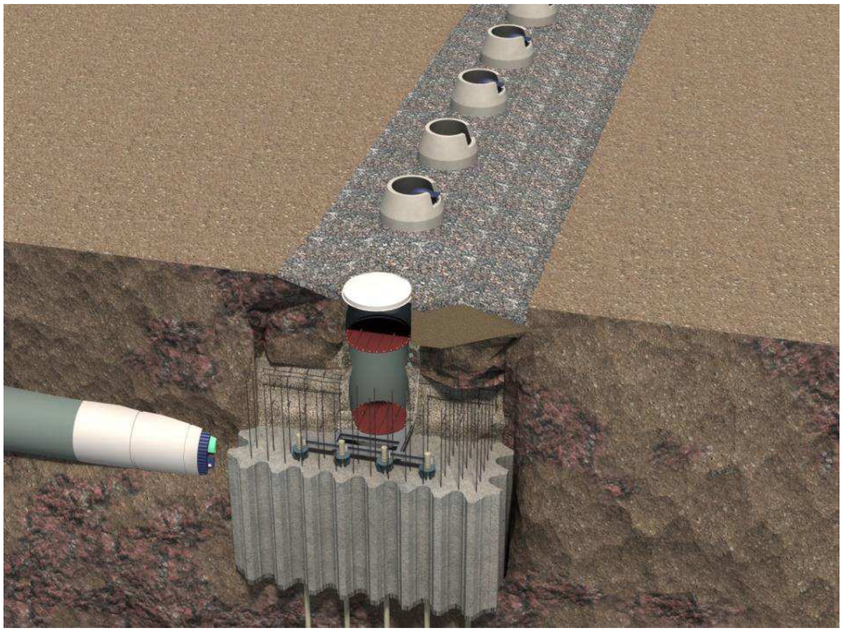
APPENDIX K
BC MINISTRY OF ENVIRONMENT EIS

K.1: Stage 1 Environmental Impact Study

(with Comments and Responses)

Annacis Island WWTP New Outfall System

Vancouver Fraser Port Authority
Project and Environmental Review Application



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CDM Smith

Golder Associates

26 August 2016

ANNACIS ISLAND WASTEWATER TREATMENT PLANT TRANSIENT MITIGATION AND OUTFALL PROJECT

Stage 1 Environmental Impact Study

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Metro Vancouver
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1 copy Golder Associates Ltd.

REPORT

Golder Associates

EXECUTIVE SUMMARY

BACKGROUND

The Annacis Island Wastewater Treatment Plant (AIWWTP), located adjacent to the Fraser River on Annacis Island, Delta, British Columbia (BC), is currently being expanded by Metro Vancouver to increase secondary treatment hydraulic capacity and a new outfall is required to augment or replace existing outfall facilities. To discharge effluent from the new outfall, the project requires an amendment of its Operational Certificate under the Integrated Liquid Waste and Resource Management Plan (ILWRMP) pursuant to the provincial *Environment Management Act* (EMA). This amendment requires an Environmental Impact Study (EIS) of the effluent discharge to identify whether or not receiving water uses could be impaired. The EIS is conducted in a staged process. Stage 1 evaluates a preliminary design and available data, and is followed by a pre-discharge monitoring program, if required, based on monitoring considerations suggested in Stage 1. The Stage 1 assessment is followed by a Stage 2 EIS, which is a refined evaluation of potential effluent-related impacts on the receiving environment and public health based on a final project design. The following report is the Stage 1 EIS for a new outfall diffuser system designed for Metro Vancouver by CDM Smith Canada ULC.

APPROACH

This Stage 1 EIS is intended to provide a preliminary assessment of potential impacts of effluent discharge from the new outfall based on the preliminary outfall diffuser design and existing effluent and receiving environment data. Objectives of the study are outlined below.

