfall events. In addition, modelling projects consistently increasing temperature trends at both the 2020 and 2050 horizons, implying that snowfall will decrease.

Estimated global sea level rise by Ouranos is 0.14 m by the 2050s and 0.26 m by the 2080s. The most recent report from the IPCC has a range in predicted sea level rise by 2100 of between 0.2 m and 0.6 m. Locally, in research conducted by Natural Resources Canada, it is reported that the Fraser River delta areas (Richmond and Delta) are sinking at a rate of 1 mm/yr to 2 mm/yr, while other areas (Vancouver, Burnaby, Surrey, Tsawwassen Heights) are uplifting at a rate of 0 mm/yr to 1 mm/yr. Therefore, for certain areas of the VSA such as Iona Island, global sea level rise will be aggravated by a sinking land surface, increasing the relative sea level rise.

Monthly average minimum and maximum temperatures are predicted to increase by 1.4°C to 2.8°C by the 2050s.

A summary of climate events is outlined below.

Summary of Climate Events.

Climate Event	Expected Change
Intense Rain	Increase in 1-day maximum rainfall: 17% by 2050s (Ouranos) [1]
Total Annual / Seasonal Rain	Increase in total annual precipitation: 14% by 2050s (Ouranos, addendum)
Sea Level Elevation	Increase in global sea level elevation[2]: 0.26 m by 2080s (Ouranos) to 1.6 m by 2100 (Rohling et al, 2007)
Storm Surge	Not quantified. Likely to increase[3].
Floods	Not quantified. Likely to increase.
Temperature (extreme high)	Increases in monthly maximum temperature: 1.4℃ to 2.8℃ by 2050s (Ouranos)
Drought	Modelling is inconclusive in trend. Average maximum length of dry spell may increase by 0.25 days by 2050s (Ouranos)
Wind (extremes, gusts)	Not quantified. Likely to increase.

Notes:
1. Estimate is based on total precipitation, which is assumed to be approximately equivalent to rainfall in the VSA.
2. Does not include local effects such as subsidence and atmospheric effects.
3. Storm surge is a significant contributor to extreme high water events and therefore lack of quantitative data is a critical information gap.

According to Ouranos, climate scenarios are difficult to produce for certain highly localized events (wind gusts, tornadoes, and thunderstorms) or events where processes are complex and depend on a number of factors (hurricanes, ice storms). Therefore, quantitative predictions of wind speed were not provided.

As described in more detail in Section 2, there are a number of uncertainties and assumptions involved in the climate projections listed above and these reflect only limited possible future scenarios for GHG emissions. In addition, regional climate is affected by large-scale oscillations known as:

- El Niño/Southern Oscillation (ENSO); and
- Pacific Decadal Oscillation (PDO).

ENSO is a well-known phenomenon characterized by an east-west shifting pattern in tropical sea surface temperatures. The time scale of the shifts is relatively short: cycles last from 2 to 7 years. Generally, El Niño winters are associated with decreased precipitation in southwestern British Columbia. The reverse trend occurs during La Niña events.

The PDO operates over the entire Pacific basin on a decadal timescale. Phases may persist for about 20 years to 35 years. The PDO shifted to a warm phase in 1976. For coastal B.C., the warm phase generally results in thinner snowpacks due to higher temperatures and generally a greater percentage of precipitation in the form of rain. A consensus has not yet been reached on whether the PDO has shifted to a cool phase.

VANCOUVER SEWERAGE AREA (VSA)

The VSA is largely a combined sewer system. Combined sewers are an older type of collection system that carry both wastewater and stormwater in the same pipe. Combined sewers were less expensive to install and maintain when they were built, generally prior to the 1960's. During heavy rainfall, combined sewers can overflow directly into a nearby waterway such as the Fraser River or Vancouver Harbour, producing a CSO. This overflow provides a "safety valve" that prevents back-ups of untreated wastewater into homes and businesses, flooding in city streets, or bursting underground pipes.

Metro Vancouver's plan is to reduce, then eliminate, CSOs through the process of gradual conversion to a separated sewer system. Metro Vancouver has committed to elimination of CSOs by 2050 in the 2002 Liquid Waste Management Plan (LWMP). The LWMP also commits Metro Vancouver to upgrade Iona Island Wastewater Treatment Plant (IIWWTP) to full secondary treatment no later than 2020. This pilot study is timely, as a planned revision of the LWMP is currently underway.

The VSA is served by the IIWWTP, the second largest wastewater treatment plant in Metro Vancouver. The design peak wet-weather flow (PWWF) of the IIWWTP is 17

m^3/s. The plant provides primary treatment to wastewater from approximately 600,000 people before discharging it through a 7 km, deep-sea outfall into the Strait of Georgia. The plant opened in 1963 and has been expanded six times for growth and treatment upgrades allowing more than 200 billion litres of wastewater to be treated here in 2001.

INFRASTRUCTURE ASSESSMENT

An important part of the Protocol is a qualitative assessment in which professional judgment and experience are used to determine the likely effect of individual climate events on individual components of the infrastructure.

COMBINED SEWERS

It is certain that increased rainfall intensities and volumes will lead to increased flows in the combined sewers in the absence of other mitigating system changes (e.g. increased efforts at green infrastructure). The effect will be reduced capacity to convey sanitary flow to the IIWWTP; as a result, CSOs will be more frequent and discharge greater volumes.

In order to find a relationship between total CSO and rainfall amount, monthly CSO volume was plotted against average monthly rainfall. Based on the derived linear relationship, approximately 30% of the monthly rainfall overflows, regardless of season. The Ouranos climate scenario report projects a seasonal rainfall increase of 18% for the December-January-February period by 2050. This provides an indication that additional sewer separation effort may be required to meet Metro Vancouver's CSO elimination goals. Further study is recommended to identify appropriate measures to meet these goals (which may include adaptive management, along with hydrologic and hydraulic modelling).

As the combined system is increasingly separated, inflow and infiltration (I&I) will become the primary concern with increasing rainfall intensities and volumes.

PUMP STATIONS

Increased flows at the pump stations may exceed pump station capacity, which could result in overflows locally or upstream. The health and environmental impact would be considered severe, but based on current operation the probability is low.

IONA ISLAND WASTEWATER TREATMENT PLANT

Hydraulic constraints within the collection system physically limit the amount of wet-weather wastewater flow that can be conveyed to the IIWWTP, and under the existing LWMP, the planned maximum capacity of the plant is 17 m^3/s. Therefore, even though climate change may result in an increase in the magnitude and frequency of intense rainfall events and thus increase the potential to generate wet-weather flows, higher peak flow rates are not expected to be received at the IIWWTP. Over time, some of the reductions to peak flow in the regional system as a result of sewer separation will be partially offset by other factors such as population growth and age-related inflow and infiltration rate decay.

However, more frequent wet-weather events (i.e. events per year) could impact the treatment process in other ways. For example, primary clarification performance may be reduced during wet-weather flow events, which could result in more days per year with increased contaminant mass loading to the marine environment in the short-term, and to the secondary treatment system in the long-term. Similarly, grit removal efficiencies are notably reduced during high-flow events.

In addition, increased frequency of such events would reduce process redundancy "windows" (e.g. clarifiers and screens taken out of service for maintenance). This situation could leave the IIWWTP with greater exposure to operations difficulties and more frequent events with increased primary effluent loading.

An increase in the average sea level would impact IIWWTP effluent disposal hydraulics. Here the primary context is the additional energy needed to pump effluent through the marine outfall due to the increase in the static head. Given the sea level predictions, it is highly probable that there will be a climate effect on this infrastructure component. Overall, a low response severity factor was selected for the assessment.

Increases in storm surge, and associated static head, will also impact the effluent outfall system from an internal jetty conduit/outfall pipe pressure perspective. The severity of this response was deemed to be critical since information exists that suggests the jetty conduit structure is under designed for the original design conditions.

Most of the IIWWTP site is above the recently estimated 2.9 m geodetic elevation total water level (i.e. 1:200 yr return frequency winter storm surge with high tide combined with a Fraser River winter flood, for a 95% confidence interval but excluding climate change and wind wave effects) (nhc, 2006). The same conclusion applies to a 3.5 m elevation that includes an assumed 0.6 m freeboard. However, based on available drawings, much of the site, including the access road, appears to be only minimally higher in elevation than the 3.5 m level. Factoring in the change in average sea level rise and land sinking, as well as potential wind wave effects, suggests that little margin may be available in the future.

OTHER VULNERABILITY FACTORS

Other factors influencing infrastructure vulnerability are noted as follows.

Sewer Separation. It was correctly pointed out by Metro Vancouver staff that the reduction in sewer flow from sewer separation will, at many locations, be vastly greater than the increase due to climate-based rainfall effects. Sewer separation will significantly decrease peak flows in the collection system and to the IIWWTP. Note that some Metro

Vancouver regional sewers will eventually be turned over to the City of Vancouver (COV) for stormwater conveyance, and some regional sewers will likely remain for sanitary sewer conveyance to the IIWWTP. Since the separation program is still in its early stages, a unique opportunity exists to adequately size the separate stormwater and sanitary sewers for the effects of climate change.

Long Range Plans. Construction projects that are part of long range plans will improve system operations, presumably increasing the ability to manage CSOs.

Infrastructure Replacement. Replacement of aging infrastructure decreases the risk of system blockages and provides the opportunity to install larger mains or separate systems.

Green Infrastructure. Increasing efforts at building green infrastructure may be used to increase resiliency in adapting to climate change. Metro Vancouver has completed significant efforts studying and promoting green infrastructure over the past number of years, with the overarching goal of net environmental benefits at a watershed scale. Green infrastructure initiatives are also expected to form a significant component of the updated LWMP, currently under development.

Inflow & Infiltration Reduction and Age Based Rate Decay. Sanitary sewer loads can decrease with inflow & infiltration reduction programs (at the municipal or regional level), but generally increase due to material deterioration over time.

Population Growth. Population growth will increase sanitary sewer loading over the entire study period. The COV is planning for an increase from 580,000 in 2006 to 675,000 in 2021.

Land Use. Planned densification can increase impervious area, leading to more runoff and combined sewer loading.

Water Conservation. Water conservation programs reduce indoor water use, decreasing sanitary loading.

Seismic Events. Landslides or ground shifting caused by seismic events break or degrade infrastructure integrity.

CONCLUSIONS

In general, it is noted that the VSA is fortunately situated with respect to climate change effects relative to other locations in Canada. Vancouver rarely experiences extreme or catastrophic weather events such as ice storms, tornadoes, drought or extreme cold. Perhaps the greatest magnitude threat is flooding of the Fraser River, and many predict this risk to decline in response to climate change.

The climate factors identified as threats to infrastructure vulnerability will be evidenced as gradual changes. In fact, the greatest pressure to initiate adaptive action comes not from climate change, but from timing of planned infrastructure improvement plans such as the treatment plant upgrades and combined sewer separation program. So while climate change effects may reveal vulnerabilities, Metro Vancouver is in an ideal position to proactively mitigate and adapt to these challenges.

The key priorities with respect to climate change adaptation in the collection system centre on increased rainfall and the associated potential increase in sewer flow, both under combined and separate sewer configurations. Accelerated separation may be necessary to achieve the target of CSO elimination by 2050. The extent of the work required requires additional study.

The vulnerabilities judged to be of the highest priority at the treatment plant are those associated with the effluent disposal system and the IIWWTP site itself because of the storm surge climate variable.

While ranked as lower priorities, the potential impacts of an increase in average sea level on the IIWWTP site and associated infrastructure are also important due to the significant uncertainty and wide range in predicted future increases in mean sea level. Additional study is required to develop more detailed information and conduct detailed analyses in the context of these potential vulnerabilities.

There are several lower-ranked potential treatment system vulnerabilities due to precipitation-related climate variables that potentially exist independent of the LWMP design limit of 17 m3/s. These vulnerabilities are related to facility capacity and redundancy, which in turn affects capacity. At this point there is considerable uncertainty in the significance (i.e. response severity) of these vulnerabilities, particularly given the relative magnitude of the estimated climate effects and the potential ability of Metro Vancouver's sewer separation policy to mitigate these vulnerabilities. Additional study to develop the relationship between these climate variables and the resultant impact on wet-weather wastewater flows may provide enhanced information to assess potential impacts on the treatment system. However, given Metro Vancouver's planned secondary treatment program for the VSA, a more practical approach is to deal with these vulnerabilities as the upgraded treatment is being planned and designed. In this case, Metro Vancouver would consider and account for potential changes in infrastructure capacity as part of the secondary treatment program development, and in the context of other uncertainties (e.g. sewer separation, future population growth, water consumption reduction), without explicitly conducting additional specific study.

The current capacity of standby power available at the IIWWTP is already a vulnerability, which is anticipated to be further exaggerated by climate change. Metro Vancouver should consider the need for remedial action to address this vulnerability.

Given the age of the IIWWTP infrastructure, it is recommended that the additional studies required consider the remaining service life of the components and in the context of other potential issues (e.g. seismic). Even if climate change-related vulnerabilities are deemed to exist, they may be overshadowed by other issues that when resolved can simultaneously address climate vulnerabilities.

Section 1

Introduction

1. INTRODUCTION

1.1 PROJECT BACKGROUND

It is widely accepted in the scientific community that climate is changing[1]. Since historical climate data is used to design infrastructure and these data are changing, it may no longer be appropriate to use historical climate data as the basis of operational designs. These factors may create vulnerabilities in the infrastructure due to the fact that the existing infrastructure may not have the resiliency required to accommodate the weather extremes caused by climate change. Furthermore, new infrastructure may not be designed with sufficient load and adaptive capacity to function at required performance levels under extreme events driven by climate change.

Engineers Canada[2] established the Public Infrastructure Engineering Vulnerability Committee (PIEVC) to oversee a national engineering assessment of the vulnerability of Canadian public infrastructure to changing climate conditions. PIEVC has developed a protocol to guide vulnerability assessments. The Protocol is a procedure to gather and examine available data in order to develop an understanding of the relevant climate effects and their interactions with infrastructure.

Metro Vancouver[3] and PIEVC are cooperating in the jointly-funded Vancouver Sewerage Area (VSA) vulnerability assessment. The VSA study is the second pilot study application of the assessment protocol (the first is the now completed Portage la Prairie water supply study). The results from this and other pilot studies will be used by PIEVC to establish a Canada-wide vulnerability assessment for buildings, roads, stormwater and wastewater, and water resources.

The present study has two primary objectives:

- vulnerability assessment of the Metro Vancouver wastewater infrastructure to climate change impacts; and
- assessment of the draft PIEVC protocol to assess municipal wastewater infrastructure.

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[1] See IPCC 2007: "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level." The Intergovernmental Panel on Climate Change (IPCC) is a scientific intergovernmental body set up by the World Meteorological Organization (WMO) and by the United Nations Environment Programme (UNEP). Its role is to assess on a comprehensive, objective, open and transparent basis the latest scientific, technical and socio-economic literature produced worldwide relevant to the understanding of the risk of human-induced climate change, its observed and projected impacts and options for adaptation and mitigation. The IPCC was awarded of the Nobel Peace Prize "for their efforts to build up and disseminate greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change".

[2] Engineers Canada is the business name of the Canadian Council of Professional Engineers (CCPE).

[3] Metro Vancouver is the common business name of four separate legal corporate entities, one of which is the Greater Vancouver Sewerage and Drainage District (GVS&DD). The GVS&DD has the legal responsibility, as defined in an Act of Legislature in 1956, to administer, construct, maintain, and operate certain sewerage and drainage infrastructure. For simplicity, “Metro Vancouver” is used in this report.

1.2 PIEVC PROTOCOL

The PIEVC Protocol (Protocol) outlines a procedure to develop relevant information on the specific elements of the climate and the specific attributes of the infrastructure that interact to create vulnerability. The PIEVC Protocol describes a step-by-step process for defining, analyzing, evaluating and prioritizing information about the impact of climate change on infrastructure. The observations, conclusions and recommendations arising from the use of this protocol provide a framework to support effective decision-making about infrastructure operation, maintenance, planning and development.

The key steps of the protocol are as follows:

1. Project Definition
2. Data Gathering and Sufficiency
3. Vulnerability Assessment (Qualitative Assessment)
4. Indicator Analysis (Quantitative Assessment)
5. Recommendations

Application of the protocol is summarized in the report text and in the accompanying worksheets (Appendix A).

1.3 STUDY SCOPE & TIME FRAME

The vulnerability assessment includes all Metro Vancouver infrastructure and operations within the VSA. Although integral to the collection system as a whole, components of municipal infrastructure (e.g. belonging to the City of Vancouver or City of Burnaby) are not directly addressed in this study.

The time frame was the first variable identified, as it determines the climate change boundary. Infrastructure life cycle is the key indicator for selecting a time frame, in concert with operational goals.

2020 and 2050 were selected for analysis of climate change effects. A discussion of the factors leading to this decision follows below.

1.3.1 COLLECTION SYSTEM

The combined sewer system that makes up much of the VSA dates to the 1960s and earlier; in fact, some sewers built in the early 1900s are still in use today. Service life of sewerage infrastructure is commonly estimated at 50 or 100 years, depending on component type and environment *(Worksheet 1, Table 4.2.4).* 2020 represents an early design life boundary for much of the early piping and appurtenances.

2020 also provides a short term reference point suitable for targeting 10-year capital plan expenditures.

A key operational target is Metro Vancouver’s commitment to elimination of combined sewer overflows (CSOs) in the VSA by 2050. (Liquid Waste Management Plan (LWMP), April 2002). Since the single largest impact of climate change on the VSA was expected to be increased rainfall (and therefore wastewater flow), a 2050 assessment of climate change was considered crucial for Metro Vancouver’s sewer separation planning.

2080 was suggested as possible long term reference point. However, this time frame is considered too far in the future for there to be adequate data and information for analysis with respect to design life and climate change factors. This term will certainly fall within the material life of some existing VSA infrastructure. However, service life dependent on loading projections is subject to considerable variability beyond the buildout conditions associated with 30-40 year planning horizons.

1.3.2 IONA ISLAND WASTEWATER TREATMENT PLANT (IIWWTP)

Wastewater treatment facilities are complex entities that include many structural, mechanical, electrical, instrumentation/control, and civil works systems (e.g. on-site roads, buried pipes). For planning purposes, structural components (e.g. process tankage, buildings) are typically assumed to have a service life in the order of 50 years. Mechanical and electrical systems are generally expected to be replaced within a 25 year time frame.

Changes in technology and regulatory requirements, combined with the need to expand treatment capacity to accommodate growth of the service population, can impact the originally envisioned design life of any given system or component.

In addition, Metro Vancouver will be undertaking a major upgrade and expansion program in the VSA over the next decade to accommodate its LWMP requirements. This program is planned to result in secondary treatment being operational by 2020.

1.4 PROJECT TEAM

This project is a jointly funded initiative of Engineers Canada (through PIEVC) and Metro Vancouver. The project was undertaken with support from the Climate Change Impacts and Adaptation Program, Natural Resources Canada.