- Characterize the receiving environment within the Study Area with respect to hydrology, water and sediment quality, and ecological resources.
- Inventory water uses in the receiving environment by ecological resources and recreational users, and select appropriate water quality guidelines (WQGs) to protect these uses.
- Identify effluent characteristics, including flows and quality, as well as the characteristics of the new outfall diffuser system.
- Determine the initial dilution of the effluent plume via modeling and estimate concentrations of constituents of concern at the edge of the initial dilution zone (IDZ).
- Evaluate the potential for impairment of identified water uses in the receiving environment within the Study Area on the basis of comparing predicted instantaneous and monthly average concentrations at the edge of the IDZ to applicable Fraser River Water Quality Objectives (FRWQOs), BC WQGs, and federal WQGs.
- Identify uncertainties in the impact assessment and make monitoring recommendations to be considered with the view to addressing these uncertainties for the Stage 2 assessment.

IMPACT ASSESSMENT FINDINGS

Predicted instantaneous and mean monthly concentrations at the edge of the IDZ for most water quality constituents are below FRWQOs and both provincial and federal WQGs, with the following noted exceedances.

- Predicted total ammonia concentrations are below aquatic life guidelines. However, predicted un-ionized ammonia concentrations are slightly above the federal WQG. Given conservatism in the derivation of both the un-ionized ammonia WQG and the IDZ monthly predictions, this Stage 1 assessment does not expect ammonia-related adverse effects on aquatic life in the Fraser River. Ammonia will be assessed in further detail during the Stage 2 EIS, based on additional effluent data and site-specific pH and temperature data.
- For the majority of metals, predicted monthly concentrations are below FRWQOs and the lowest WQG. Predicted monthly concentrations of dissolved aluminum, and total aluminum, chromium, iron, lead, mercury, and zinc are greater than FRWQOs or the lowest WQG, but are not distinguishable from the relevant ambient river condition.
- With respect to instantaneous metal concentrations, total iron and cadmium are above the FRWQO or the lowest WQG, but according to the rationale provided in the assessment adverse effects on aquatic life would not be expected.
- Predicted total copper concentrations are above the lowest receiving environment guideline, but are only distinguishable from ambient conditions during part of the year. Dissolved copper concentrations are below total copper guidelines indicating that a proportion of predicted total concentrations would not be expected to be bioavailable for uptake by aquatic biota. At this preliminary Stage 1 level of assessment, adverse effects to aquatic life would not be expected. However, the assessment will be refined in the Stage 2 EIS based on the final diffuser design, an expanded effluent and ambient water quality dataset, refined water quality modeling procedures, and further consideration of copper bioavailability under site-specific conditions in the receiving environment.
- For organic compounds, predicted concentrations of total polychlorinated biphenyls (PCBs) and 17α-ethinylestradiol (EE2) concentrations are above guidelines. However, these predictions are based on inputs that are at detection limits higher than corresponding WQGs or are based on a small sample size for both effluent and ambient conditions. Additional data should be included in the Stage 2 EIS to reduce these uncertainties.
- Predicted total residual chlorine (TRC) exceeds the selected recreational screening criterion, but both the predictions (based on elevated detection limits that were subsequently improved in 2014) and the screening criterion (based on the inhalation pathway) are considered highly conservative. A secondary screening against the dermal contact criterion for TRC indicates that risks are acceptable for public health.

Overall, the Stage 1 assessment, based on conservative assumptions, indicated that pollution as defined under EMA is unlikely to occur as a result of the hydraulic upgrade to the AIWWTP and resultant treated effluent discharge; specifically:

- Adverse effects on aquatic life and impairment of other receiving environment uses identified for the Study Area (i.e., secondary recreational contact, wildlife use, agricultural use [i.e., irrigation and livestock watering]) are not expected based on a preliminary assessment of predicted concentrations at the edge of the IDZ.
- The secondary treated whole effluent at the point of discharge is not expected to be acutely lethal to aquatic life, and following dilution and mixing, conditions within the IDZ would likewise not be expected to be acutely toxic to aquatic life. Chronic toxicity is not expected beyond the IDZ boundary.

Based on the most recent characterization of effluent presented for the period 2011 to 2014, the AIWWTP effluent meets effluent limits specified in the ILWRMP for the Greater Vancouver Sewerage and Drainage District. The AIWWTP effluent also meets federal National Performance Standards (i.e., meets effluent limits and is not acutely toxic) and so is not considered a deleterious substance under the federal *Fisheries Act*.