Kerr Wood Leidal Associates Ltd (KWL) and Associated Engineering (B.C.) Ltd. (AE) greatly appreciate the assistance of Brent Burton, M.A.Sc., P.Eng., for tireless and timely project participation.

The project team also acknowledges the enthusiastic support of the City of Vancouver (COV), City of Burnaby and Metro Vancouver staff who participated in the workshop or in individual interviews.

The following table outlines the Project Team participants.

Table 1-1: Project Team

Organization	Role of Organization	Individuals
Public Infrastructure Engineering Vulnerability Committee (PIEVC)	National Engineering Assessment Funding Partner	David Lapp
Metro Vancouver	Infrastructure Owner Funding Partner	Brent Burton
NodelCorp	Project Facilitators	Joan Nodelman Joel Nodelman
Kerr Wood Leidal	Prime Consultant Collection System Assessment	Andrew Boyland Erica Ellis Christine Norquist
Associated Engineering	Subconsultant Treatment Plant Assessment	Dean Shiskowski Arash Masbough
Ouranos Consortium	Climate Change Data	Caroline Larrivée Travis Logan
Pacific Climate Impacts Consortium (PCIC)	Supplementary Climate Change Data	Trevor Murdock
PIEVC Stormwater and Wastewater Expert Working Group (SWEWG)	Advisory Task Group	Brian Crowe (City of Vancouver) Darryl Dormuth (National Research Council) Joan Klassen (Environment Canada) Jennifer Lefevre (OpenGate Properties)

Section 2

Climate Change

2. CLIMATE CHANGE

2.1 BACKGROUND

The Earth's climate is changing. Some of this change is due to natural variations that have been taking place for millions of years but, increasingly, human activities that release heat-trapping gases into the atmosphere are warming the planet by contributing to the "greenhouse effect".

According to the Intergovernmental Panel on Climate Change (a global scientific body set up by the World Meteorological Organization and the United Nations Environment Program), the warming that has been experienced over the last half century is likely without precedent in at least the past 1300 years. Without coordinated action to reduce greenhouse gas emissions, the world's average surface temperature will continue to warm with expected increases of between 1.1 and 6.4ºC over the period 1990-2100 (IPCC 2007).

Studies relevant to Metro Vancouver indicate that climate-change related regional effects will likely include:

- sea level rise, aggravated in some low-lying areas by ground subsidence;
- shifts in precipitation (i.e. more precipitation in winter, less precipitation in summer and more precipitation falling as rain rather than snow);
- increasing frequency of extreme weather events, including precipitation; and
- potentially earlier spring runoff, higher water temperature and lower freshet flows in river in the snowmelt-dominated Fraser River.

Addressing climate change requires two complementary actions: mitigation and adaptation. Canadian municipalities have demonstrated leadership in mitigating greenhouse gas emissions through energy efficiency measures and the use of alternative energy sources. In Metro Vancouver, minimizing the region's contribution to global climate change is one of the primary goals of the current Air Quality Management Plan. And through a new Energy Planning Program, Metro Vancouver is also actively pursuing opportunities to recover energy within its own operations, often with related benefits of overall reduction in greenhouse gas (GHG) emissions. However, across Canada the challenges of adapting to climate change have received far less attention.

2.1.1 CLIMATE CHANGE ADAPTATION

The degree to which a municipality is able to deal with the impacts of climate change is often referred to as adaptive capacity. The IPCC has defined adaptation as "the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences" (IPCC 2007).

Currently, engineers use historical climate records when designing most urban water drainage systems. As precipitation patterns change, urban drainage systems could fail, causing problems such as sewer backups and basement flooding.

By evaluating existing infrastructure capacity and estimating the capacity that will be required in response to climate change impacts, it is hoped that infrastructure components that lack adaptive capacity may be identified before the remaining capacity is used up.

2.1.2 OTHER CLIMATE EFFECTS

In addition to climate change, other large-scale oscillations that affect the climate in Metro Vancouver include:

- El Niño/Southern Oscillation (ENSO); and
- Pacific Decadal Oscillation (PDO).

ENSO is a well-known phenomenon characterized by an east-west shifting pattern in tropical sea surface temperatures. The time scale of the shifts is relatively short: cycles last from 2 to 7 years. During El Niño events, sea surface temperatures in the tropical eastern Pacific are higher than normal, resulting in excess precipitation in that region. La Niña events are associated with unusually warm sea surface temperatures in the western Pacific, along with strong convection and precipitation in that region. Generally, El Niño winters are associated with increased precipitation south of 40°N (California) and less precipitation to the north (including southwestern British Columbia). The reverse trend occurs during La Niña events.

The PDO operates over the entire Pacific basin on a decadal timescale. The warm (positive) phase of the PDO is characterized by below normal sea surface temperatures in the central and western north Pacific and unusually warm sea surface temperatures along the west coast of North America. The pattern is reversed during the cool (negative) phase of the PDO. Phases may persist for about 20 years to 35 years. The PDO shifted to a warm phase in 1976. For coastal BC, the warm phase generally results in thinner snowpacks due to higher temperatures and generally a greater percentage of precipitation in the form of rain. Warm PDO phases also tend to coincide with an increased frequency of El Niño events. A consensus has not yet been reached on whether the PDO has shifted to a cool phase.

Both ENSO and the PDO are linked to atmospheric circulation patterns over North America and the North Pacific. These cycles affect precipitation (including extremes, form and spatial distribution), streamflow, and sea levels. Assuming that these cycles continue to operate as they have done historically, effects of climate change will be superimposed on the cycles. The result of the superimposition may be additive (i.e. both climate change impacts and ENSO/PDO impacts operating in the same direction) or may offset each other. For the purposes of this report, climate change impacts have been considered to be operating on a stationary baseline climate in order to simplify the analysis.

2.2 GEOGRAPHY OF STUDY AREA

The VSA encompasses the City of Vancouver, University of British Columbia (UBC) campus, UBC Endowment Lands, part of the City of Burnaby and part of the City of Richmond (Figure 2-1). The VSA has relatively low topographic relief, with elevations ranging from sea level to a maximum of over 120 m (Queen Elizabeth Park, City of Vancouver). To the north, the Coast Mountains are a steep topographic barrier that influences the local climate on the North Shore.

The VSA is bounded by ocean to the north (Burrard Inlet) and west (Strait of Georgia), which has a moderating effect on the climate. The Fraser River, a large snowmelt-dominated river, defines the southern boundary of the VSA. Because the Fraser River drains a significant portion of the province, peak flows are not highly correlated with local rain events. Flooding at the boundaries of the VSA may arise from high river water levels (the annual snowmelt freshet), or from the combined effects of ocean and river (a winter high tide/storm surge event).

The predominant large-scale atmospheric circulation pattern is west-to-east, and in the winter the climate is dominated by repeated cyclonic storms, which yield high volumes of precipitation and often high winds. Given the generally low elevations and relatively mild temperatures, precipitation inputs typically come as rain in the VSA. Precipitation is much lower in the summer, and prolonged periods without rainfall may occur. Convective storms are relatively rare.

2.3 CLIMATE BASELINE

In Step 1 of the PIEVC Protocol, the climate factors of interest are summarized, and in Step 2 the baseline data is summarized. Only the climate data that is relevant to the design, development and management of the infrastructure is included. Based on a consideration of the wastewater infrastructure and baseline climate data, the following climate factors were identified as being particularly significant:

- Rainfall (intensity-frequency relationships, annual and seasonal totals);
- Sea Level Elevation;
- Storm surge;
- Rain on snow events (another flood generation mechanism);
- Extreme temperatures (low and high);
- Drought conditions;

- Snowfall;
- Wind speed (extremes and gusts);
- Frost (freeze-thaw cycles); and
- Ice.

It should be noted that this list includes both extreme weather events and climatic conditions that are subject to more gradual change.

Climate change modelling was performed by the Ouranos Consortium[4] (Ouranos) using the Canadian Regional Climate Model to quantify expected changes to various climate factors. A data request was made to Ouranos in the early stages of the project. As part of the climate modelling deliverables Ouranos includes summary statistics for existing conditions based on data obtained from a number of Environment Canada stations (Table 2-1). The selection criteria used by Ouranos include:

- A minimum data series length of 20 years.
- Less than 10% missing data.
- Final year of record no earlier than 1995.

Table 2-1: Environment Canada Climate Stations (from Ouranos)

Station Name	ID	Data Used For:
Abbotsford Airport	**1100030**	Temperature (max, min), Rain, Snow
Haney East	**1103326**	Temperature (max, min), Rain, Snow
Haney UBC Research Forest	**1103332**	Temperature (max, min), Rain, Snow
Pitt Polder	**1106180**	Temperature (max, min), Rain, Snow
Stave Falls	**1107680**	Rain, Snow
Surrey Kwantlen Park	**1107873**	Rain
Surrey Municipal Hall	**1107876**	Rain
Vancouver International Airport	**1108447**	Rain
White Rock STP	**1108914**	Rain
Note: Refer to Ouranos report in Appendix C for details.		

It should be noted that none of the stations used by Ouranos is actually located within the VSA: all stations in Table 2-1 are either to the south or east of the VSA boundaries. Given the prevailing patterns of precipitation and temperature, stations that are further east (as well as being at higher elevation) are likely to experience higher precipitation than the VSA, and to experience greater temperature extremes (both low and high).

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[4] The Ouranos Consortium pools the expertise and disciplines of numerous researchers in order to advance the understanding of the issues and the associated requirements for adaptation resulting from climate change on the scale of the North American continent. The creation of Ouranos stems from the initiative and participation of the Government of Québec, Hydro-Québec, the Meteorological Service of Canada, and Valorisation-Recherche Québec. Ouranos is international in its scope, with a team including more than one hundred scientists and specialists.

2.4 CLIMATE CHANGE ASSUMPTIONS

Climate change modelling was performed by Ouranos using the Canadian Regional Climate Model to quantify expected changes to various climate factors. Climate factors were ranked in the information request submitted early in the project. In general, Ouranos was able to provide quantitative estimates for most of the factors that the project team gave a high ranking. Results were provided for two model runs, both using the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) “A2” greenhouse gas and aerosol projected evolution. The results were provided for the study time frame (2020s and 2050s), and one additional time horizon (2080s).

Model results are discussed in the following sections. Additional data on various factors have been provided, where available.

UNCERTAINTY

As indicated in the Ouranos report (Appendix C), modelling results were produced by the same Regional Climate Model, driven by two runs of the same Global Climate Model (Canadian Global Climate Model, CGCM3) and the same greenhouse gas emissions scenario (A2). Differences between the two model runs arise from slight differences in the initial conditions.

As indicated above, the modelling conducted for this project covers only a small portion of the spectrum or envelope of changes that would be produced via the use of multiple greenhouse gas scenarios and multiple driving models (or even multiple Regional Climate Models). The difference between the two model runs provided gives an indication of the possible range of climate responses, but it is necessarily incomplete. Therefore, it should be noted that there is a degree of uncertainty to the model results that cannot be quantified at this time.

2.4.1 PRECIPITATION

Ouranos

Ouranos modelling results were initially separated into liquid (rain) and solid (snow) components, rather than total precipitation (both liquid and solid). However, there are difficulties associated with the rain-snow separation that are related to how the ground topography is represented in the model. The grid for the Regional Climate Model (RCM) is relatively coarse (45 km by 45 km cells) which means that in mountainous areas such as Metro Vancouver an individual model cell can contain a range of elevations within it (e.g. from sea level to mountain peaks). Each 45 km by 45 km cell is assigned an average elevation. Averaging of near sea level terrain in the VSA with the nearby Coast Mountains elevations yields an “average” elevation for this cell of about 345 m, which is much higher than the actual average elevation of the VSA. The elevation bias influences the form of the estimated precipitation and alters the ratio of snow to rain, since higher elevation areas receive more precipitation in the form of snow compared to lower elevation areas. As a result, projected increases in rainfall are overestimated.

The elevation bias was identified during the course of the analysis. In order to correct for the elevation bias in the modelling results, Ouranos proposed that the only total precipitation be evaluated, rather than evaluating rain and snow separately. Given that the VSA contains mostly low-elevation terrain, existing snowfall accumulations are quite low (about 3% of total precipitation) and expected to diminish due to climate change. Therefore, estimated changes in total precipitation could be assumed to *generally* represent changes in rainfall. Ouranos has provided a revised report that summarizes the climate modelling results for total precipitation. The revised modelling results are discussed in the following sections.

Pacific Climate Impacts Consortium (PCIC)

In addition to the climate modelling conducted by Ouranos, the Pacific Climate Impacts Consortium[5] (PCIC) has recently assessed modelling results for the entire province of British Columbia for both Global and Regional Climate Models (PCIC 2007b). All five available runs of the Global Climate Model CGCM3 were assessed using the A2 emissions scenario. The ensemble of CGCM3 results indicates a strong warming trend, but the precipitation result is less clear both in magnitude of the estimated change and in the trend (i.e. increasing and decreasing). The report also notes that different models represent the climate differently; therefore ideally results would be pooled from many runs of different climate models and different emissions scenarios.

Regional Climate Model results were derived from the Canadian Regional Climate Model version 4.1.1 (CRCM v. 4.1.1) using the A2 emissions scenario and driven by Run 4 of the CGCM3 (i.e. similar to Ouranos). Estimated total annual precipitation for the grid cell containing the VSA is shown in Table 2-2.

Table 2-2: Estimated Changes in Total Precipitation from PCIC Modelling

Event	Estimated Increase by 2050s (%)
Total Annual Precipitation	10 - 12
Winter Precipitation (December/January/February)	0 - 10
Summer Precipitation (June/July/August)	0 - 10
Note: Results from Figure 4.2.1b and Figure 4.2.3 of PCIC (2007b).	

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[5] The Pacific Climate Impacts Consortium was formed by the BC Ministry of Environment and BC Hydro, at the University of Victoria, building on the capacity of the Canadian Institute for Climate Studies located within the University of Victoria's Centre for Global Studies.

As stated by PCIC, Regional Climate Model projections may be considered to be more robust than Global Climate Model (GCM) projections. However, there is additional uncertainty because of the low number of available model runs, and the use of only one emissions scenario. Compared with the full spread of GCM projections using multiple global climate models and multiple emissions scenarios, the RCM projections are relatively small and therefore the predictions may be uncertain.

2.4.2 RAINFALL

As noted in Section 2.4.1, climate modelling of total precipitation by Ouranos is assumed to be generally representative of trends in rainfall as the proportion of precipitation that falls as snow in the VSA is quite small. Various indices of total precipitation were provided by Ouranos, including:

- 24-hour precipitation frequency (for events greater than 5 mm, 10 mm and 20 mm);
- Average maximum annual precipitation amount;
- Average total annual and seasonal precipitation amount;
- Simple daily intensity index (average precipitation for any wet day); and
- Average length of wet spell (average maximum number of consecutive days with precipitation).

For all indices, baseline conditions were provided as well as the modelled change at the various time horizons (2020, 2050 and 2080). For the purposes of the report, precipitation and rainfall are assumed to be approximately equivalent in the discussion of the modelling results.

In general, all indices suggest that there will be an increase in total rainfall amount, and in the frequency and magnitude of rainfall events. Model results did not include changes to the intensity-duration-frequency (IDF) relationships that are typically used for design of infrastructure; only annual statistics and exceedance probabilities for various intervals were provided. Variability was highest between the two model runs in the seasonal precipitation totals, and the estimates of event frequency (2020 time horizon primarily), although no difference in trend was estimated.

Estimated seasonal totals of precipitation show increases for all seasons in 2020 with the largest estimated increases occurring in the spring (March, April and May). For 2050, precipitation is projected to increase in all seasons except summer (which shows a very slight decrease). Winter (December, January and February) and spring (March, April and May) increases in precipitation are the largest in 2050.

Wastewater infrastructure is affected by rainfall storm events and, to a lesser degree, by the total annual rainfall. Estimated changes in these two factors are summarized in Table 2-3.

Table 2-3: Estimated Changes in Precipitation From Ouranos Modelling

Event	Observed (mm)	Average Estimated Change 2020s (%)	Average Estimated Change 2050s (%)	Range in Model Estimates: 2020s (%)	Range in Model Estimates: 2050s (%)
Average Annual 1-day Maximum Precipitation	73.1	+7	+17	2	1
Total Annual Rain	1881	+9	+14	9	4

Note: Climate simulations by Ouranos were produced by two runs of CRCM 4.2.0 driven by CGCM3 using the A2 GHG emissions scenario. Average is based on the results of the two model runs provided by Ouranos. Range is the difference between the two model predictions for a given factor and time horizon.
See Appendix C for complete listing of all Ouranos modelling results.

Trends in historical precipitation patterns in Metro Vancouver have been analyzed previously by KWL (2002) and also by PCIC (2007a) in an update to the KWL report. KWL (2002) found that high intensity rainfall threshold exceedance showed increasing trends since the last cool phase of the Pacific Decadal Oscillation (PDO) (1947-1976). These trends were statistically significant for April, May and June months, and for shorter durations (up to 2 hours).

The 2007 PCIC update report also concluded that rainfall intensity and threshold exceedance have generally been increasing in Metro Vancouver (PCIC 2007a). Identified trends in annual rainfall intensity are summarized in Table 2-4.

Table 2-4: Trends in Historical Annual Maximum Rainfall Intensity Records (PCIC 2007a)

Rainfall Duration	Stations Exhibiting Significant Trend (%)	Range in Significant Trends (mm/hr per century)
5 minute	28	34 – 64
10 minute	35	17 – 46
15 minute	21	14 – 38
30 minute	21	5 – 20
1 hour	43	4 – 10
2 hour	50	4 – 7
6 hour	21	3
12 hour	14	2 – 3
24 hour	7	2

Note: Results summarized from Table 3.3 of PCIC (2007a). Total number of stations analyzed is 14 except for the 24 hour duration for which only 13 stations were analyzed. Trends were analyzed for significance at 99.9%, 99%, 95% and 90% levels and the summary includes all identified significant trends.

Increasing trends in the annual maximum rainfall intensity are greatest for 5-minute to 30-minute duration events. At durations greater than 2 hours, few significant trends were discerned. Increasing trends are more evident in seasonally-averaged data (spring and winter seasons) than for annual maxima.

It is difficult to directly compare historical precipitation trends to the modelling results provided by Ouranos, as precipitation intensity was only modelled at 24-hour duration or longer.

2.4.3 SNOWFALL

Climate modelling predicts increasing temperatures in all months; therefore snowfall is expected to decrease. Due to the elevation bias discussed in Section 4.2.1, climate modelling results for snowfall are not available at this time (only total precipitation, of which snowfall is a very small proportion). Given that snowfall is likely to decrease in the future, this weather event was removed from the vulnerability matrix.

2.4.4 SEA LEVEL RISE

Global Sea Level Rise

Estimated global sea level rise was provided by Ouranos, based on CGM3 results. Estimated global sea level rise is summarized in Table 2-5. Results were provided for only one model run.

Table 2-5: Estimated Global Sea Level Rise Based on CGM3

Event	2020s (m)	2050s (m)	2080s (m)
Sea Level Rise	0.06	0.14	0.26

The most recent report from the IPCC has a range in estimated sea level rise by 2100 of between 0.2 m and 0.6 m for results of the 6 greenhouse gas scenarios (Solomon et al, 2007). As stated in the IPCC report, these results exclude future rapid dynamical changes in ice flow, which might further increase the rate of sea level rise. Recent research examining the influence of enhanced polar ice melting predicts that global sea level rise could be much greater than that estimated by the IPCC: 0.8 m to 0.9 m (Overpeck et al, 2006) and possibly up to 1.6 m (Rohling et al, 2007).

Local Sea Level Rise

It should be noted that the rates discussed above are global eustatic rates of sea level rise. Local sea level is relative, and is determined by a number of factors, including:

- eustatic change in global ocean levels (due to thermal expansion of the ocean and melting of land-based ice)
- local ground level movement (rising or sinking); and
- local dynamics related to changes in wind.

Some of these factors act to increase local sea level (e.g. land subsidence), while others act to decrease local sea level (e.g. land uplift).

Lambert et al (2008) find that the Fraser River delta areas (Richmond and Delta) are sinking at a rate of 1 mm/yr to 2 mm/yr, while other areas (Vancouver, Burnaby, Surrey, Tsawwassen Heights) are uplifting at a rate of 0 mm/yr to 1 mm/yr. Therefore, for certain areas of the VSA such as Iona Island, global sea level rise will be aggravated by a sinking land surface, increasing the relative sea level rise. Assuming a rate of land subsidence of 2 mm/yr would yield a subsidence of about 0.16 m by the 2080s that would need to be added to the global sea level rise estimate.

Atmospheric effects may be of local importance as well. In winter months, a northward wind is common along the outer coast, which acts in combination with the effects of the Earth's rotation to push ocean water toward shore, thereby elevating sea level. This effect is even more common during El Niño events, and can be substantial: mean wintertime sea level is about 0.5 m higher than summer sea level on Washington's coasts and estuaries (Mote et al, 2008). The atmospheric effect would need to be considered in addition to global sea level rise and local ground movement.

Trends in regional sea level rise have been recently analyzed by Lambert et al (2008). Analysis of two local tide gauges yielded a very low estimate of 0.3 mm ± 0.8 mm/yr (Lambert et al, 2008), while an analysis of other gauges in the region yielded a higher rate of 1.7 mm ± 0.5 mm/yr (Mazzotti et al, 2007). Linearly extrapolating the higher estimate yields an estimated sea level rise by 2100 of about 0.15 m. However, it is important to note that rates of global sea level rise are predicted to accelerate in the future (i.e. the rate of increase is not linear), and therefore a simple linear extrapolation will likely underestimate the true sea level rise.

Summary

As discussed above, estimates of global sea level rise vary widely and projections based on existing climate models are likely to be low. Local sea level rise is influenced by a number of factors and is spatially variable. For the purposes of this analysis, only global sea level rise was considered.

2.4.5 TEMPERATURE

Monthly average minimum and maximum temperatures are projected to increase in 2020 and 2050. Average estimated increase by 2020 is 1.2°C to 1.3°C, and by 2050 is 2.1°C to 2.3°C (Table 2-6 and Table 2-7). The greatest increases are projected for January and July, and the increases are least for June and April.

Similarly, the annual minimum temperature is projected to increase in both time horizons. The annual maximum shows a difference in estimated trend for the 2020 horizon, but an increasing trend for the 2050 horizon.

Table 2-6: Estimated Changes in Average Minimum Temperature (from Ouranos)

Month	Observed (°C)	Average Estimated Change 2020s (°C)	Average Estimated Change 2050s (°C)	Range in Model Estimates: 2020s (°C)	Range in Model Estimates: 2050s (°C)
January	**-0.6**	2.1	3.4	0.1	0.4
February	**0.6**	1.6	2.6	0.4	0.6
March	**1.8**	0.8	1.5	1.2	0.9
April	**4.0**	1.2	2.0	0.7	0.3
May	**7.0**	1.1	1.8	0.2	0.9
June	**9.9**	0.5	1.5	0.2	0.4
July	**11.4**	1.4	2.7	0.1	0.8
August	**11.4**	1.3	2.5	1.1	0.6
September	**8.9**	1.3	2.3	1.1	0.7
October	**5.6**	1.35	1.8	1.1	0.5
November	**2.4**	1.5	2.4	0.1	0.2
December	**0.0**	1.1	2.7	0.2	1.2

Note: Climate simulations by Ouranos were produced by two runs of CRCM 4.2.0 driven by CGCM3 using the A2 GHG emissions scenario. Average is based on the results of the two model runs provided by Ouranos. Range is the difference between the two model predictions for a given factor and time horizon.
See Appendix C for complete listing of all Ouranos modelling results.

Table 2-7: Estimated Changes in Average Maximum Temperature (from Ouranos)

Month	Observed (°C)	Average Estimated Change 2020s (°C)	Average Estimated Change 2050s (°C)	Range in Model Estimates: 2020s (°C)	Range in Model Estimates: 2050s (°C)
January	**5.2**	**1.8**	**2.7**	0.01	0.02
February	**8.0**	**1.2**	**2.0**	0.4	0.4
March	**10.5**	**0.7**	**1.4**	1.1	0.6
April	**13.9**	**1.1**	**2.1**	0.8	0.3
May	**17.6**	**1.0**	**1.8**	0.2	1.0
June	**20.3**	**0.4**	**1.4**	0.1	0.5
July	**23.4**	**1.5**	**2.8**	0.01	0.9
August	**23.5**	**1.2**	**2.5**	1.35	0.7
September	**20.4**	**1.3**	**2.2**	1.3	0.8
October	**14.4**	**1.2**	**1.6**	1.3	0.4
November	**8.7**	**1.5**	**2.2**	0.3	0.2
December	**5.6**	**0.9**	**2.3**	0.2	0.9

Note: Climate simulations by Ouranos were produced by two runs of CRCM 4.2.0 driven by CGCM3 using the A2 GHG emissions scenario. Average is based on the results of the two model runs provided by Ouranos. Range is the difference between the two model predictions for a given factor and time horizon.
See Appendix C for complete listing of all Ouranos modelling results.

2.4.6 DROUGHT

Ouranos modelled the average maximum dry spell, defined as the average yearly maximum number of consecutive days with less than 1 mm of precipitation between April 1 and October 31. The observed data indicate an average value of about 20 days. Modelling results for future conditions are somewhat inconclusive. The two model runs show disagreement in trend the 2020 time horizon. At the 2050 time horizon, both runs predict a small increase in the maximum length of dry spell.

Summer (June, July and August) precipitation is projected to increase at the 2020 horizon, but there is a disagreement in trend between the runs for the 2050 horizon. 2080 modelled totals indicate a consistent, small decrease in summer precipitation amount (about 5% less).

2.4.7 WIND SPEED

According to Ouranos, climate scenarios are difficult to produce for certain highly localized events (wind gusts, tornadoes, and thunderstorms) or events where processes are complex and depend on a number of factors (hurricanes, ice storms). Therefore, quantitative predictions of wind speed were not provided. A summary of expected trends based on the literature was provided instead, which suggests:

- Tropical cyclones (typhoons and hurricanes) are likely to become more intense in the future due to increases in tropical sea surface temperatures.
- There are no clear trends in the estimated frequency of hurricanes.
- Some modelling suggests that the atmosphere over mid-latitude areas may become more unstable, which would lead to increased convective activity.

2.4.8 STORM SURGE

Storm surge is the rise in the level of the ocean that results from the decrease in atmospheric pressure associated with hurricanes and other storms. Storm surge can be a significant component of an overall high water event, in combination with high tides and large waves. Based on historical tide gauge data for Point Atkinson, maximum estimated storm surge heights are on the order of 0.8 m to 1.1 m (Triton Consultants, 2006).

Climate change is expected to result in more frequent high water events and higher extreme water levels (BC Ministry of Water Land and Air Protection 2002). The height of extreme high water events has increased at the rate of 3.4 mm/yr at Point Atkinson during the 20th century (BC Ministry of Water Land and Air Protection 2002).

Work has recently been conducted by PCIC and the Ministry of Environment on historical extreme water level events and potential climate change impacts to extreme water levels. However, the results of the study are not yet publically available. It is anticipated that a report synthesizing this work, and other recent work on relative sea level rise, land subsidence, and storm surge prediction will be published in the spring or summer of 2008 (B. Kangasniemi, pers.comm.).

Metro Vancouver is encouraged to obtain a copy of this report as it becomes available and use it to update vulnerabilities identified in this report that are sensitive to sea water levels.

2.4.9 FLOODING

For the purposes of this study, flooding is assumed to be generated by two different mechanisms:

- surface flooding associated with extreme rainfall events; and
- flooding associated with the Fraser River.

Climate change impacts on extreme rainfall have been discussed earlier in the report. It is difficult to define a simple relationship between surface flooding and rainfall since flooding of this nature is often highly localized and dependant on antecedent conditions. In general, surface flooding is expected to increase with rainfall.

The Fraser River freshet is snowmelt-generated and occurs in late spring or early summer, and is not highly correlated with local rainfall. Previous research indicates that climate change may decrease the magnitude of the freshet peak flow and shift the timing to earlier in the spring (Morrison et al, 2002). However, it is not known how large-scale changes such as mountain pine beetle and increase in land development may modulate the freshet response.

Recent modelling of the lower Fraser River indicates that the design flood profile in the lower river is governed by the winter profile (the 200-year return period winter storm surge with high tide combined with the Fraser River winter flood) (nhc, 2006). The winter profile exceeds the freshet profile starting at a point 1,400 m downstream of the Alex Fraser bridge crossing, for the entire lower 28 km of the river. This implies that Fraser River flood events that could impact the VSA would likely occur in the winter.

As reported in the modelling study, in the reach where the winter design condition governs, the magnitude of the river discharge has almost no effect on the computed water level (nhc, 2006). This indicates that during winter flood conditions the ocean level has a high degree of control on the river profile. Therefore climate change impacts to Fraser River flooding within the VSA will be related to impacts on storm surge rather than to impacts on discharge. It should be noted that projected increases in rainfall for the VSA would be unlikely to significantly impact Fraser River discharge given the relative size of the watershed.

2.5 SUMMARY OF CLIMATE CHANGE ASSUMPTIONS

Based on an assessment of the available climate change data, climate events were identified for the vulnerability assessment. Climate events included in the analysis are summarized in Table 2-8.

Table 2-8: Summary of Climate Events.

Climate Event	Estimated Change
Intense Rain	Increase in 1-day maximum rainfall: 17% by 2050s (Ouranos)[1]
Total Annual / Seasonal Rain	Increase in total annual precipitation: 14% by 2050s (Ouranos)
Sea Level Elevation	Increase in global sea level elevation[2]: 0.26 m by 2080s (Ouranos) to 1.6 m by 2100 (Rohling et al, 2007)
Storm Surge	Not quantified. Likely to increase[3].
Floods	Not quantified. Likely to increase.
Temperature (extreme high)	Increases in monthly maximum temperature: 1.4°C to 2.8°C by 2050s (Ouranos)
Drought	Modelling is inconclusive in trend at the 2020 time horizon. Average maximum length of dry spell may increase by about 0.25 days by 2050s (Ouranos).
Wind (extremes, gusts)	Not quantified. Likely to increase.

Notes:
1. Estimate is based on total precipitation, which is assumed to be approximately equivalent to rainfall in the VSA.
2. Does not include local effects such as subsidence and atmospheric effects.
3. Storm surge is a significant contributor to extreme high water events and therefore lack of quantitative data is a critical information gap.

Metro Vancouver

Vulnerability of Vancouver Sewerage Area Infrastructure to Climate Change

Legend

🟨 **Vancouver Sewerage Area Catchment**

KERR WOOD LEIDAL
associates limited
CONSULTING ENGINEERS

Project No.	Date
251-219	March 2008

Vancouver Sewerage Area Location Map

Figure 2-1

Map Document: (O:\0200-0299\251-219\430-GIS\MXD_Rp\251219Fig2-1_V2.mxd)
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Section 3

Infrastructure

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3. INFRASTRUCTURE

3.1 INTRODUCTION & OBJECTIVES

This section of the report covers the first two steps of the PIEVC Protocol, *Project Definition* and *Data Gathering and Sufficiency* as they relate to the infrastructure. The objectives of these steps are to determine which components of the infrastructure will be studied and to develop an understanding of how the infrastructure currently functions.

Appendix A contains the PIEVC Protocol worksheets that KWL and AE completed. The worksheet tables that cover the first two protocol steps are as follows:

Worksheet 1

- Table 4.1.1
- Table 4.1.2
- Table 4.1.3
- Table 4.1.4
- Table 4.1.5
- Table 4.1.6
- Table 4.1.7

Worksheet 2

- Table 4.2.1
- Table 4.2.2
- Table 4.2.4
- Table 4.2.5
- Table 4.2.6
- Table 4.2.7

KWL and AE used the worksheets to log preliminary ideas and information as they refined the project scope. As a result, the information contained within the report document supersedes that contained in the worksheets.

3.2 VANCOUVER SEWERAGE AREA

The VSA includes the sewer systems of the City of Vancouver, the University Endowment Lands, the University of British Columbia, and small portions of the City of Burnaby and the City of Richmond. The VSA is approximately 13,000 hectares.

The replacement value of the sewer system, both municipal and regional, in the VSA is valued at well into the billions of dollars. The value of the VSA's assets highlights the need for a sound and proactive management approach. As the sewer infrastructure was built over many decades, so too should the system's repair and replacement take place over many decades. This strategy leads to fiscally reasonable programs and does not place the burden of a potential infrastructure crisis on any particular generation of the area's inhabitants.

3.2.1 COLLECTION SYSTEM

The VSA's first sewers were constructed in the City of Vancouver in 1890, more than 100 years ago. Beginning in 1911, major trunks and outfalls were built. These trunk sewer systems were combined sewers – systems in which the same pipe carries both sanitary sewage and stormwater runoff – designed to discharge untreated wastewater to False Creek, English Bay, Vancouver Harbour, or the North Arm of the Fraser River. Building combined sewer systems was a common practice in the early 1900s, mainly because it was less expensive to install one pipe in the ground rather than two.

Historically, the design of some combined sewers was based on IDF (rainfall intensity-duration-frequency) curves but some of the very old sewers may have been sized more for practical operational reasons that aren't well documented.

Originally, prior to commissioning the IIWWTP, these combined sewers were designed to discharge directly to the receiving bodies of water. In the early 1950s, the need to eliminate the direct discharge of sanitary sewage became apparent. Consequently, a system of major interceptors was built to convey sanitary sewage to a central location for treatment (Iona Island).

The size of the interceptors enabled conveyance of all sanitary sewage to the central treatment plant in dry weather. During wet-weather periods, however, the interceptors could convey only a portion of the stormwater. Again, economic considerations drove the interceptors' design. The portion of the combined flow that the interceptors could not convey was removed from the system by allowing CSOs at designated overflow points. This overflow provides a "safety valve" that prevents back-ups of untreated wastewater into homes and businesses, flooding in city streets, or bursting underground pipes.

Metro Vancouver's plan is to reduce, then eliminate, CSOs through the process of gradual conversion to a separate sewer system. Generally, sewers at the municipal level are being separated first. Separate municipal storm and separated sewers convey water to combined Metro Vancouver trunk sewers. Starting in the early 1970s, the City of Vancouver began a sewer reconstruction program to maintain their aging system. As part of this program, combined pipes were replaced with separate sanitary and stormwater piping systems. Currently, over 40% of the COV has a separate system.

Metro Vancouver has committed to elimination of CSOs by 2050 in the current LWMP. This pilot study is timely, as a planned revision of the LWMP is currently underway. By LWMP policy, no new combined sewers are to be built in the region.

3.2.2 IONA ISLAND WASTEWATER TREATMENT PLANT

The VSA is served by the IIWWTP, the second largest wastewater treatment plant in Metro Vancouver and the first sewage treatment plant constructed in the region. The plant, located at the mouth of the North Arm of the Fraser River, began operating in 1963. The plant provides primary treatment to wastewater from approximately 600,000 people before discharging it through a 7 km, deep-sea outfall into the Strait of Georgia. At this point, the wastewater disperses into the receiving water at a depth of about 90 metres below mean sea level.

The plant has been expanded six times for growth and treatment upgrades, allowing more than 200 billion litres of wastewater to be treated in 2001. The current plan is to upgrade to secondary treatment in the VSA by 2020. Metro Vancouver is committed, through the LWMP, to providing a maximum peak treatment capacity of 17 m^3/s[6].

3.3 INFRASTRUCTURE COMPONENTS

3.3.1 COLLECTION SYSTEM

Figure 3-1 is a map of the collection system showing the infrastructure components. Appendix B contains a system schematic of the VSA. The components selected for study are described below.

PHYSICAL INFRASTRUCTURE

Combined Sewer Trunks. Trunk sewers convey the flow from the municipal mains to the larger interceptors.

Combined Sewer Interceptors. The largest interceptor is the Highbury Interceptor (HI). The English Bay Interceptor (EBI), 8th Avenue Interceptor (8AI), and North Arm Interceptor (NAI) all feed into the HI, which conveys the flow from virtually all VSA sewer catchments to the IIWWTP. Many of the gravity flow trunks and interceptors were originally designed to operate under surcharge[7] during high flows. Over time, as flows have increased, the amount of time the sewers operate under surcharge has increased.

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[6] GVRD's Liquid Waste Management Plan 2001, p. 18.

[7] Surcharge is a condition where the hydraulic grade line rises above the crown of the pipe. Surcharge can occur without overflow in a gravity sewer if either 1) the HGL is above the crown but below the ground surface, or 2) the manholes are sealed and the pipe behaves as a force main.

Designated Force Mains. In some locations pump stations lift sewer flows from lower elevations through force mains to trunks and interceptors at higher elevations. These force mains are considered "designated force mains", to differentiate them from gravity mains that operate under pressure during surcharge.

Siphons. A triple-pipe siphon under the Fraser River conveys flow from the HI to the IIWWTP.

Outfalls. Most flow is conveyed to the IIWWTP; however, Metro Vancouver has fourteen outfalls that discharge flows to receiving waters, either the ocean or the Fraser River, during heavy rain events or certain operational conditions. These discharges are referred to as combined sewer overflows (CSOs).

Pump Stations & Wet Wells. Metro Vancouver operates nine pump stations in the VSA.

Manholes. A large number of manholes in the VSA have bolted lids so that during system surcharge, the manholes provide additional storage capacity without allowing wastewater to overflow onto the streets.

Flow & Level Monitors. Monitors throughout the system are used to collect information on system functioning and / or provide information for real-time controls.

Flow Control Structures. Weirs are used to measure flow and to prevent CSOs by directing flows until overtopping occurs. Gates are used limit or stop flow, and their position is controlled by flow measurement at an associated weir.

Grit Chambers. A few grit chambers are located within the collection system network. Grit chambers are designed to slow flow so that solids such as rocks and sand drop out of the waste stream, preventing damage to pipes, weirs or pump stations.