UNCERTAINTY IN THE ASSESSMENT

The main uncertainties of the assessment of the proposed AIWWTP outfall include:

- Stratification in the Fraser River has the potential to reduce dilution and limited data are available to characterize stratification in the Study Area.
- Current speed measured at the Gravesend Reach buoy was used as a key input to the dilution model because limited data are available to characterize current speed at the proposed diffuser location, which is 6 to 7 km upstream of the buoy,
- The Shrivastava-Adams equation used in Stage 1 may not fully represent dilution during unstratified conditions for the proposed diffuser design and may need to be updated based on scaled physical modeling planned for Stage 2.
- Ambient and effluent water quality characterized by method detection limits results in overestimates of concentrations that would occur at the edge of the IDZ, with the degree of overestimation depending on the percentage of samples that have non-detected values.
- Data for some organic constituents in particular are limited in sample size and are reported at varying method detection limits that approximate or are higher than corresponding WQGs, which results in uncertainty in the ability to characterize both effluent and ambient conditions and uncertainty in the resulting predicted IDZ concentrations.
- Interaction of constituent mixtures could result in effects different from that estimated through comparison of predicted constituent concentrations to WQG; however, toxicity tests on the existing effluent mixture, which consider these interactions, have shown no acute lethality to rainbow trout (*Oncorhynchus mykiss*).

SUMMARY OF MONITORING CONSIDERATIONS FOR STAGE 2 EIS

The potential need for pre-discharge monitoring was determined in consideration of provincial EIS guidance by BC MELP (2000) and in consultation with BC MoE. These discussions determined that pre-discharge monitoring to support the Stage 2 EIS would mainly focus on the collection of supplemental water and sediment quality data, with the collection of some benthic invertebrate data during the sediment quality survey. Supplemental monitoring was subsequently undertaken in late summer/fall 2015 (water) and late winter 2016 (water, sediment, benthic invertebrates) in advance of submission of this Stage 1 EIS. These data were not intended to be included in the Stage 1 EIS, but rather were to be reported separately and included in the Stage 2 EIS.

Supplemental monitoring to support the Stage 2 EIS was undertaken so that data would be collected during the appropriate season, thus mitigating the potential for delay in preparation of the Stage 2 EIS. Effluent and ambient Fraser River data were collected within the Study Area for the following components:

- Water quality data downstream of the proposed outfall location in late summer/fall (2015—conventional parameters, metals, nutrients, bacteriological constituents, nonylphenols, and polycyclic aromatic hydrocarbons [PAHs]).
- Water property vertical profile data (late winter 2016—depth profile measurements of pH, dissolved oxygen, salinity, conductivity, temperature, and turbidity).
- Addition of select organic constituents to the late winter 2016 IDZ monitoring program for effluent, IDZ, and reference locations (2016—PAHs, polybrominated diphenyl ethers [PBDEs], PCBs, pesticides).
- Sediment quality data and preliminary benthic invertebrate data (late winter 2016).

Further monitoring is currently being considered for fall 2016 to provide additional supplemental data for the Stage 2 EIS, most notably:

- Inclusion of a comparable organic parameter suite (nonylphenols, sterols and hormones, PAHs, PBDEs, PCBs, pesticides) as for the late winter 2015 IDZ program in late summer/fall 2016 monitoring at the reference location to better characterize ambient concentrations of these parameters in the Fraser River.
- Inclusion of a comparable organic parameter suite (nonylphenols, sterols and hormones, PAHs, PBDEs, PCBs, pesticides) in concurrent effluent monitoring to better characterize effluent concentrations.
- Detailed in situ pH and temperature monitoring near the proposed outfall location, outside of the zone of influence of the existing effluent, to better characterize pH conditions over a range of river flow and tidal conditions. The in situ pH and temperature data will be used for a detailed ammonia assessment in the Stage 2 EIS.
- Additional depth profile data at both the reference and IDZ monitoring stations to better characterize the vertical temperature and conductivity/salinity structure of the Fraser River near the proposed outfall location to be collected during late summer/early fall 2016 when the river is at low flow (preferably <1,000 m^3/s, but consideration of sampling could occur if flows were <2,000 m^3/s) and predicted tide levels are favorable for migration of the saltwater wedge up the river.