SUPPORTING SYSTEMS / INFRASTRUCTURE

Power Sources. Power is required at the pump stations, flow monitors, control gates and SCADA locations. Power is provided by BC Hydro, except at IIWTTP as discussed below.

Communications. Modes of communication include telephone, two-way radio, e-mail, Internet, and importantly, telemetry (SCADA). SCADA signals are sent by antenna from control points (e.g. a weir) to a control device (e.g. a gate) and to the operations centre.

Transportation. Transportation refers to the road conditions and driving conditions that can affect operations and staff response time.

Personnel, Facilities, and Equipment. Consideration is given to facilities, equipment and staffing situations not discussed under specific items above. This includes the Lake City Operations Centre and works yards.

Records. Records includes data collected concerning daily infrastructure operations as well as weather conditions and events.

KEY OPERATIONS FOR CSO MANAGEMENT

The routing of flow to either the outfalls or the IIWWTP depends on complex hydraulic conditions that are partially regulated by control structures throughout the system (GVRD 2003, GVRD 2005). A study of the full extent of operational tools for CSO management is outside the scope of this study. A couple of key operations are discussed below.

During significant wet weather events, the lower sections of the HI and the western sections of the NAI are heavily surcharged, causing CSOs. The surcharging is caused by collection system capacity restrictions and IIWWTP influent pumping capacity and hydraulics (high wet well levels). (Metro Vancouver has studied the benefits of lowering the wet well levels (pumping more into the IIWWTP) during wet weather events).

Flow is measured at a weir located at Highbury Street and 4th Avenue, at the upstream end of the HI. This information is sent via SCADA to the Yukon Gate, located on the 8AI at Yukon Street. When flows rise high enough in the HI that there is a risk of causing CSOs into English Bay, the Yukon Gate closes, preventing additional flows from entering the HI from the VSA's eastern catchments.

3.3.2 IONA ISLAND WASTEWATER TREATMENT PLANT

PROCESS

The IIWWTP was initially constructed in 1960 and has undergone several expansions and upgrades since that time. Figure 3-2 illustrates a simplified process flow diagram for the current IIWWTP.

The following timeline highlights the main expansion and upgrade dates:

Stage 1 (1960)	screens influent pumping station grit channels primary treatment trains #1 to #5 digesters #1 and #2 with gas electricity co-generation system administration building sludge control building #1 sludge lagoons maintenance shop building

Stage 2 (1972)	primary treatment trains #6 to 10
Stage 3 (1978)	sludge thickener #2 digesters # 3 and #4 sludge control building #2
Stage 4 (1983)	primary treatment trains #11 to 13
Stage 5 (1986)	primary treatment trains #14 to 15 sludge thickener #1
Stage 6 (1986)	effluent pumping station with jetty conduits, control structure and deep sea outfall

Screening. Following discharge from the siphons, six (6) vertical bar screens (12.7 mm bar spacing) remove course debris from raw wastewater.

Influent Pumping. After screening, raw wastewater is lifted into the treatment process by the influent pumping station. The station consists of six (6) centrifugal pumps.

Grit Removal. Grit removal is provided at two locations at the IIWWTP. Screened wastewater discharged from the influent pumping station is first conveyed through six (6) long, narrow channels equipped with longitudinal scraper mechanisms, where some initial grit removal occurs. The flow then enters the influent channel, where it is distributed to fifteen (15) primary treatment trains. Pre-aeration tanks, located at the head of each primary treatment train, provide additional grit removal and oxygen entrainment via a course-bubble aeration system.

Primary Clarification (including CEPT). Following the pre-aeration tanks, the wastewater enters the associated primary clarifiers (15 in total) that remove settleable solids and the associated carbon that exerts a biochemical oxygen demand in the wastewater. Primary effluent is collected in the effluent channel and directed to the effluent pumping station and marine outfall.

The IIWWTP also currently includes a temporary chemical storage and handling facility, which allows a chemically-enhanced primary treatment (CEPT) operation mode. Addition of a primary coagulant (i.e. aluminum sulphate), to the wastewater in the distribution channel downstream of the grit removal channels, and an anionic organic flocculent aid, into both sides of each pre-aeration tank, promotes coagulation and flocculation of non-settleable colloidal material contained in the wastewater, thus increasing its removal in the clarifiers. CEPT operation assists the IIWWTP in meeting its current regulatory requirements for effluent quality.

Sludge Thickening. Primary sludge generated in the clarifiers is pumped to two (2) gravity thickeners. Thickened sludge is pumped to the anaerobic digester system.

Sludge Digestion. Thickened primary sludge undergoes mesophilic (37°C) anaerobic digestion in four (4) digester units. Digesters #1 and #2 operate in series, with Digesters #3 and #4 operating in series. Microbially generated gas, containing methane, is directed to three of five (5) co-generation engines that provide electricity generation for on-site use. Two co-generation engines remain off-line for standby. Digester gas can also either be flared off or recycled to the digesters to promote mixing.

Sludge Lagoons. Stabilized sludge is pumped to one of four (4) storage lagoons located on the IIWWTP site. Lagoon supernatant is recycled back to the influent pumping station. Settled, accumulated sludge is occasionally removed from the lagoons and stockpiled on the site.

HYDRAULICS

Treatment Liquid-Stream. Although not an infrastructure component per se, this sub-category refers to the conveyance of wastewater through the IIWWTP once it arrives on site and through the treatment process and up until the effluent pump station. This sub-category considers the ability of the infrastructure to convey the peak flows.

Effluent Disposal. This sub-category deals specifically with the hydraulics of discharging effluent from the IIWWTP site, from the effluent pumping station through to the terminus of the marine outfall in Georgia Strait.

The effluent pumping station contains six (6) centrifugal pumps. Effluent is pumped through the deep sea outfall, which consists of a 4 km jetty section and 3 km marine section that terminates at a depth of approximately 90 m into the Strait of Georgia.

SUPPORTING SYSTEMS / INFRASTRUCTURE

On-Site Pipelines. This sub-category includes the on-site pipelines and channel structures located at the IIWWTP, including the raw wastewater siphons and the land sections of the effluent outfall. This category also includes the jetty section of the outfall as well as the ocean section.

Buildings, Tankage and Housed Process Equipment. This sub-category includes the process tankage and building sub- and super-structures, building mechanical (i.e. HVAC) and electrical systems, and all process-related equipment housed in the buildings.

Standby Generators. There are no dedicated standby generators at the IIWWTP. Instead, the electrical co-generation engines that burn digester gas provide electrical power in the event the site loses BC Hydro power.

The ability of the co-generation engines to power the IIWWTP depends on the wastewater flow rate. Under dry-weather flow conditions (e.g. 2 influent pumps working) they can power the facility but effluent has to be directed to the beach outfall rather than the deep sea marine outfall. In this situation the effluent pumps draw too much power to run on the power supplied by the co-generation engines alone. Depending on the wastewater flow rate and influent pumping requirements, some electrical loads may need to be shed by taking non-essential equipment off-line.

If a BC Hydro power outage occurs during a wet-weather, high flow event, some fraction of the wastewater will need to be bypassed around the treatment process and subsequently blended with primary effluent before the blended effluent is discharged to the beach outfall.

3.4 SPECIFIC JURISDICTIONAL CONSIDERATIONS

3.4.1 COLLECTION SYSTEM

Components of the Metro Vancouver collection system originate in each of the Cities of Burnaby, Richmond and Vancouver and access is provided by easements where required on private property.

Metro Vancouver has an approved LWMP (LWMP, 2002) formed under the Province of British Columbia's *Waste Management Act (*now the *Environmental Management Act).* Specific provisions in the LWMP include:

- As a condition of provincial acceptance of the LWMP the minister has directed that Metro Vancouver "eliminate all sanitary sewer overflows in the district that occur during storm or snowmelt events with less than a 5-year return period, by January 31, 2012";

- Following Commitment C15, Metro Vancouver will “"target elimination of combined sewer overflows in VSA by 2050".

- Commitment C13 is devoted to operational improvements to reduce CSOs, and identifies numerous targets to fast track the elimination of Clark Drive CSOs earlier than 2050.

The LWMP also outlines numerous policies necessary to meet the commitments. A complete listing of the policies is too extensive to list here. For convenience, a copy of the LWMP can be obtained online at http://www.gvrd.bc.ca/sewerage/lwmp.htm.

Other key legislation relevant to Metro Vancouver operations includes *The Municipal Act* and *The Greater Vancouver Sewerage and Drainage District Act.*

Of note, as the combined sewers in the VSA are separated, ownership of many sewers will transfer from Metro Vancouver to the municipalities. Metro Vancouver will operate the separated sanitary sewers while the municipalities take over the storm sewers, potentially transferring some risk of storm overflows from Metro Vancouver to the municipalities.

3.4.2 IONA ISLAND WASTEWATER TREATMENT PLANT

Metro Vancouver operates the IIWWTP under a variety of jurisdictional considerations. Most directly, under its LWMP, the IIWWTP is regulated by an Operational Certificate specific to the facility.

The LWMP also commits Metro Vancouver to upgrade IIWWTP to full secondary treatment no later than 2020 (amended LWMP Commitment C8).

Effluent discharged from the IIWWTP is also subject to the federal Department of Fisheries and Oceans *Fisheries Act*. Under the general provisions of Section 36 of the Act, deleterious substances are not to be discharged to fish-bearing waters.

The federal government is planning to introduce a new wastewater effluent regulation under the *Fisheries Act* in 2009. This regulation will have evolved from the ongoing work of the Canadian Council of Ministers of the Environment (CCME) and Environment Canada to develop a Canada-wide strategy for the management of municipal wastewater effluent. Once legislated, this regulation will apply to the IIWWTP facility.

Metro Vancouver controls the non-domestic discharges to the IIWWTP through its Sewer Use Bylaw No. 164.

3.5 DATA SUFFICIENCY

The *Project Definition* step of the assessment is intended to compile general information on the infrastructure details. At a broad level, several recent documents provided a good general description of the key process elements at the IIWWTP as well as the history of facility development over time. System maps and GIS data provided sufficient information on the major components of the collection system. Communications with Metro Vancouver staff helped to fill in some of the development details that were absent from these materials. From the perspective as to what comprises the IIWWTP and the collection system, no significant data gaps were obvious.

The *Data Gathering and Sufficiency* step of the assessment is intended to further define the infrastructure. A significant amount of information was gathered during this step of the project - all such material had to be requested from Metro Vancouver, which responded promptly and to the best of its ability. Large volumes of detailed information, in the form of GIS data, Excel spreadsheets, and operational reports, were available for the collection system. However, the complexity, age and multi-stage upgrade and expansion timeline of the IIWWTP presented a variety of challenges in pulling together facility information and data.

The effluent pumping station provides an example of the types of challenges encountered. Although concept- and design-level reports, pump supply contract specifications, and operations and maintenance manual information was reviewed, no clear and concise summary was provided in the reviewed material that documented the design assumptions for the various elements that made up the static head of the outfall system hydraulic curve. Such information would have simplified the assessment of impacts of mean sea level rise and storm surge on outfall capacity.

Regardless of the difficulties, the data and information available on the IIWWTP infrastructure *per se* was generally sufficient for the level-of-detail required for the initial activities of the project.

Metro Vancouver

Vulnerability of Vancouver Sewerage Area Infrastructure to Climate Change

Legend

▲ Major CSO Location (MV)

● Pump Station (MV)

◩ Weir (not all shown)

⊗ Gate (not all shown)

● Bolted Manhole

— Contour Lines (metres)

— Vancouver Sewerage Area Catchment

— Non-MV Pipes (All Diameters)

— MV Sewer Forcemain

Pipe Diameter (mm), showing install date

1916 —	100 - 1200
1915 —	1200 - 2400
1960 —	2400 - 7500

KERR WOOD LEIDAL
associates limited
CONSULTING ENGINEERS

1,000 500 0 1,000
Scale in Metres

Project No.	Date
251-219	March 2008

Vancouver Sewerage Area Existing Infrastructure

Figure 3-1

Map Document: (O:\0400-0499\471-163\430-GIS\MXD-Rp\251219Fig3-1.mxd)
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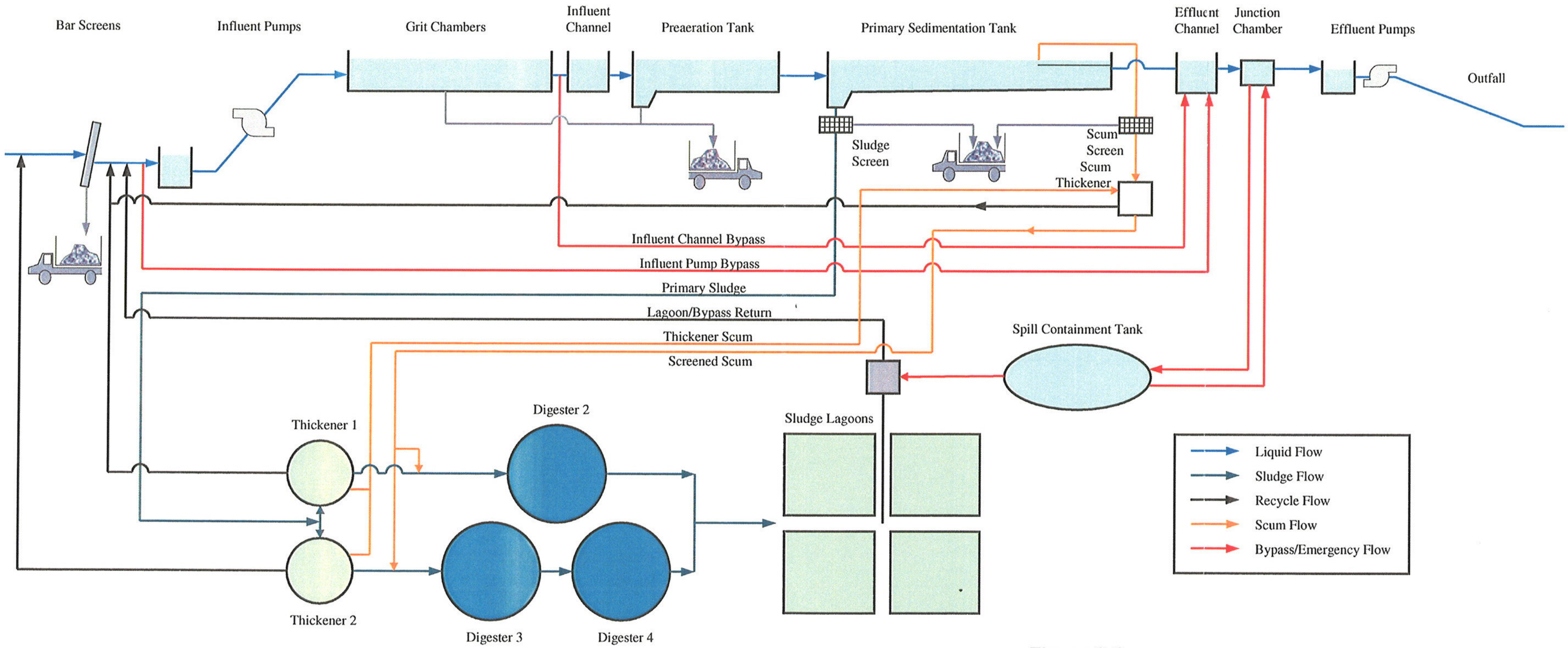
Iona Island WWTP Process Diagram



Digester 1 currently out of service

Figure 3-2
IIWWTP Process Flow Diagram
(courtesy of Metro Vancouver)

Section 4

Vulnerability Assessment

4. VULNERABILITY ASSESSMENT

4.1 OBJECTIVES AND METHODOLOGY

This section of the report covers the third step of the PIEVC Protocol, *Vulnerability Assessment*, corresponding to Worksheet 3. Table 4.3.4 from this worksheet is included in Appendix A. The other tables and analyses required for step three are included in this section of the report.

Step three is a qualitative assessment in which professional judgment and experience are used to determine the likely effect of individual climate events on individual components of the infrastructure. To achieve this objective, the Protocol uses an assessment matrix to assign a probability and a severity to each interaction. Appendix D contains the full Protocol and explanation of vulnerability assessment methodology.

The Protocol specifies that a scaling system with values ranging from 0 to 7 be applied to rank both the climate events and the response severity. Three different interpretations of the scale values are provided in the Protocol. For this project, Method A (climate probability scale factors) and Method E (response severity scale factors) were selected as being the most appropriate based on the available data. Scale values for both methods are summarized in the table below.

Table 4-1: Selected Scale Factor Methods from PIEVC Protocol

Scale	Method A Climate Probability Scale Factors	Method E Response Severity Scale Factors
0	Negligible or not applicable	Negligible or not applicable
1	Improbable / highly unlikely	Very low / Unlikely / Rare Measureable change
2	Remote	Low / Seldom / Marginal Change in Serviceability
3	Occasional	Occasional Loss of some capacity
4	Moderate / Possible	Moderate Loss of some capacity
5	Often	Likely Regular Loss of Capacity and Loss of Some Function
6	Probable	Major / Likely / Critical Loss of Function
7	Certain / Highly probable	Extreme / Frequent / Continuous Loss of Asset

The PIEVC protocol states that the climate probability scale factors are to be used to express a professional opinion regarding the probability that a climate event will occur; however, such a judgement is outside the scope of our professional field of expertise and would be based on very limited data. Instead, the climate probability scale factors have been interpreted as the probability that a climate event will interact with the infrastructure. The scale therefore does not reflect the relative likelihood that the climate event will occur, since this is difficult to quantify. The same approach was applied in the previous PIEVC pilot study for Portage la Prairie (Genivar 2007).

Based on the climate modelling scenarios provided by Ouranos, only those climate events that are likely to occur with a greater frequency or intensity have been included in the matrix. For this reason, extreme low temperature and snowfall are not included in the matrix because model results suggest that extreme low temperatures will increase (i.e. become less severe), and snowfall amount and intensity will decrease.

The vulnerability assessment matrix for this project is included at the end of this section. Under each climate effect column heading, there are four sub-headings, as follows:

1. **Y/N (Yes/No).** This field is marked “Y” if there is an expected interaction between the infrastructure component and the climate effect, and “N” if not.

2. **S_C (Climate Probability Scale Factor).** This is the assumed probability of an interaction between the infrastructure component and the climate effect.

3. **S_R (Response Severity Scale Factor).** This is the assumed severity of the interaction.

4. **P_C (Priority of Climate Effect).** This is calculated as S_C multiplied by S_R. This priority value is used to determine how the interaction will be assessed in the next steps of the protocol. Because this is a qualitative assessment, the P_C should not be used to prioritize recommended actions.

At the end of this assessment, three categories of infrastructure-climate interactions emerge:

1. **$P_C \geq 36$.** Strong probability of a severe effect. These effects are discussed in the recommendations section of the report.

2. **$12 < P_C > 36$.** Possibility of a major effect. These effects are considered to be in a “grey area”, where it is uncertain whether the impact is sufficient to develop recommendations. In Step 4 of the protocol, a quantitative analysis is used to determine which effects to leave aside and which to discuss further.

3. **$P_C \leq 12$.** Unlikely to have much effect. These infrastructure-climate interactions are left aside without further analysis or recommendations.

To complete the vulnerability assessment, additional data and information was gathered as needed from requests to Metro Vancouver, consultations, and a workshop.

4.2 CONSULTATIONS & WORKSHOP

4.2.1 CONSULTATIONS

In addition to data requests handled by project team staff at Metro Vancouver, direct consultation was initiated in a series of interviews and site meetings.

Collection System

Four interviews were held with key personnel familiar with operations, emergency preparations, and design in the VSA. Notes from these interviews have been worked into the text that follows. Additionally, the following items of interest from the interviews are noted:

- Emergency Response Plans (ERPs) exist on three levels: Site Specific, Division Wide, and Corporate. IIWTP has its own ERP focused on fires, flooding and heavy rain.

- Currently, many Metro Vancouver facilities are not equipped for power failure. Previously, design criteria for facilities were not focused on redundancy because sewers went directly to the sea. Portable generators are used in the case of power failure. Many new pump stations have back-up power. There is a program in place to install back-up power at all facilities, but it is not yet complete.

Iona Island Wastewater Treatment Plant

Project staff met with IIWWTP management and Metro Vancouver WWTP Division staff on December 12, 2007 at the IIWWTP for a facility tour and consultation session. Beyond this session, many communications were initiated with IIWWTP management and operations staff to obtain additional information on facility operations, current issues and potential future issues. The consultation session and staff communications provided valuable information to the project team.

4.2.2 WORKSHOP

On Friday January 8, 2008, a workshop was held at the Hilton Hotel in Burnaby. The workshop brought together participants from:

- Metro Vancouver;
- PIEVC;

- City of Vancouver;
- City of Burnaby;
- Kerr Wood Leidal; and
- Associated Engineering

The objectives of the workshop included:

- learning more about interactions between infrastructure components and weather events;
- identifying anecdotal evidence of infrastructure responses to weather events;
- discussing other factors that affect infrastructure capacity;
- compiling data for the quantitative analysis (e.g. rated capacity of infrastructure components to withstand heat, wind, submersion, etc.); and
- identifying actions that could address climate effects.

Information obtained during the brainstorming session and the roundtable discussions has been incorporated into this report.

4.3 ASSESSMENT RESULTS

4.3.1 GENERAL

The tables at the end of this section summarize the results of the vulnerability assessment and the text below provides the rationale behind the values in the matrix table.

COLLECTION SYSTEM

The highest severity ratings have been given to performance responses that lead to environmental contamination or risks to public health and safety (primarily CSOs and wastewater overflows).

Planning for the effects of extreme events can be aided by recording not only the weather event data, but also by logging system responses. In the case of the conveyance system, essential data to collect includes daily CSO volumes at each outfall, sewer flows at key points, such as control points, and maintenance and operations records related to extreme events. The values in the "Records" row on the assessment matrix indicate the importance of compiling records for the particular climate effect.

Extreme weather events also increase construction costs directly through delays, wear and tear on materials and equipment, and increased insurance costs for contractors.

IONA ISLAND WASTEWATER TREATMENT PLANT

The primary performance responses considered in the IIWWTP Vulnerability Assessment were related to functionality, operations and maintenance, and integrity of both the infrastructure components and the site itself. Within these broad categories, capacity and redundancy, which impacts capacity, were of particular importance. The discussions contained in the following sections highlight specific performance responses considered in the Vulnerability Assessment.

4.3.2 INTENSE RAIN

COLLECTION SYSTEM

High intensity short duration (1-12 hour) storms are generally a greater concern for municipal collection systems than for regional facilities, and Ouranos did not provide climate change effects for rainfall durations less than 24 hours. Intense rain in this context refers to maximum 24 hour rainfall and the resulting peak flows and potential for localized flooding.

Exceeded capacity or failure of larger mains has a more severe impact than failure of smaller mains. The matrix values are based on the current, combined sewer system.

Combined Sewer Trunks

Rainwater enters combined sewer mains via the street catchbasins, roof leaders and drain tiles connected to collection system mains. It is certain that increased rainfall intensities and volumes will lead to increased flows in the combined sewers, in the absence of other mitigating system changes. The effect will be reduced capacity to convey sanitary flow to the IIWWTP; instead, CSOs will be more frequent and discharge greater volumes.

Combined Sewer Interceptors

The difference between the trunks and interceptors is that the capacity of the interceptors is more critical for preventing CSOs: the effect of capacity exceedance for these larger mains would lead to higher CSO volume and CSOs at more locations. In consequence, the severity of impact is rated higher than for combined sewer trunks.

Sanitary Mains

Even in a completely separated storm sewer and sanitary sewer system, rainwater enters sanitary sewer mains through inflow and infiltration (I&I). Inflow is the direct ingress of water from sources such as storm-sewer cross-connections and overland flow through manhole lids. Infiltration occurs when water first seeps into the ground then enters the pipes or manholes through defects. Sanitary mains are designed to convey some I&I; currently the LWMP allows for a maximum of 11,200 Litres per hectare per day for storms with less than a five year return period. It is certain that increased rainfall intensities and volumes will lead to increased I&I. The impact on the VSA system as a whole (i.e. the contribution to CSOs) is currently low to moderate, due to the relatively small proportion of sanitary mains, and the redundancy of the combined system as it exists today.

As the combined system is increasingly separated, I&I will become the primary concern with increasing rainfall (i.e., increased intensity and increased total annual volume). Metro Vancouver's I&I reporting template standard acknowledges a linear relationship between rainfall and I&I. I&I rate creep with climate change induced rainfall increase is a key consideration for the current revision of the LWMP. Analysis of the relationship between increased rainfall and I&I rates in the VSA is not directly feasible because of the combined sewer system. However, it is recommended that Metro Vancouver investigate similar relationships in other separate sewer catchment areas.

Designated Force Mains

Pumps and force mains are designed in conjunction with each other, such that force mains convey design flows at an acceptable velocity and head loss. The effect of increased rainfall (and system flow) will be increased periods of (or more continuous) operation of the forcemain, or increased periods of higher flow and velocity as additional pumps within a station are required to operate. The resulting impact is increased wear.

Under this scenario, the probability of interaction is high, but the severity of response is not considered to be high.

Siphons

Increased rainfall would increase the flow, velocities, and headloss in the siphons, which has the potential to cause backups down the Highbury Interceptor, resulting in CSOs. Information gathered from Metro Vancouver during this study, however, indicates that the siphons are not understood to be vulnerable.

Outfalls

Increased rainfall will increase the flows in the outfalls. If the outfalls are undersized for the flows, higher discharge velocities will lead to erosion at the mouth of the outfall pipe, or, for very high flows, the outfalls could act as choke points, with flow surcharging upstream. It is not expected that these effects will be severe based on the current effective operation of the outfalls.

Pump Stations & Wet Wells

Increased flows at the pump stations may exceed pump station capacity, which could result in overflows locally or upstream. The health and environmental impact would be considered severe, but based on current operation the probability is low to occasional.

In addition, more incidents of high flows would lead to smaller windows for maintenance of pump stations and downstream sewer infrastructure, although this is more strongly related to annual rainfall statistics.

Manholes

Increased rainfall would result in increased flows through the manholes. The deeper the manholes, the more capacity they have for storage of peak flows during intense rain events. There is a risk, however, of overflows onto the street if the wastewater rises to ground level and the manhole is not sealed and bolted. As discussed in Section 3, some sections of the system are designed to operate under surcharge conditions during heavy rain events (i.e., manhole lids are bolted shut).

With heavier rain events in the future, it is possible that additional sections that currently have unbolted manholes will also surcharge. Though it is certain that flows in manholes would increase with more rain, it is less certain that these flows would cause a severe response (of wastewater overflows onto the street).

Flow and Level Monitors

Some types of monitors may not work properly under extreme high flow conditions, such as those that would occur during high flow events. As a result, data on event magnitude would be unavailable. More importantly, if a particular monitor is linked to operation of a control structure, the sewer system may not work as intended. There is currently insufficient information on the types of monitors and their sensitivity to know the likelihood and nature of these performance responses; furthermore, it was noted during information gathering that several of the flow monitors are not currently serviceable.

Therefore, they have been assigned a moderate probability of interaction with a major consequent performance response.

Flow Control Structures

Performance of flow control structures such as gates and weirs is not expected to degrade with increased peak flows, however, operation or sizing of the structures may be influenced.

For the vulnerability assessment, the likelihood is considered moderate to probable, with a moderate severity.

Grit Chambers

During low flows, coarse materials may remain on the bottom of the collection system pipes while finer grit is carried with the flows (Andoh 2007). During peak flows, the higher velocities mobilize the coarser materials. More intense rain events would mean that coarse materials would be caught by the grit chambers more frequently, though the total annual grit load may be the same. As a result, the chambers may need to be cleaned more frequently.

IONA ISLAND WASTEWATER TREATMENT PLANT

IIWWTP Process and Hydraulics

Hydraulic constraints within the collection system physically limit the amount of wet-weather wastewater flow, impacted by rainfall induced inflow and infiltration and stormwater, which can be conveyed to the IIWWTP. Therefore, even though climate change may result in an increase in the magnitude and frequency of intense rainfall events and thus increase the potential to generate wet-weather flows, higher peak flow rates are not expected to be received at the IIWWTP, given the LWMP design limit of 17 m^3/s.

However, more frequent wet-weather events (i.e. events per year) could impact the treatment process in other ways. For example, primary clarification performance may be reduced during wet-weather flow events, which could result in more days per year with increased contaminant mass loading to the marine environment, in the short-term, and to the secondary treatment system in the long-term. Similarly, grit removal efficiencies are notably reduced during high-flow events, which results in grit transfer to the anaerobic digesters via primary sludge. In the same context, increased duration of individual wet-weather events (i.e. hours per event) could impact the IIWWTP in a similar manner.

In addition, increased frequency of such events would reduce process redundancy “windows” (e.g. clarifiers and screens taken out of service for maintenance). This situation could leave the IIWWTP with greater exposure to operations difficulties and more frequent events with increased primary effluent loading. From a treatment liquid-stream hydraulic point of view, current difficulties with flooding of the Parshall Flume used for flow measurement and the v-notch weirs in the primary clarifier effluent lauders could be exaggerated.

From an operations perspective, more frequent wet-weather events would also impact influent and effluent pumping energy requirements.

Overall, the probability of intense rain impacting liquid-stream treatment process performance and hydraulics, as well as effluent disposal hydraulics, was deemed to be probable. The assigned response severity varied with infrastructure component on the basis of available redundancy and importance in overall system.

Intense rain events would directly impact the sludge lagoons through the effects of direct precipitation onto them. However, given the relatively short duration of intense rain events and the volume of material in the lagoons, the severity of this impact was judged to be very low.

IIWWTP Supporting Systems / Infrastructure

Increased maintenance should be expected due to additional wear and tear on liquid-stream process mechanical components.

4.3.3 TOTAL ANNUAL / SEASONAL RAIN

COLLECTION SYSTEM

Collection System Physical Infrastructure

Increased rain will lead to increased flows within the collection system, but the intense events, not the average rainfall, cause the significant performance responses. However, higher average rainfall is due to both more intense rain and more rain days with rain, which reduces maintenance windows. This would be the case for most collection system infrastructure, but most vulnerable are trunks, interceptors, and sanitary sewers.

Increased seasonal rainfall will increase flow, dilute wastewater and reduce the wastewater temperature. These factors have potential to improve system performance, reducing corrosion, increasing scouring, and reducing odour.

IONA ISLAND WASTEWATER TREATMENT PLANT

IIWWTP Process and Hydraulics

In most seasons the average total rainfall amount is estimated to notably increase because of climate change effects. While some of the additional rainwater that enters the collection system may not reach the IIWWTP because it will cause collection system overflows during more intense events, some fraction of the entering rainwater will in fact be conveyed to the IIWWTP in the wet-weather flows. Therefore, it is highly probable that increases in total annual / seasonal rain will impact liquid-stream treatment process performance (e.g. effluent quality and mass loading in primary effluent), capacity (e.g. displacing capacity for generated wastewater) and operations (e.g. increased influent and effluent pumping costs), as well as hydraulic capacity, in some manner.

Alternately, the sludge lagoons will be impacted directly by increased rainfall amounts over extended periods, which could impact sludge storage volumes and the quality of lagoon supernatant returned to the liquid-stream treatment process.

In terms of the severity of infrastructure responses, a moderate value has been assigned to the process and hydraulic components.

IIWWTP Supporting Systems / Infrastructure

Increased maintenance should be expected due to additional wear and tear on mechanical components.

4.3.4 SEA LEVEL ELEVATION

COLLECTION SYSTEM

Sea level rise will affect discharge hydraulics at outfalls, though negative effects will be marginal. A significant rise in sea level, especially combined with high tides and storm surge, could result in sea water ingress to the collection system, though the impact of this on the collection system itself would be minimal.

IONA ISLAND WASTEWATER TREATMENT PLANT

IIWWTP Process

A general rise in average sea level is projected to occur due to climate change and, in theory, there is the potential for a climate effect on the wastewater treatment process. Specifically, sea water intrusion into the collection system (e.g. at IIWWTP, pump station wet-wells are typically below sea level, as is some tankage), if it were to occur due to rising sea level, could impact the ionic strength and relative concentrations of ions in wastewater. In turn, particle coagulation and flocculation in the primary clarifiers and gravity sludge thickeners, and thus performance, could be impacted. However, based on information available, the probability of a climate effect is judged to be remote with a similarly low infrastructure severity response.

IIWWTP Hydraulics

An increase in the average sea level would impact IIWWTP effluent disposal hydraulics. Here the primary context is the additional energy needed to pump effluent through the marine outfall due to the increase in the static head. Given the sea level predictions, it is highly probable that there will be a climate effect on this infrastructure component. In this context, the severity of this effect may range significantly given the wide range in total dynamic head that the pumps operate against. Overall, a low response severity factor was selected for the assessment.

IIWWTP Supporting Systems / Infrastructure

The IIWWTP is located immediately adjacent to the Pacific Ocean; therefore, an increase in mean sea level will raise groundwater elevations in IIWWTP area. This occurrence will translate into higher hydrostatic uplift forces on below-grade pipelines, open channel conduits and structures that are lower than the current water table elevation. This issue is particularly important for tankage that normally contains wastewater but is drawn down on occasion for maintenance. The potential impact on the deeper structures will likely be limited (e.g. influent pumping station), given the small relative increase in hydrostatic pressure. Shallower structures (i.e. bottom of the sludge hoppers of the primary clarifiers) would see larger relative increases in uplift forces. Overall, the probability of a climate effect was judged to be probable, but with a moderate response severity. These scores were applied to both the on-site pipelines and buildings, tankage and housed process equipment categories.

The IIWWTP is also potentially at risk from increases in average sea level from a site flooding perspective. Most of the IIWWTP site is above a 3.5 m geodetic elevation and thus much higher than a mean sea level elevation that is presumably near the 0.0 m geodetic elevation (i.e. mean sea level at the Lulu Island WWTP = 0.23 m geodetic). However, as noted in Section 2.4, there is considerable uncertainty in the long-term predictions in sea level rise – they vary over one order-of-magnitude. Complicating the situation are local influences such as atmospheric effects and sinking of the land surface at the IIWWTP site. Given the estimated increases in local sea level and the rate of settling of the general geographic land area, it was judged to be remote that this climate effect will impact the IIWWTP site (i.e. buildings, tankage, housed process equipment) in the context of flooding. However, in recognition of the severity of an effect should there be one, an extreme response severity factor was assumed.

4.3.5 STORM SURGE

COLLECTION SYSTEM

Although little vulnerability is envisioned for the collection system infrastructure, flooding may be caused by storm surge combined with high tide and higher sea level. Assuming no dikes are constructed in low-lying areas, flooding could lead to sanitary contamination near combined sewer overflows.

IONA ISLAND WASTEWATER TREATMENT PLANT

IIWWTP Hydraulics

Given its location in the lower estuary of the Fraser River, extreme water levels in the vicinity of the IIWWTP are governed by a combination of high tides and storm surge during the winter season. This is an important mechanism since climate change is expected to induce higher extreme water levels. Specifically, increases in extreme static head, due to enhanced storm surge, will impact effluent disposal hydraulics from a pumping capacity perspective. Given the linkage between storm surge and hydraulic static head for the outfall system, it is reasonable to assume that there will be a probable climate effect on effluent disposal hydraulics. We have assigned a major response severity factor to this component because of the current capacity of the system, operations experience during storm events, and the redundancy issue.

IIWWTP Supporting Systems / Infrastructure

Increases in storm surge, and associated static head, will also impact the effluent outfall system from an internal jetty conduit/outfall pipe pressure perspective. The severity of this response was deemed to be critical since information exists that suggests the jetty conduit structure is under designed for the original design conditions (AE, 1994). Additional static head, due to climate induced storm surge effects, would exaggerate this deficiency.

Increased storm surge can also potentially impact the IIWWTP site in the context of flooding, although the IIWWTP has not experienced such induced flooding in the past. However, extreme water levels can coincide with large wave events. Several such storms in recent years have generated large wave events that have damaged the foreshore area between the jetty and effluent pump station and necessitated fill and rip rap replacement.

Most of the IIWWTP site is above the recently estimated 2.9 m geodetic elevation total water level (i.e. 1:200 yr return frequency winter storm surge with high tide combined with a Fraser River winter flood, for a 95% confidence interval but excluding climate change and wind wave effects) (nhc, 2006). The same conclusion applies to a 3.5 m elevation that includes an assumed 0.6 m freeboard. However, based on available drawings, much of the site, including the access road, appears to be only minimally higher in elevation than the 3.5 m level. Factoring in the change in average sea level rise and land sinking, as well as potential wind wave effects, suggests that little margin may be available in the future. The probability of a climate effect will vary depending on the magnitude of predicted increase in sea level rise used in the assessment. However, to be conservative, a probable climate probability scale factor and a major response severity factor were selected for the assessment.

4.3.6 FLOODS

COLLECTION SYSTEM

Pump Stations

Street flooding following a rain event may inundate pump stations and damage electrical equipment. Some pump stations are above-ground and others are buried, but generally with critical electrical components above-ground. Older pump stations were not built with flood protection. The risk of pump stations experiencing flooding depends on the location and design of individual pump stations, with some at high risk and others at low risk. Flooding affects access, making it difficult to refuel standby power. The impact of a pump station failure would be wet well overflow that could cause local environmental contamination and human health risk. Although the impacts are severe, the probability of flooding induced vulnerability is moderate.

Transportation

Street flooding would make it more difficult for Metro Vancouver crews to respond to emergency situations in the vicinity of the flooding (such as pump station failure as described above).

4.3.7 HIGH TEMPERATURE

IONA ISLAND WASTEWATER TREATMENT PLANT

IIWWTP Process

Most physical and physical-chemical treatment processes are impacted to some extent by temperature. Given the estimated increase in monthly average maximum temperatures, we expect that the probability for a climate effect on the grit removal and primary clarification processes will be remote and it is unlikely that there would be a measurable response in terms the severity of the effect on performance or capacity. Alternatively, it is anticipated that the warmer temperatures will increase the solids fermentation potential within the gravity sludge thickeners and so a moderate climate probability was assigned to this infrastructure component. Increased fermentation will increase odour generation potential and return additional soluble carbon to the liquid-stream treatment process that will ultimately leave the system in the primary effluent, but the response severity for these effects is expected to be low.