The 2015/2016 pre-discharge monitoring described above, that has already been undertaken or is currently being scheduled, serves to address both EIS guidance and a substantial proportion of the uncertainties identified in this Stage 1 EIS. Based on the evaluation of 2011 to 2014 data by this Stage 1 EIS, the following should also be considered to support the Stage 2 EIS.

- The short-list of organic parameters considered for the Stage 1 EIS should be reviewed in consideration of the additional effluent and ambient data collected in 2015 and 2016. This should then form the basis of the short-list of organic parameters considered for the Stage 2 EIS.
- The list of parameters monitored in effluent and the ambient environment between 2011 and 2016 (subject to data availability) should be reviewed to confirm that parameters have been monitored in both media.
- Some parameters such as EE2 and pesticides in the effluent and ambient environment were reported at method detection limits higher than corresponding WQGs. This is a source of uncertainty in IDZ predictions based on these values and the resulting water quality impact assessment. It is recommended that recent chemistry data (2015-2016) be reviewed with respect to sampling and analytical procedures employed and the need for sampling in addition to that described above.

Statement of Limitations

This report was prepared for the exclusive use of Metro Vancouver and CDM Smith Canada ULC. No other party may use or rely on this report or any portion thereof without Golder's express written consent. Golder will consent to any reasonable request by the Client to approve the use of this report by other parties as Approved Users. Regulators are considered Approved Users. Any use that a third party may make of this report, or any reliance on or decisions made based on it, is the responsibility of the third parties. Golder Associates Ltd. accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report. We disclaim responsibility for consequential financial effects on transactions or property values, or requirements for follow-up actions and costs.

In preparing this report, we have relied in good faith on information provided by others, notably CDM Smith Canada ULC and Envirowest Consultants Inc. We assume that the information provided is factual and accurate. We accept no responsibility for any deficiency, mis-statement or inaccuracy contained in this report as a result of omissions, misinterpretations or fraudulent acts of persons interviewed or contacted. As indicated in the report, Golder is responsible for the content of this report with the exception of Section 5.0 and Appendix A that was prepared by CDM Smith Canada ULC and Appendices C and D that were prepared by Envirowest Consultants Inc.

The services performed as described in this report were conducted in a manner consistent with the level of care and skill normally exercised by other members of the engineering and science professions currently practicing under similar conditions, subject to the time limits and financial and physical constraints applicable to the services. The content of this report is based on information compiled during preparation of the report, our present understanding of site conditions, the assumptions stated in this report, and our professional judgement in light of such information at the time of preparation of this report. This report provides a professional opinion and, therefore, no warranty is expressed, implied, or made as to the conclusions, advice and recommendations offered in this report. This report does not provide a legal opinion regarding compliance with applicable laws. With respect to regulatory compliance issues, it should be noted that regulatory statutes and the interpretation of regulatory statutes are subject to change.

The findings and conclusions of this report are valid only as of the date of the report. If new information is discovered in future work, or if the assumptions stated in this report are not met, Golder Associates Ltd. should be requested to re-evaluate the conclusions of this report, and to provide amendments as required.

LIST OF ABBREVIATIONS AND ACRONYMS

AIWWTP	Annacis Island Wastewater Treatment Plant
BC	British Columbia
BCCSN	British Columbia Cetacean Sighting Network
BDE	brominated diphenyl ether
CBOD	carbonaceous biological oxygen demand
CCME	Canadian Council of Ministers of the Environment
CDC	Conservation Data Centre
CDM Smith	CDM Smith Canada ULC
COPC	constituents of potential concern
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CRA	commercial, recreational, and aboriginal
CTD	conductivity, temperature, and depth
CWS	Canadian Wildlife Services
Delta	Corporation of Delta
DFO	Fisheries and Oceans Canada
EDC	endocrine disrupting compound
EE2	17α-ethinyl-estradiol
EIS	environmental impact study
EMA	*Environment Management Act*
FRAP	Fraser River Action Plan
FRAMP	Fraser River Ambient Monitoring Plan
FREMP	Fraser River Estuary Monitoring Program
FRWQO	Fraser River Water Quality Objective
FSC	food, social and ceremonial (purposes)
Golder	Golder Associates Ltd.
GVS&DD	Greater Vancouver Sewerage and Drainage District
IBA	Important Bird Area
IDZ	initial dilution zone
ILWRMP	Integrated Liquid Waste and Resource Management Plan
LC50	median lethal concentration resulting in mortality to 50% of a test group
LOEC	lowest-observed-effects-concentration
MCA	marine conservation analysis
MDL	method detection limit
MELP	Ministry of Environment, Lands, and Parks
MoE	Ministry of Environment
MV	Metro Vancouver

MWR	Municipal Wastewater Regulation
NH_3-N	un-ionized ammonia as nitrogen
NH_4^+	ionized ammonia
NO_3^-	nitrate
NWA	National Wildlife Area
O_2	oxygen
PAH	polycyclic aromatic hydrocarbon
PBDE	polybrominated diphenyl ether
PCB	polychlorinated biphenyl
the Port	the Port of Vancouver
PPCP	pharmaceutical and personal care product
QP	qualified professional
REM	Receiving Environment Monitoring Program
SARA	*Species At Risk Act*
TEQ	toxic equivalency quotient
TOR	terms of reference
TRC	total residual chlorine
TSS	total suspended solids
US EPA	US Environmental Protection Agency
v/v	volume by volume
WHSRN	Western Hemisphere Shorebird Reserve Network
WQG	water quality guidelines
WMA	Wildlife Management Areas
WSER	Wastewater Systems Effluent Regulation
WWTP	wastewater treatment plant

UNITS

%	percent
°C	degrees Celcius
km	kilometres
km^2	square kilometre
m	metres
m^3	cubic metres
m^3/day	cubic metres per day
m^3/s	cubic metres per second
m^3/year	cubic metres per year
µg/L	micrograms per litre
mg/L	milligrams per litre
ML/d	million litres per day
mm	millimetres
ng/L	nanograms per litre
NTU	nephelometric turbidity units
pH	acidity units
pg/L	picograms per litre

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1.0 INTRODUCTION

The Annacis Island Wastewater Treatment Plant (AIWWTP) is currently being expanded by Metro Vancouver (MV) to increase secondary treatment hydraulic capacity and a new outfall is required to augment or replace existing outfall facilities. The AIWWTP is located adjacent to the Fraser River on Annacis Island, Delta, British Columbia (BC). CDM Smith Canada ULC (CDM Smith) was retained by MV to provide consulting engineering services for the AIWWTP Transient Mitigation and Outfall Project (henceforth referred to as the project).