IIWWTP Supporting Systems / Infrastructure

Anaerobic sludge digestion requires heat inputs to maintain internal digester temperatures in the appropriate range (e.g. 38^{o}C for mesophilic units). Warmer ambient outside air temperatures will reduce the heating requirements and thus create additional capacity in the existing heating system. Because this situation is a benefit of climate change, rather than a vulnerability, no scale factors were applied to either the climate probability or response severity.

Increases in extreme high temperatures could also impact heating / ventilation / air conditioning systems (HVAC), which could affect staff working conditions and process equipment (e.g. high temperature cut-out of heat sensitive equipment such as variable frequency drives on electric motors). Although no specific design information was reviewed in this context, Metro Vancouver operations staff did not indicate any particular concerns along these lines under current operations.

Increased ambient temperatures could also impact the IIWWTP infrastructure from a corrosion perspective. Specifically, increased wastewater temperatures would enhance wastewater fermentation in the collection system, in turn producing more hydrogen sulphide. Additional hydrogen sulphide released into the atmosphere at the IIWWTP would augment corrosion at the facility.

Given the estimated increase in ambient temperatures, the probability of this climate effect was deemed to be possible, while the severity response was rated low.

4.3.8 DROUGHT

IONA ISLAND WASTEWATER TREATMENT PLANT

IIWWTP Process

Extended summer dry-weather periods could result in higher strength wastewater (i.e. less rainfall dilution) over longer durations, which could impact primary effluent quality and necessitate more frequent use of CEPT in order to meet primary effluent quality requirements. However, the probability of this climate factor affecting the IIWWTP was judged to be remote given the estimated (i.e. minimal) magnitude of change in the average maximum duration of dry-weather periods. Similarly, the severity response on the IIWWTP was also deemed to be low.

IIWWTP Supporting Systems / Infrastructure

The situation described above could also increase the corrosion potential due to hydrogen sulphide generation and release from the wastewater. Again, due to the minimal change in duration of the dry-weather periods, both the climate probability and response severity factors were assigned low values.

4.3.9 WIND

COLLECTION SYSTEM

Communications

SCADA disruption due to antenna damage during high winds could mean that system controls would not work. Even if rated for high winds, blown debris or nearby tree branches could interfere with an antenna. For example, it was noted that at Highbury Street and Fourth Avenue, there is a SCADA antenna near trees. This antenna signals the Yukon Gate to open and close, based on the level at the Highbury & 4th weir. The gate closure affects CSO locations and volumes.

Power Sources

As mentioned previously, not all facilities have redundant power supplies. Frequency or severity of power outages may increase with increased convective wind storms.

IONA ISLAND WASTEWATER TREATMENT PLANT

IIWWTP Process

Although climate change effects on wind-related events are difficult to predict, as noted in Section 2, an increase in the frequency of wind gusts could impact the IIWWTP operations. The sludge lagoons could be affected directly by more frequent wind gusts, which if sustained could re-suspend settled solids and reduce the quality of lagoon supernatant returned to the liquid-stream treatment process. While the probability that this climate effect could impact the lagoons was deemed possible, the severity response was considered to be low.

IIWWTP Supporting Systems / Infrastructure

An increase in high wind events could result in a higher occurrence of BC Hydro power loss (i.e. power lines blown down). Given the current inability to operate all effluent pumps during high effluent flow events on the power produced by the co-generation engines (i.e. standby generators), it is reasonable to expect that there would be more frequent bypass of effluent to the near shore outfall. This situation is another example of where cumulative climate effects (i.e. intense rain plus high winds during a storm) could impact the IIWWTP. An occasional probability scale factor was assigned to this climate effect, but a likely loss of function response severity factor was identified due to the limitations in on-site power generation in the context of the effluent pumping station.

4.4 OTHER POTENTIAL CHANGES THAT AFFECT THE INFRASTRUCTURE

4.4.1 COLLECTION SYSTEM

A number of upcoming changes will affect the system:

Sewer Separation. It was correctly pointed out by Metro Vancouver staff that the reduction in sewer flow from sewer separation will, in general, be vastly greater than the increase due to climate-based rainfall effects. Sewer separation will significantly decrease inflow into the collection system. Note that design flows at the IIWWTP will remain at 17 m^3/s, as specified in the LWMP. The goal is to achieve complete sewer separation by 2030 in the City of Burnaby and 2070 in the City of Vancouver[8]. Note that the LWMP commitment is to achieve CSO elimination (by 2050) before sewer separation in the VSA is complete. This is possible since elimination of CSOs is not dependent on 100% separation of the combined system.

Since the separation program is still in progress, a unique opportunity exists to adequately size the separate stormwater and sanitary sewers for the effects of climate change.

Another effect of progressive sewer separation frequently identified during the project is increasing wastewater strength, although this is unrelated to climate change factors.

Long Range Plans. Construction projects that are part of long range plans will improve system operations, presumably increasing the ability to manage CSOs; however,

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[8] Based on conversations with Workshop participants.

discussions of the objective of each project are outside the scope of the present study. Following is a list of upcoming construction projects:

- Jervis Forcemain extension from False Creek to EBI and 8AI (2009)
- Highbury Interceptor weir construction at 8AI (2013)
- Columbia Pump Station upgrade (2008)
- Southwest Marine Drive Interceptor twinning, west of HI (2015)
- Highbury Interceptor Siphon Upgrade (2011).

Infrastructure Replacement. Replacement of aging infrastructure decreases the risk of system blockages and provides the opportunity to install larger mains or separate systems. New sanitary sewer mains have lower inflow and infiltration rates than older mains. The design life (for materials, not capacity serviceability) is considered to be 100 years for mains and 50 years for pump stations. As shown on Figure 3-1, a large number of mains have another 50 years of design life, while a large number are nearing the end of their design life.

Green Infrastructure. Increasing efforts at building green infrastructure may be used to increase resiliency in adapting to climate change. Green infrastructure can be defined as "systems and practices that use or mimic natural processes to infiltrate, evapotranspirate, or reuse stormwater or runoff on the site where it is generated" (EPA 2008). The objective of green stormwater infrastructure would be to prevent stormwater from entering sewer pipes. This objective would be achieved by allowing stormwater to infiltrate into the ground or by collecting it and using it in a greywater system (such as for lawn watering or toilet flushing). Examples of green infrastructure include porous pavement, rain gardens, green roofs, and rain barrels.

If sufficient rainwater is kept from entering pipes in the first place, then CSOs could be reduced. This method of reducing CSOs may be less expensive than other methods (EPA 2008) (i.e., separating combined sewer systems or building stormwater retention tanks).

The Federation of Canadian Municipalities has published the *National Guide for Sustainable Infrastructure (InfraGuide)*, which contains best management practices for stormwater management, including the development of green infrastructure components.

Metro Vancouver has completed significant efforts studying and promoting green infrastructure over the past number of years, with the overarching goal of net environmental benefits at a watershed scale. Green infrastructure initiatives are also expected to form a significant component of the updated LWMP, currently under development.

Inflow & Infiltration Reduction and Age Based Rate Decay. Sanitary sewer loads can decrease with inflow & infiltration reduction programs (at the municipal or regional level), but generally increase due to material deterioration over time. Metro Vancouver has initiated a study of the effectiveness of I&I reduction measures that is to be finalized at about the same time as this study. Results are expected to indicate that the 11,200 L/ha/d target set by the LWMP will become increasingly difficult to achieve without increasing effort (i.e. private lateral management etc.) as a result of aging and climate change based rainfall increase.

Population Growth. Population growth will increase sanitary sewer loading over the entire study period. Metro Vancouver has approved the Liveable Region Strategic Plan, which envisions population growth of approximately 1 million people (to 2.75 million) from 1996 to 2021. The growth concentration area (including Vancouver, Burnaby and six other communities) will provide up to 73% of the required housing. The City of Vancouver is planning for an increase from 580,000 in 2006 to 675,000 in 2021. This plan, now known as the Growth Management Strategy, is also undergoing review in 2008.

Land Use. Planned densification may increase total impervious area, leading to more runoff and combined sewer loading. To the contrary, the City of Vancouver has seen significantly declining industrial land uses over the past 20 years, with an associated decrease in process waste stream.

Water Conservation. Water conservation programs reduce indoor water use, decreasing sanitary loading. Another potential effect of water conservation is the reduced inclination to flush the sewer system with potable water (from hydrants). System flushing is used to clear out the deposition of solids in mains that occurs during dry periods, which are expected to increase with climate change.

Seismic Events. Landslides or ground shifting caused by seismic events break or degrade sewer main integrity. Earthquake activity is not thought to be climate change related, however landslide frequency is directly related to saturated soil conditions and heavy rainfall.

4.4.2 IONA ISLAND WASTEWATER TREATMENT PLANT

Many of the IIWWTP works are almost 50 years old, with the most recent works approximately 20 years old. By Year 2020, which is earliest period in the vulnerability assessment, the age of the infrastructure components will vary between about 35 and 60 years old. Based on the Section 1.3 discussion, it can be seen that many major infrastructure components will be reaching the typically expected service life in the relative near term.

As part of their ongoing maintenance activities since the mid-1990s, Metro Vancouver has replaced or upgraded some elements of various systems that support the treatment processes: influent pump electric motors, primary clarifier flights, addition of digester scum mixing system, conversion of digesters #1 and #2 roofs from floating to fixed configuration and replacement digester gas co-generation engines. The facility is on its third set of influent screens.

Metro Vancouver will be embarking soon on a significant program to expand and upgrade treatment in the VSA to full secondary treatment. The upgraded works are intended to be in service by 2020. The planned expansion and upgrade program affords Metro Vancouver the opportunity to design climate change adaptation measures into the facilities as part of regular infrastructure renewal and the secondary treatment program. So while climate change effects may reveal vulnerabilities, Metro Vancouver is in the position to proactively mitigate these challenges.

Metro Vancouver's sewer separation program will also impact the IIWWTP over the long-term. The reduction in frequency of high wet-weather wastewater flow events, as well as their duration, will help to mitigate existing vulnerabilities at the IIWWTP. It is also reasonable to expect that as the policy is implemented over time that it will help to off-set climate change induced vulnerabilities. Many of the potential changes highlighted in Section 4.4.1 also apply to the IIWWTP.

4.5 DATA SUFFICIENCY

The Vulnerability Assessment step of the evaluation required judgements on significance, likelihood, response and uncertainty in the context of the probability of climate effects and the severity of infrastructure responses to the effects. Some judgements could be fairly easily made based on available information – for example, vulnerability of the IIWWTP to flooding due to increases in storm surge sea level. However, many of the judgements had to be made using "indirect" information. For example, while estimated increases in total annual precipitation were available, how this climate effect could translate into wet-weather wastewater flows was unknown – such a complex analysis was outside the scope of the assessment. This complicated assessing the response severity of this climate effect on infrastructure operations, and, more specifically, introduced additional uncertainty into the assessment. Conversely, information obtained from discussions with Metro Vancouver staff provided useful insights which assisted the vulnerability assessment.

Metro Vancouver's LWMP commitments provide secondary treatment in the VSA by 2020. This large infrastructure upgrade program will afford Metro Vancouver the well-timed opportunity to rectify any climate-related vulnerabilities of the existing IIWWTP infrastructure. However, the Vulnerability Assessment was conducted "independent" of this program; that is, any vulnerability of the existing IIWWTP infrastructure, regardless of this impending program, was identified. The same approach was used in the context of Metro Vancouver's 2050 sewer separation policy, which will impact the collection system and IIWWTP over time.

In general, the data available were sufficient for the non-numerical, engineering judgment-based screening purposes of the vulnerability assessment.

Table 4-2 Vulnerability Assessment Matrix

Infrastructure Components	CLIMATE CHANGE EFFECTS																															
	Intense Rain				Total Annual/Seasonal Rain				Sea Level Elevation				Storm Surge				Floods				Temperature (extreme high)				Drought				Wind (extremes, gusts)			
	mm				mm				m				m				m^3				ºC				days				km/h			
	Y/N	S_C	S_R	P_C	Y/N	S_C	S_R	P_C	Y/N	S_C	S_R	P_C	Y/N	S_C	S_R	P_C	Y/N	S_C	S_R	P_C	Y/N	S_C	S_R	P_C	Y/N	S_C	S_R	P_C	Y/N	S_C	S_R	P_C
COLLECTION SYSTEM																																
PHYSICAL INFRASTRUCTURE																																
Combined Sewer Trunks	Y	7	6	42	Y	7	3	21	N				N				Y	6	1	6	N				N				N			
Combined Sewer Interceptors	Y	7	6	42	Y	7	3	21	N				N				Y	1	0	0	N				N				N			
Sanitary Mains	Y	7	6	42	Y	7	2	14	N				N				Y	3	3	9	N				N				N			
Designated Force Mains	Y	4	1	4	Y	4	0	0	N				N				N				N				N				N			
Siphons	Y	5	2	10	Y	3	2	6	N				N				N				N				N				N			
Outfalls	Y	6	2	12	Y	3	2	6	Y	3	2	6	Y	3	2	6	N				N				N				N			
Pump Stations & Wet Wells	Y	6	3	18	Y	7	1	7	Y	2	4	8	Y	2	4	8	Y	4	7	28	Y	3	4	12	Y	2	3	6	N			
Manholes	Y	4	5	20	Y	3	3	9	Y	3	3	9	Y	3	3	9	Y	7	1	7	N				N				N			
Flow & Level Monitors	Y	4	6	24	N				Y	3	3	9	Y	3	3	9	Y	3	4	12	N				Y	4	1	4	N			
Flow Control Structures	Y	4	4	16	Y	3	1	3	N				N				N				N				N				N			
Grit Chambers	Y	6	2	12	Y	4	2	8	N				N				N				N				N				N			
SUPPORTING SYSTEMS / INFRASTRUCTURE																																
Power Sources	N				N				N				Y	1	4	4	Y	1	3	3	Y	1	7	7	Y	2	3	6	Y	5	6	30
Communications	N				N				N				N				Y	2	3	6	N				N				Y	4	7	28
Transportation	Y	6	2	12	N				N				Y	1	3	3	Y	5	4	20	Y	1	2	2	N				Y	5	2	10
Personnel, Facilities, and Equipment	Y	1	1	1	N				N				Y	2	2	4	Y	4	3	12	N				N				Y	4	2	8
Records	Y	7	5	35	N				N				N				Y	7	5	35	N				N				N			
TREATMENT (IIWWTP)																																
PROCESS																																
Screening	Y	6	2	12	Y				N				N				N				N				N				N			
Influent Pumping	Y	6	3	18	Y	7	3	21	N				N				N				N				N				N			
Grit Removal	Y	6	3	18	Y	7	3	21	N				N				N				Y	2	1	2	N				N			
Primary Clarification (including CEPT)	Y	6	4	24	Y	7	3	21	Y	2	2	4	N				N				Y	2	1	2	Y	2	2	4	N			
Sludge Thickening	N				N				Y	2	2	4	N				N				Y	4	2	8	N				N			
Sludge Digestion	Y	6	3	18	Y				N				N				N				N				N				N			
Sludge Lagoons	Y	7	1	7	Y	7	3	21	N				N				N				N				N				Y	4	2	8
HYDRAULICS																																
Treatment Liquid-Stream	Y	6	3	18	Y	7	3	21	N				N				N				N				N				N			
Effluent Disposal	Y	6	3	18	Y	7	3	21	Y	7	2	14	Y	6	6	36	N				N				N				N			
SUPPORTING SYSTEMS / INFRASTRUCTURE																																
On-site Pipelines (includes tankage for sea level event)	N				N				Y	6	3	18	Y	6	6	36	N				N				Y	2	2	4	N			
Buildings, Tankage and Housed Process Equipment	Y	6	3	18	Y	7	3	21	Y	2	7	14	Y	6	6	36	N				Y	4	2	8	Y	2	2	4	N			
Standby Generators	N				N				N				N				N				N				N				Y	3	6	18

Table 4-3: Climate Effect Ratings Between 12 and 36

Infrastructure Component	Climate Variable	Priority of Relationship
COLLECTION SYSTEM		
Physical Infrastructure		
Combined Sewer Trunks	Total Annual/Seasonal Rain	21
Combined Sewer Interceptors	Total Annual/Seasonal Rain	21
Sanitary Mains	Total Annual/Seasonal Rain	14
Pump Station and Wet Wells	Intense Rain	18
	Floods	28
Manholes	Intense Rain	20
Flow & Level Monitors	Intense Rain	24
Flow Control Structures	Intense Rain	16
Supporting Systems / Infrastructure		
Power Sources	Winds(extreme, gusts)	30
Communications	Winds(extreme, gusts)	28
Transportation	Floods	20
Records	Intense Rain	35
TREATMENT (IIWWTP)		
Process		
Influent Pumping	Intense Rain	18
	Total Annual/Seasonal Rain	21
Grit Removal	Intense Rain	18
	Total Annual/Seasonal Rain	21
Primary Clarification (including CEPT)	Intense Rain	24
	Total Annual/Seasonal Rain	21
Sludge Digestion	Intense Rain	18
Sludge Lagoons	Total Annual/Seasonal Rain	21
Hydraulics		
Treatment Liquid Stream	Intense Rain	18
	Total Annual/Seasonal Rain	21
Effluent Disposal	Intense Rain	18
	Total Annual/Seasonal Rain	21
	Sea Level Elevation	14
Supporting Systems / Infrastructure		
On-site Pipelines (includes tankage for sea level event)	Sea Level Elevation	18
Buildings, Tankage and Housed Process Equipment	Intense Rain	18
	Total Annual/Seasonal Rain	21
	Sea Level Elevation	14
Standby Generators	Winds (extreme, gusts)	18

Table 4-4: Climate Effect Ratings Greater than or Equal to 36

Infrastructure Component	Climate Variable	Priority of Relationship
COLLECTION SYSTEM		
Combined Sewer Trunks	Intense Rain	42
Combined Sewer Interceptors	Intense Rain	42
Sanitary Mains	Intense Rain	42
TREATMENT (IIWWTP)		
Process		
Effluent Disposal	Storm Surge	36
Hydraulics		
Effluent Disposal	Storm Surge	36
Buildings, Tankage and Housed Process Equipment	Storm Surge	36

Section 5

Indicator Analysis

5. INDICATOR ANALYSIS

5.1 OBJECTIVES AND METHODOLOGY

This section of the report covers the fourth step of the PIEVC Protocol, *Indicator Analysis*, corresponding to Worksheet 4. The tables and analyses required for step four are included in this section of the report.

The objective of this section is to analyse infrastructure-climate interaction to determine whether infrastructure components have sufficient adaptive capacity to support climate loads. If so, no recommendations are needed. If not, the interaction is discussed further in the recommendations section.