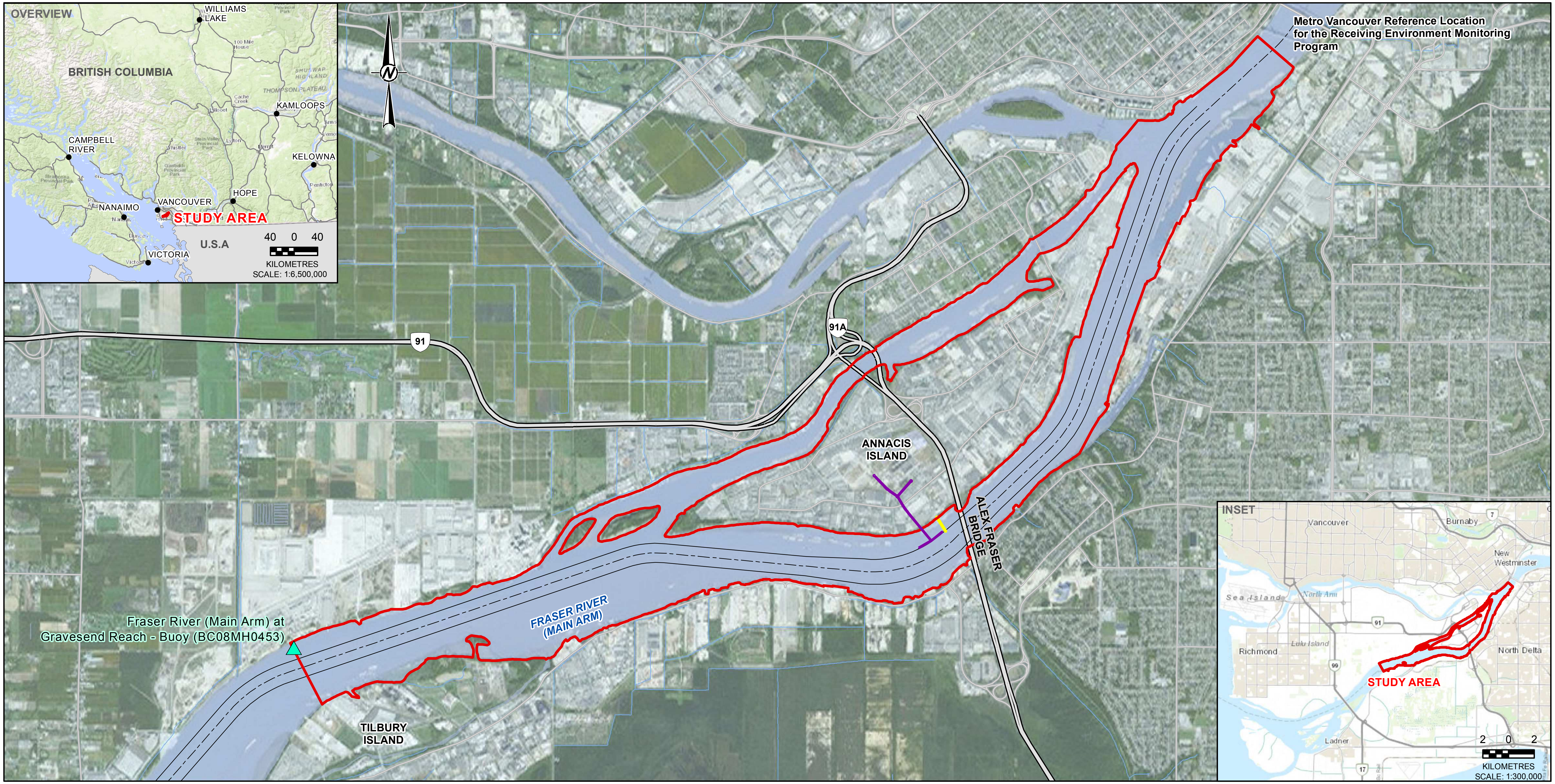
To discharge effluent from the new outfall, the project requires an amendment of its Operational Certificate ME-00387 under the BC Municipal Wastewater Regulation (MWR) (BC Reg 87/2012; OC 230/2012), and its Integrated Liquid Waste and Resource Management Plan (ILWRMP) pursuant to the provincial *Environment Management Act* (EMA). The amendment of Operational Certificate ME-00387 requires an Environmental Impact Study (EIS) of the effluent discharge to identify whether or not receiving water uses could be impaired. The EIS is used by the Ministry of Environment (MoE) in their permitting decisions and is used by the discharger, in this case MV, as part of their due diligence to verify that they meet the requirements of EMA, the ILWRMP, and relevant federal legislation.

Golder Associates Ltd. (Golder) was retained by CDM Smith on behalf of MV to prepare an EIS for the new outfall diffuser system, to support the application to amend Operational Certificate ME-00387, in accordance with provincial guidance (BC Ministry of Environment, Land and Parks [MELP] 2000). Generic provincial guidance in BC MELP (2000) specifies a staged EIS process that typically comprises of a Stage 1 assessment of the preliminary design and available data, a pre-discharge monitoring program (if required), followed by a Stage 2 EIS. The Stage 2 EIS represents a refined evaluation of potential effluent-related impacts on the receiving environment and public health based on the final project design.

1.1 Project Description

The AIWWTP is the largest of the three secondary wastewater treatment plants owned and operated by MV that discharge to the lower Fraser River. The AIWWTP is located on Annacis Island, Delta, BC (Figure 1-1). This plant discharges an approximate average 490 million litres per day (ML/d) of secondary treated effluent into the Annieville Channel of the Main Arm of the Fraser River through three pipes to a distance of about 160 m from the north shore, immediately downstream of the Alex Fraser Bridge (ENKON 2015a) (Figure 1-1). The AIWWTP treats wastewater generated by over 1 million residents within in the Fraser Sewerage Area that consists of all or portions of Burnaby, Coquitlam, Delta, Langley, Maple Ridge, Richmond, New Westminster, Pitt Meadows, Port Coquitlam, Port Moody, Surrey, White Rock and a small portion of the City of Vancouver. Sewage consists of industrial, commercial, and domestic wastewaters.