The Indicator Analysis requires the assessment of the various factors (indicators) that affect load and capacity of the infrastructure. Vulnerability exists when infrastructure has insufficient capacity to withstand the effects placed on it. Resiliency exists when the infrastructure has sufficient capacity to withstand increasing climate change effects.

5.2 VULNERABILITY QUANTIFICATION

The Indicator Analysis table is included at the end of this section. As evident in the table, specific load and capacity values are not available. Several reasons explain their absence. The first reason is that most of the climate variables do not place a direct load on the IIWWTP or collection system. For example, wet-weather flows do place a load on the IIWWTP, but a climate variable such as intense rain, which affects wet-weather flows, does not impact the facility directly. Second, in many cases, and consistent with this example, the relationship between the estimated climate effect and the variable directly impacting the infrastructure was unavailable. Third, where there may be a relatively direct impact of a climate variable on the infrastructure (e.g. mean sea level affecting ground water elevations and uplift forces on buried infrastructure), the wide range of individual infrastructure elements at the site precludes a single calculation.

The vulnerability quantification was conducted using a combination of assumptions based on professional judgment in consideration of information reviewed and, in some cases, limited calculations using engineering data available.

Section 5.3 provides further comment on these issues in the context of data sufficiency.

5.2.1 CSO VOLUME ANALYSIS

In order to find a relationship between total CSO and rainfall amount, monthly CSO volume from January 2005 to December 2006 was plotted against average monthly rainfall from nine rainfall gauges in VSA for the same period (Figure 5-1). Although overflows are commonly understood to be triggered by individual rainfall events on the order of 1-24 hours in duration, monthly overflow volumes are the shortest interval available on a historical basis. Furthermore, it was noted that overflows occasionally occur during dry weather (possibly due to operational issues such as power failure or blockage) making it difficult to determine the minimum rainfall or rainfall intensity required to trigger an overflow.

The monthly CSO plotted is the sum of the overflow volume from all 16 outfalls in VSA for each month over the past two years. This was done because similar rainfall events can trigger overflows at various locations depending on the SCADA controlled interceptor operation. Note that CSO volume is normalized to mm by dividing the monthly CSO volume by the total area of VSA.

It can be seen that monthly CSO and monthly rainfall have a solid linear relationship with an R^2 factor of 0.97.

Ouranos has provided seasonal rainfall climate factors. To correlate change in seasonal rainfall with CSO volume, seasonal overflow totals are shown in Figure 5-2. Based on the linear relationship, approximately 30% of the monthly rainfall overflows, regardless of season. Although a strong correlation is shown, the graph should not be considered to illustrate a direct causal relationship. The true relationship between rainfall and overflow volume is likely complex and may involve antecedent soil moisture conditions, distribution of rainfall intensity, and other factors commonly considered in hydrologic modelling.

A late revision to the Ouranos climate scenario report (Appendix C) predicts a seasonal rainfall increase of 18% for the December-January-February period by 2050. This provides an indication that additional sewer separation effort may be required to meet Metro Vancouver's CSO elimination goals. Further study is recommended to identify appropriate measures to meet these goals (which may include adaptive management and further hydrologic and hydraulic modelling).

5.3 DATA SUFFICIENCY

The Indicator Analysis step of the evaluation required judgments on the vulnerability or resiliency of the infrastructure to withstand the climate-induced effects placed on it. These judgments were applied to those infrastructure component and climate effect relationships that had mid-range Vulnerability Assessment scores (i.e. > 12 and < 36).

As noted in the PIEVC Protocol, much of the data needed for the Indicator Analysis step may not exist or be very difficult to acquire. This situation certainly applied to the current study; however, the Protocol recognizes that the analysis requires the application of professional judgment. Such an approach fits well with the stated objective of ranking the relative vulnerability and resiliency of the infrastructure.

Specific comments on data availability is shown in the indicator analysis table that follows.

Table 5-1 Indicator Analysis

Infrastructure Component	**Climate Variable**	**Vulnerability (V_R)** $V_R = L_T/C_T$	**Continue to STEP 5** **Y/N**	**Adaptive Capacity (A_R)** $A_R = C_T/L_T$	**Capacity Deficit (C_D)** $C_D = L_T-C_T$	**Comments / Data Sufficiency**
COLLECTION SYSTEM						
PHYSICAL INFRASTRUCTURE						
Combined Sewer Trunks Combined Sewer Interceptors Sanitary Mains	Total Annual Seasonal Rain (mm)	>1	Y	<1	n/a	These components are considered together since they are all part of the piping system; however, hydraulic model and operations information from MV indicates that the interceptor capacities are key to the presence of CSOs. See the report text for a quantitative analysis of the relationship between rainfall and CSOs. For this analysis, only monthly total rainfall and monthly total CSOs at each outfall were available for use within the scope of this project. To better understand the relationship, it would be necessary to review daily total rainfall and daily total CSO at each outfall, since it is logical that rainfall-driven CSOs are triggered by individual storm events. Increased flows due to climate change could be mitigated by the sewer separation policy (as well as other factors, such as green infrastructure programs). Insufficient information is currently available on expected flow volumes in the VSA during and following the sewer separation program.
Pump Stations and Wet Wells	Intense Rain (mm)	>1	Y	<1	n/a	Climate impacts are related to capacity exceedance during rainstorms. Assessment of individual pump station capacity is a recommended future task. Increased flows could be mitigated by the sewer separation policy. Insufficient information is currently available on expected flow volumes in the VSA following sewer separation.
	Floods (m^3)	>1	Y	<1	n/a	Climate impacts are related to damage caused by water ingress. Some pump stations are more vulnerable than others, due to location and design. There is insufficient information on individual pump stations and localized flood risk to evaluate numerically. Further study is recommended.
Manholes	Intense Rain (mm)	>1	Y	<1	n/a	Climate impacts are related to surcharge conditions during heavy flows caused by rain events. Surcharge in manholes with unbolted lids poses health and environmental risks. More frequent surcharging of manholes with lids currently bolted decreases the maintenance window. Increased flows could be mitigated by the sewer separation policy. Insufficient information is currently available on expected flow volumes in the VSA following sewer separation.
Flow & Level Monitors	Intense Rain (mm)	>1	Y	<1	n/a	Type and condition of each measurement device is currently unknown. Continuous flow monitoring will be key to assessing adaptive capacity.
Flow Control Structures	Intense Rain (mm)	<1	N	>1	n/a	Climate impacts related to increased flows exceeding capacity or causing improper operation. Increased flows could be mitigated by the sewer separation policy. Insufficient information is currently available on expected flow volumes in the VSA following sewer separation. Insufficient information is available on the effects of climate change on daily or hourly rainfall intensities in order to determine future loads and assess if capacity is sufficient.
SUPPORTING SYSTEMS / INFRASTRUCTURE						
Power Sources	Wind (extremes, gusts) (km/h)	>1	Y	<1	n/a	Although climate projections are inconclusive with regards to wind, vulnerability currently exists with respect to lack of available standby power capacity in the event of BC Hydro power loss during a wind storm.
Communications	Wind (extremes, gusts) (km/h)	>1	Y	<1	n/a	Insufficient information is available on the increasing likelihood of SCADA failure under climate change or the effect on individual control points and the system as a whole.
Transportation	Floods (m^3)	<1	N	>1	n/a	Based on professional judgment due to lack of sufficient analysis criteria, it is not expected that greater transportation vulnerability exists due to future changes in flooding.
Records	Intense Rain (mm)	>1	Y	<1	n/a	Climate impact is related to the need to record weather data (hourly/daily flows and rainfall) and incident information (infrastructure performance responses) during weather events.
	Floods (m^3)	>1	Y	<1	n/a	Climate impact is related to (1) the need to record weather data and incident information (infrastructure performance responses) during weather events, and (2) the possibility of localized flooding damaging equipment (such as flow meters) and recorders (such as circular charts)

Table 5-1 Indicator Analysis

TREATMENT (IIWWTP)						
PROCESS						
Influent Pumping	Intense Rain (mm)	**>1**	Y	<1	n/a	Climate impact is related to capacity in the context of redundancy because of more frequent and longer duration wet-weather flow events. Sewer separation policy will mitigate impact to some extent in long-term. Climate change projections were not available in the context of actual wet-weather flows.
	Total Annual Seasonal Rain (mm)	**>1**	Y	<1	n/a	Climate impact is related to pumping energy requirements, as well as capacity since rain water component of wet-weather flows will displace capacity for actual wastewater. Sewer separation policy will mitigate impact to some extent in long-term. Climate change projections were not available in the context of actual wet-weather flows.
Grit Removal	Intense Rain (mm)	**>1**	Y	<1	n/a	Climate impact is related to capacity under high flows (i.e. grit transfer to digesters via primary clarifiers) and redundancy. Sewer separation policy will mitigate impact to some extent in long-term. Climate change projections were not available in the context of actual wet-weather flows.
	Total Annual Seasonal Rain (mm)	**>1**	Y	<1	n/a	Climate impact is related to capacity since rain water component of wet-weather flows will displace capacity for actual wastewater. Sewer separation policy will mitigate impact to some extent in long-term. Climate change projections were not available in the context of actual wet-weather flows.
Primary Clarification (including CEPT)	Intense Rain (mm)	**>1**	Y	<1	n/a	Climate impact is related to capacity in context of redundancy and primary effluent loading. Sewer separation policy will mitigate impact to some extent in long-term. Climate change projections were not available in the context of actual wet-weather flows.
	Total Annual Seasonal Rain (mm)	**>1**	Y	<1	n/a	Climate impact is related to capacity since rain water component of wet-weather flows will displace capacity for actual wastewater. Primary effluent loading also an issue. Sewer separation policy will mitigate impact to some extent in long-term. Climate change projections were not available in the context of actual wet-weather flows.
Sludge Digestion	Intense Rain (mm)	<1	N	>1	n/a	Climate impact is grit transfer into digesters via primary clarifiers, reducing their capacity because of internal volume reduction. Addressed under Grit Removal item.
Sludge Lagoons	Total Annual Seasonal Rain (mm)	<1	N	>1	n/a	Sludge lagoon system currently planned to be replaced with a mechanical dewatering system prior to the 2021 implementation of secondary treatment. Given this time frame sufficient resiliency was assumed to be available.
HYDRAULICS						
Treatment Liquid-Stream	Intense Rain (mm)	**>1**	Y	<1	n/a	Climate impact is related to more frequent / longer duration flooding of the Parshall Flume used for flow measurement and the v-notch weirs in the primary clarifier effluent launders. Sewer separation policy will mitigate impact to some extent in long-term. Climate change projections were not available in the context of actual wet-weather flows.
	Total Annual Seasonal Rain (mm)	**>1**	Y	<1	n/a	Climate impact is related to pumping energy requirements, as well as capacity since rain water component of wet-weather flows will displace capacity for actual wastewater. Sewer separation policy will mitigate impact to some extent in long-term. Climate change projections were not available in the context of actual wet-weather flows.
Effluent Disposal	Intense Rain (mm)	<1	Y	>1	n/a	Climate impact is related to pumping energy requirements and redundancy associated with more frequent and longer duration wet-weather events. Sewer separation policy will mitigate impact to some extent in long-term. Climate change projections were not available in the context of actual wet-weather flows.
	Total Annual Seasonal Rain (mm)	**>1**	Y	<1	n/a	Climate impact is related to pumping energy requirements, as well as capacity since rain water component of wet-weather flows will displace capacity for actual wastewater. Sewer separation policy will mitigate impact to some extent in long-term. Climate change projections were not available in the context of actual wet-weather flows.
	Sea Level Elevation (m)	<1	N	>1	n/a	Climate impact is related to pumping energy requirements and not capacity.
SUPPORTING SYSTEMS / INFRASTRUCTURE						
On-Site Pipelines (includes tankage)	Sea Level Elevation (m)	**>1**	Y	<1	n/a	Large variation in predicted changes in mean sea level, and by extension groundwater levels and thus impact severity potential, necessitates further analysis.
Buildings, Tankage and Housed Process Equipment	Intense Rain (mm)	<1	N	>1	n/a	Climate impact is related to increased maintenance requirements for process-mechanical equipment and not capacity per se. Sewer separation policy will mitigate impact to some extent in long-term.
	Total Annual Seasonal Rain (mm)	<1	N	>1	n/a	Climate impact is related to increased maintenance requirements for process-mechanical equipment and not capacity per se. Sewer separation policy will mitigate impact to some extent in long-term.
	Sea Level Elevation (m)	<1	Y	>1	n/a	Large variation in predicted changes in mean sea level, and thus the potential for an impact, necessitates further analysis.
Standby Generators	Wind (extremes, gusts) (km/h)	**>1**	Y	<1	n/a	Although climate projections are inconclusive with regards to wind, vulnerability currently exists with respect to lack of available standby power capacity in the event of BC Hydro power loss during a wind storm.

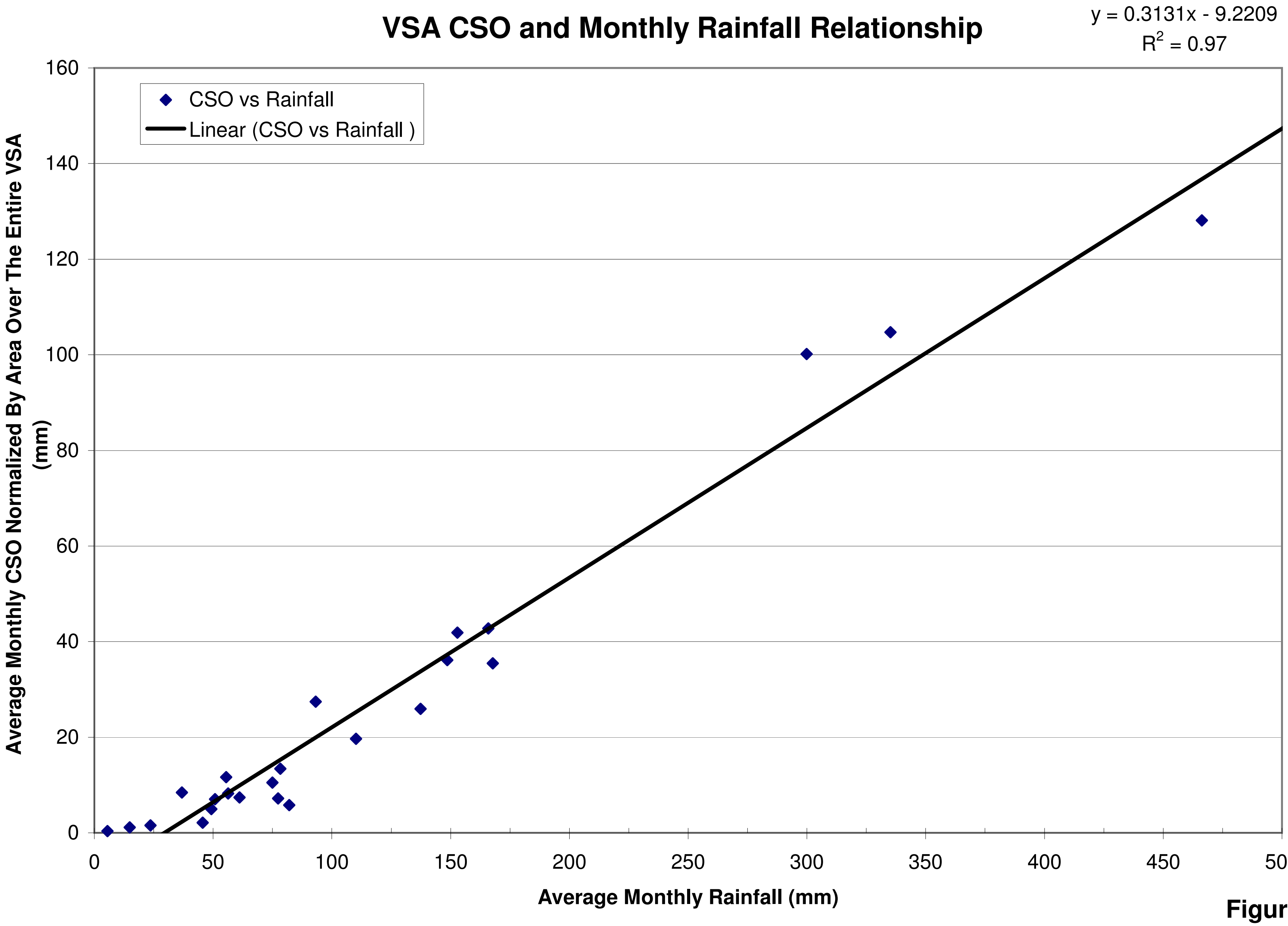
VSA CSO and Monthly Rainfall Relationship
y = 0.3131x - 9.2209
$R^2 = 0.97$
CSO vs Rainfall
Linear (CSO vs Rainfall)
Average Monthly CSO Normalized By Area Over The Entire VSA (mm)
160
140
120
100
80
60
40
20
0
0
50
100
150
200
250
300
350
400
450
500
Average Monthly Rainfall (mm)

Figure 5-1

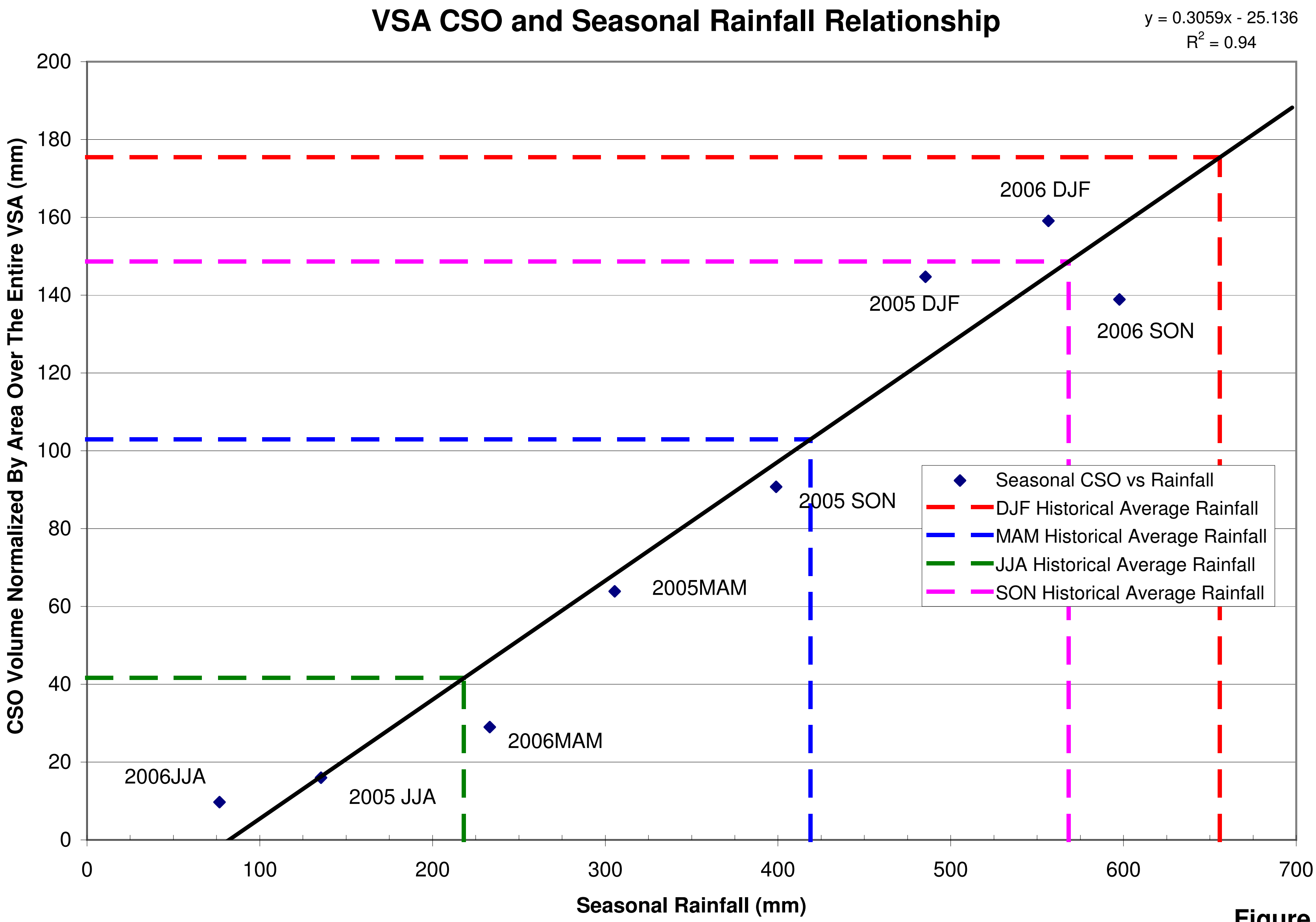
VSA CSO and Seasonal Rainfall Relationship
y = 0.3059x - 25.136
R^2 = 0.94
CSO Volume Normalized By Area Over The Entire VSA (mm)
0
20
40
60
80
100
120
140
160
180
200
Seasonal Rainfall (mm)
0
100
200
300
400
500
600
700
2006 DJF
2005 DJF
2006 SON
2005 SON
2005MAM
2006MAM
2006JJA
2005 JJA
Seasonal CSO vs Rainfall
DJF Historical Average Rainfall
MAM Historical Average Rainfall
JJA Historical Average Rainfall
SON Historical Average Rainfall

Figure 5-2

Section 6

Conclusions and Recommendations

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associates limited
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6. CONCLUSIONS AND RECOMMENDATIONS

6.1 LIMITATIONS

Infrastructure performance response depends greatly on the magnitude of extreme events. Although much engineering design and evaluation uses design events with a duration of less than 24 hours, the shortest projected event duration available from Ouranos was 24 hours. This lack of data contributed to the limited ability of the study team to make quantitative estimates of the effect of climate change on infrastructure.