The AIWWTP is currently being expanded by MV to increase the secondary treatment hydraulic capacity and a new outfall is required to augment or replace the existing outfall facilities. Metro Vancouver is currently implementing Stage V improvements to increase the peak wet weather capacity of the plant from 12.6 m^3/s to 18.9 m^3/s, and future Stage VIII plans are also being made to further increase the peak wet weather capacity to 25.3 m^3/s. A new outfall diffuser system is required because the current AIWWTP is not able to provide sufficient dilution to the effluent, particularly at times of slack water and low flow in the river, and lacks sufficient hydraulic capacity to discharge the planned flow increases at high river levels (CDM Smith 2016) (Appendix A).



LEGEND

🟥	STUDY AREA
▲	FRESHWATER QUALITY MONITORING BUOY
—	PROPOSED WWPT OUTFALL
—	EXISTING WWPT OUTFALL
▭	WATER
—	WATERCOURSE

FRASER RIVER SHIPPING CHANNEL

– –	CENTRE OF CHANNEL
—	OUTER CHANNEL BOUNDARY
═	HIGHWAY
—	MAJOR ROAD

0 0.5 1 1.5 2

1:40,000 KILOMETRES

REFERENCES
1. SHIPPING CHANNEL SUPPLIED BY BLACK & VEATCH
2. ROADS, WATERCOURSE AND WATERBODY DATA OBTAINED FROM GEOGRATIS, © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED
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CLIENT
CDM SMITH CANADA ULC AND METRO VANCOUVER

PROJECT
ANNACIS ISLAND WWTP TRANSIENT MITIGATION & OUTFALL UPGRADE
DELTA, B.C.

CONSULTANT
Golder Associates

YYYY-MM-DD	2016-07-28
DESIGNED	PM
PREPARED	JP
REVIEWED	PM
APPROVED	EI

TITLE
ANNACIS ISLAND WWPT STAGE 1 ENVIRONMENTAL IMPACT STUDY AREA

PROJECT NO.	CONTROL	REV.	FIGURE
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1.2 Company Information

Metro Vancouver, through the Greater Vancouver Sewerage and Drainage District (GVS&DD), owns and operates three secondary wastewater treatment plants that discharge to the lower Fraser River.

The main contact information for the company is:

Metro Vancouver
Ken Masse, Senior Project Engineer,
Project Delivery, Liquid Waste Services
4330 Kingsway,
Burnaby, BC, V5H 4G8

1.3 Stage 1 EIS Objectives

This Stage 1 EIS is intended to provide a preliminary assessment of potential impacts of the effluent discharge from the new outfall based on the preliminary outfall diffuser design described by CDM Smith (2016) in Appendix A and existing effluent and receiving environment data.

The objectives of the study are outlined below.

- Characterize the receiving environment within the Study Area with respect to hydrology, water and sediment quality, and ecological resources.
- Inventory water uses in the receiving environment by ecological resources and by recreational users and select appropriate water quality guidelines (WQG) to protect these uses.
- Identify effluent characteristics, including flows and quality, as well as the characteristics of the new outfall diffuser system.
- Determine the initial dilution of the effluent plume via modeling and estimate the concentration of constituents of potential concern (COPCs) at the edge of the initial dilution zone (IDZ). The IDZ is the three-dimensional zone around the point of discharge where mixing of the effluent and the receiving water occurs. For a large waterbody such as the lower Fraser River, the IDZ is commonly defined as a cylindrical body of water around the outfall with a lateral radius of 100 m from the outfall and extending upwards to the surface of the water column.
- Evaluate the potential for impairment of identified water uses in the receiving environment within the Study Area on the basis of comparing predicted IDZ concentrations to applicable WQGs.
- Identify uncertainties in the preliminary impact assessment and make monitoring recommendations to be considered with the view to addressing these uncertainties for the Stage 2 assessment.

A Stage 1 EIS is prepared as a preliminary evaluation at the planning stage to check on the acceptability of a proposed treated effluent discharge before detailed studies and designs are undertaken and to assist in focusing those detailed investigations.