Both the limited number of modelling runs (discussed in Section 2) and the available event duration of modelling results contribute to uncertainty in the assessment of the likelihood and magnitude of climate - infrastructure interactions (infrastructure performance responses), as discussed in Sections 4 and 5. The results of this study are, however, based on applying professional judgement to the assessment of the most current information available within the scope of the PIEVC protocol, and can therefore be used as a guide for future action on the part of Metro Vancouver.

6.2 OVERVIEW

This section of the report covers the fifth step of the PIEVC Protocol, *Recommendations*, corresponding to Worksheet 5. The objective of this section is to provide recommendations to address the critical infrastructure-climate interactions identified in the previous steps.

The recommendation categories are based on the PIEVC protocol and are as follows:

- Remedial engineering or operations action required
- Management action required
- Additional study or data required
- No further action required.

In general, it is noted that the VSA is fortunately situated with respect to climate change effects relative to other locations in Canada. Vancouver does not experience extreme or catastrophic weather events such as ice storms, tornadoes, drought or extreme cold. Perhaps the greatest magnitude threat is flooding of the Fraser River, and this is projected to decline in response to climate change (although there is uncertainty surrounding some climate related impacts like the effect of mountain pine beetle on deforestation, runoff and the resulting peak flows).

The climate factors identified as threats to infrastructure vulnerability will be evidenced as gradual changes. However, often the extremes, even if uncommon, have a far greater impact on public perception of risk. Under climate change scenarios, these events may occur more frequently.

In fact, the greatest pressure to initiate adaptive action comes not from climate change but from timing of planned infrastructure improvement plans such as the IIWWTP upgrades and combined sewer separation program. So while climate change effects may reveal vulnerabilities, Metro Vancouver is in an ideal position to proactively mitigate and adapt to these challenges.

Increasing efforts at developing green infrastructure may be used to increase resiliency in adapting to climate change.

6.3 COLLECTION SYSTEM

Application of the PIEVC protocol to the VSA has identified a number of potential vulnerabilities, as identified in Table 6-1.

The key priorities with respect to climate change adaptation in the collection system centre on increased rainfall and the associated increase in sewer flow, both under combined and separate sewer configurations. Accelerated separation may be necessary to achieve the target of CSO elimination by 2050. The extent of the work required requires additional study.

Many of the recommendations in this study would be most effective if completed in conjunction with municipal initiatives. A similar study of City of Vancouver infrastructure, including sewer separation and the development of green infrastructure, would complement this study and would fill many data gaps with respect to sewer flow quantification.

6.4 IONA ISLAND WASTEWATER TREATMENT PLANT

The vulnerabilities judged to be of the highest priority at the treatment plant are those associated with the effluent disposal system and the IIWWTP site itself because of the storm surge climate variable.

While ranked as lower priorities, the potential impacts of an increase in average sea level on the site itself and associated infrastructure are also important due to the significant uncertainty and wide range in estimated future increases in mean sea level. Additional study is required to develop more detailed information and conduct detailed analyses in the context of these potential vulnerabilities.

There are several lower-ranked potential treatment system vulnerabilities due to precipitation-related climate variables that potentially exist independent of the LWMP

PWWF limit of 17 m3/s. These vulnerabilities are related to facility capacity and redundancy, which in turn affects capacity. At this point there is considerable uncertainty in the significance (i.e. response severity) of these vulnerabilities, particularly given the relative magnitude of the estimated climate effects and the potential ability of Metro Vancouver's sewer separation policy to mitigate these vulnerabilities. Additional study to develop the relationship between these climate variables and the resultant impact on wet-weather wastewater flows may provide enhanced information to assess potential impacts on the treatment system. However, given Metro Vancouver's secondary treatment program for the VSA, a more practical approach to deal with these vulnerabilities may be to incorporate them into design of upgrade facilities. In this case, Metro Vancouver would consider and account for potential changes in infrastructure capacity as part of the secondary treatment program development, and in the context of other uncertainties (e.g. sewer separation, future population growth, water consumption reduction), without explicitly conducting additional specific study.

The current capacity of standby power available at the IIWWTP is already a vulnerability, which is anticipated to be further exaggerated by climate change. Metro Vancouver should consider remedial action to address this vulnerability.

Given the age of the IIWWTP infrastructure, it is recommended that Metro Vancouver consider the remaining service life of the components in the context of other potential issues (e.g. seismic). Even if climate change-related vulnerabilities are deemed to exist, they may overshadowed by other issues that when resolved can simultaneously address climate vulnerabilities.

Table 6-1 Recommendations

Infrastructure Component	Climate Variable	Recommendations	Recommendation Comments	Prioritization
				Principal Risks Associated with Infrastructure Performance Response
COLLECTION SYSTEM				
Combined Sewer Trunks Combined Sewer Interceptors Sanitary Mains	Intense Rain, Total Annual and Seasonal Rain (mm)	Additional Study as a prerequisite for Remedial Action and/or Management Action	It is recommended that Metro Vancouver continue to work with the Cities of Vancouver and Burnaby to determine the effect of climate change on achievable flow reduction through sewer separation and inflow and infiltration targets based on age, soil conditions and flow monitoring. Design of storm sewers is based on IDF curves (rainfall Intensity Duration Frequency curves). Metro Vancouver updates IDFs based on historical rainfall; however, new climate modelling information now exists that could be used to modify design values based on climate change. As an alternative, design methods could be based on sensitivity analyses or risk management tools. Infrastructure vulnerability exists to increased rain in the form of overflow risk. Mitigation is possible through planned sewer separation. Beyond this, the extent of the impact is largely dependent on the design of the separate sewer systems and the allowance for inflow and infiltration. Further study is required to identify the relationship between increased rainfall and inflow and infiltration rates in the VSA. Development of policies and commitments, especially as part of the Liquid Waste Management Plan, are suggested to set targets for adaptation. Green infrastructure can be used as a tool to increase resiliency in adapting to climate change. Many of the recommendations in this study would be most effective if completed in conjunction with ongoing and new municipal initiatives. A similar study of City of Vancouver infrastructure would complement this study and would fill many data gaps with respect to sewer flow quantification.	Public Health / Safety Environmental Health Monetary Cost to MV Public Perception
Pump Stations and Wet Wells	Intense Rain (mm)	Additional Study as a prerequisite for Remedial Action and/or Management Action	Study recommended to determine future loads for each pump station related to capacity exceedance during rainstorms. For those pump stations at risk of capacity exceedance, modify the design and/or operation and/or emergency plans.	Public Health / Safety Environmental Health Monetary Cost to MV Public Perception
	Floods (m^3)	Additional Study as a prerequisite for Remedial Action and/or Management Action	Study the current susceptibility to flooding and effects of water damage at each pump station. Correlate with records of street flooding (see "Records" below). Modify pump station design and/or emergency plans as appropriate.	Monetary Cost to MV
Manholes	Intense Rain (mm)	Additional Study as a prerequisite for Remedial Action	As part of the study on the effects of sewer separation, the pros and cons of designed surcharges (through sections with bolted manholes) should be considered. If surcharge will continue, provisions for additional maintenance resources may be required. Design of the separated system should be such that, where practical, additional sections of main do not surcharge above ground level.	Public Health / Safety Environmental Health Monetary Cost to MV Public Perception
Flow & Level Monitors	Intense Rain (mm)	Additional Study as a prerequisite for Remedial Action	Evaluate the condition and location of current monitors. Ensure monitors are robust enough to adapt to increased flow, sea level, flooding.	Public Health / Safety Environmental Health Monetary Cost to MV Public Perception
Flow Control Structures	Intense Rain (mm)	Additional Study as a prerequisite for Remedial Action	Determine the current capacity and future loads at each structure subsequent to sewer separation.	Public Health / Safety Environmental Health Monetary Cost to MV Public Perception
Power Sources	Wind (extremes, gusts) (km/h)	Additional Study as a prerequisite for Remedial Action and/or Management Action	Vulnerability currently exists with respect to lack of available standby power capacity in the event of BC Hydro power loss during a wind storm. Ensure adequate backup power and / or emergency plans for pump stations and control points.	Public Health / Safety Environmental Health Monetary Cost to MV Public Perception
Communications	Wind (extremes, gusts) (km/h)	Additional Study as a prerequisite for Remedial Action	Inspect each SCADA installation to determine level of risk to windstorms and determine remedial action necessary (e.g. remove nearby trees).	Environmental Health
Records	All	Management Action	Log events and situations (such as infrastructure failure, maintenance issues, operations responses) related to extreme weather in an easily accessible database.	Implement record-keeping for each type of infrastructure / climate effect in conjunction with carrying out the recommendations above.
	Intense Rain (mm)		Require easily accessible data on daily CSO volumes at each outfall and sewage flows at key locations within the VSA. The density of the monitoring network and increased efforts of Quality Assurance / Quality Control may need to be implemented.	
	Total Annual Seasonal Rain (mm)		Log information on available maintenance windows.	
	Sea Level Elevation (m)		At a minimum, monitor water level at English Bay, and the North Arm of the Fraser River mouth.	
	Storm Surge (m)		Record storm surge levels at English Bay, Burrard Inlet (in East Vancouver), and the North Arm of the Fraser River mouth. Document associated problems.	
	Floods (m^3)		Record locations of street flooding, approximate degree of flooding, and impacts on operations, emergency response, and the public. Estimate future extent of street flooding by correlating rainfall and flood data.	
	Wind (extremes, gusts) (km/h)		Record problems related to wind damage, extent of damage (including downed trees and near misses), and impacts on operations, emergency response, and the public.	

Table 6-1 Recommendations

Infrastructure Component	Climate Variable	Recommendations	Recommendation Comments	Prioritization
				Principal Risks Associated with Infrastructure Performance Response
TREATMENT (IIWWTP)				
PROCESS				
Influent Pumping	Intense Rain (mm)	Management Action	Secondary treatment program development should consider climate change-induced increases in wet-weather flows and how they may be mitigated by the sewer separation policy. The context is capacity as related to redundancy.	
	Total Annual Seasonal Rain (mm)	Management Action	Secondary treatment program development should consider climate change-induced increases in wet-weather flows and how they may be mitigated by the sewer separation policy. The context is capacity available for generated wastewater versus rainwater entering the collection system.	
Grit Removal	Intense Rain (mm)	Management Action	Secondary treatment program development should consider climate change-induced increases in wet-weather flows and how they may be mitigated by the sewer separation policy. The context is capacity and performance, and as related to redundancy. The transfer of wastewater grit to the digesters, via grit passed to and removed in the primary clarifiers, is the main issue.	
	Total Annual Seasonal Rain (mm)	Management Action	Secondary treatment program development should consider climate change-induced increases in wet-weather flows and how they may be mitigated by the sewer separation policy. The context is capacity available for generated wastewater versus rainwater entering the collection system.	
Primary Clarification (including CEPT)	Intense Rain (mm)	Management Action	Secondary treatment program development should consider climate change-induced increases in wet-weather flows and how they may be mitigated by the sewer separation policy. The context is capacity and performance, and as related to redundancy. High primary effluent loads to the marine environment, in the short-term, and to the future secondary treatment system, in the longer term, are the main issues.	
	Total Annual Seasonal Rain (mm)	Management Action	Secondary treatment program development should consider climate change-induced increases in wet-weather flows and how they may be mitigated by the sewer separation policy. The context is capacity available for generated wastewater versus rainwater entering the collection system.	
HYDRAULICS				
Treatment Liquid-Stream	Intense Rain (mm)	Management Action	Secondary treatment program development should consider climate change-induced increases in wet-weather flows and how they may be mitigated by the sewer separation policy. This information can then be used to assess capacity and performance, as well as the context of redundancy. More frequent / longer duration flooding of the Parshall Flume used for flow measurement and the v-notch weirs in the primary clarifier effluent launders are the main issues.	
	Total Annual Seasonal Rain (mm)	Management Action	Secondary treatment program development should consider climate change-induced increases in wet-weather flows and how they may be mitigated by the sewer separation policy. The context is capacity available for generated wastewater versus rainwater entering the collection system.	
Effluent Disposal	Intense Rain (mm)	Management Action	Secondary treatment program development should consider climate change-induced increases in wet-weather flows and how they may be mitigated by the sewer separation policy. The context is capacity, and as related to redundancy. Climate impact is related to pumping energy requirements and redundancy associated with more frequent and longer duration wet-weather events.	
	Total Annual Seasonal Rain (mm)	Management Action	Secondary treatment program development should consider climate change-induced increases in wet-weather flows and how they may be mitigated by the sewer separation policy. The context is capacity available for generated wastewater versus rainwater entering the collection system.	
	Storm Surge (m)	Additional Study	Increased pumping heads associated with future surge conditions may reduce the capacity of the existing effluent pumping station. The feasibility of using larger pumps, while potentially able to restore lost capacity, needs to be assessed also in the context of internal pressures in the jetty conduit and marine sections of the outfall.	
SUPPORTING SYSTEMS / INFRASTRUCTURE				
On-Site Pipelines (includes tankage)	Sea Level Elevation (m)	Additional Study	Large variation in predicted changes in mean sea level, and thus the potential for an impact, necessitates further analysis. This analysis should consider the remaining service life of individual infrastructure components and other factors (e.g. seismic) that may impact the service life. The analysis should evaluate the vulnerability of individual components, as their relative buried depths vary significantly.	
On-Site Pipelines	Storm Surge (m)	Additional Study	The effluent marine outfall system, and in particular the outfall jetty conduit, may be especially vulnerable to increases in internal pressures that may result from increased pumping heads under future storm surge conditions.	
Buildings, Tankage and Housed Process Equipment	Sea Level Elevation (m)	Additional Study	Large variation in predicted changes in mean sea level, and thus the potential for an impact, necessitates further analysis. This analysis should consider the remaining service life of individual infrastructure components and other factors (e.g. seismic) that may impact the service life. The analysis should evaluate the vulnerability of individual components, as their relative buried depths vary significantly.	
	Storm Surge (m)	Additional Study	Additional analysis is required to assess the potential for site flooding under storm surge, in consideration of such factors as wind waves, land sinking and the uncertainty in average sea level increases.	
Standby Generators	Wind (extremes, gusts) (km/h)	Remedial Action	Assess installation of additional standby power sufficient to run the effluent pump station at maximum capacity, in addition to other electrical loads deemed necessary for facility operation under high wastewater flow and storm surge conditions.	

6.5 REPORT SUBMISSION

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ACRONYMS

8AI - Eight Avenue Interceptor
AE - Associated Engineering (BC) Ltd.
CCME - Canadian Council of Ministers of the Environment
CCPE - Canadian Council of Professional Engineers
CCPE - Canadian Council of Professional Engineers
CEPT - Chemically Enhanced Primary Treatment
CGCM - Canadian Global Climate Model
COV - City of Vancouver
CRCM - Canadian Regional Climate Model
CSO - Combined Sewer Overflow
EBI - English Bay Interceptor
ENSO - El Niño Southern Oscillation
ERPs - Emergency Response Plans
FCM - Federation of Canadian Municipalities
GCM - Global Climate Model
GHG - Greenhouse Gas
GVRD - Greater Vancouver Regional District
GVSDD - Greater Vancouver Sewerage and Drainage District
HI - Highbury Interceptor
HVAC - Heating, Ventilation, and Air-conditioning
I&I - Inflow and Infiltration
IDF - Intensity-Duration-Frequency
IIWWTP - Iona Island Wastewater Treatment Plant
IPCC - Intergovernmental Panel on Climate Change
KWL - Kerr Wood Leidal Associates Ltd.
LWMP - Liquid Waste Management Plan
NAI - North Arm Interceptor
P_C - Priority of Climate Effect
PCIC - Pacific Climate Impacts Consortium
PDO - Pacific Decadal Oscillation
PIEVC - Public Infrastructure Engineering Vulnerability Committee
RCM - Regional Climate Model
S_C - Climate Probability Scale Factor
SCADA - Supervisory Control and Data Acquisition
S_R - Response Severity Scale Factor
SRES - Special Report on Emissions Scenarios
STP - Sewage Treatment Plant
UBC - University of British Columbia
UNEP - United Nations Environment Programme
VSA - Vancouver Sewerage Area
WMO - World Meteorological Organization
WWTP - Wastewater Treatment Plant

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Appendix A

Worksheets

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Appendix B

Vancouver Sewerage Area – System Schematic

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Appendix C

OURANOS Report on Climate Change Scenarios

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Appendix D

PIEVC Engineering Protocol Rev 7.1

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