1.4 Consultation with Ministry of the Environment

Golder prepared a draft terms of reference (TOR) for the Stage 1 EIS based on Section 5.2.1 of BC MELP (2000) guidance for preparing EIS documents, as well as preliminary input provided by BC MoE technical specialists at a meeting with MV, CDM Smith, Golder, and Envirowest Consultants Inc. (Envirowest) on 19 October 2015. BC MoE provided comments on the draft TOR to MV in December 2015 and the following scope of work for the EIS was agreed to in the final TOR dated 16 May 2016.

The consultation noted here was of a technical and regulatory nature. In addition, MV has been engaged in consultation with First Nations, municipalities, other stakeholders, and MV citizens on broader issues relating to upgrades in sewage treatment infrastructure. Consultation with regulators and key stakeholders on this effluent discharge permit amendment has been an ongoing process.

1.5 Report Overview

Consistent with the suggested scope outlined in Section 5.2.1 of BC MELP (2000), this Stage 1 EIS is comprised of tasks grouped under the following general headings, which were undertaken subject to the extent of the outfall design and the availability of effluent and receiving environment data, as well as consultation with BC MoE.

- Characterization of the Receiving Environment (Sections 2.1 and 2.2)
- Receiving Environment Use (Section 2.3)
- Regulatory Setting (Section 3.0)
- Characterization of Effluent Quality (Section 4.0)
- Receiving Water Quality Predictions (Section 5.0)
- Preliminary Impact Assessment (Section 6.0)
- Uncertainty Assessment (Section 7.0)
- Considerations for Pre-Discharge Monitoring to support a Stage 2 EIS (Section 8.0)

The EIS was undertaken by Qualified Professionals (QPs) as shown in Table 1-1.

Table 1-1: Stage 1 Environmental Impact Study: Authorship and Professional Certification

Section #	Section Title	Company[a]	Name	Accreditation and Number
Section 1	Introduction	Golder	Elaine Irving	RPBio #2685
Section 2	Receiving Environment Characterization and Use	Golder	Elaine Irving	RPBio #2685
Section 3	Regulatory Setting	Golder	Elaine Irving	RPBio #2685
Section 4	Effluent Quality Assessment	Golder	Elaine Irving	RPBio #2685
Section 5	Receiving Water Quality Predictions	CDM Smith	Kapila Pathirage	PEng #128077
Section 6	Preliminary Impact Assessment	Golder	Elaine Irving	RPBio #2685

Section #	Section Title	Company[a]	Name	Accreditation and Number
Section 7	Uncertainty Assessment	Golder CDM Smith	Elaine Irving Kapila Pathirage	RPBio #2685 PEng #128077
Section 8	Monitoring Considerations	Golder CDM Smith	Elaine Irving Kapila Pathirage	RPBio #2685 PEng #128077
Appendix A	Multiport Diffuser Design and Initial Dilution Modeling Report	CDM Smith	Kapila Pathirage	PEng #128077
Appendix B	Fraser River Ambient Water Quality Summary	Golder	Elaine Irving	RPBio #2685
Appendix C	Fish and Fish Habitat and Species of Management Concern Assessment	Envirowest	Rolf Sickmuller	RPBio #826
Appendix D	Species at Risk Tables	Envirowest Golder	Rolf Sickmuller Elaine Irving	RPBio #826 RPBio #2685
Appendix E	Development Activity in the Study Area	Golder	Elaine Irving	RPBio #2685

[a] Golder Associates Ltd. (Golder); CDM Smith Canada ULC (CDM Smith); Envirowest Consultants Inc. (Envirowest)

2.0 RECEIVING ENVIRONMENT CHARACTERIZATION AND USE

The AIWWTP is located within the Corporation of Delta (Delta), on Annacis Island in the Fraser River Main Arm, downstream of the New Westminster 'trifurcation' where the river channel is split into three channels. The North Arm extends from New Westminster Quay past Sea Island and receives about 10 to 15% of the Fraser River flows. The Main Arm (referred to as South Arm in Fraser River Estuary Monitoring Program [FREMP]) is larger, conveying 80 to 85% of Fraser River flows, and serves as the main navigation channel for the Fraser River (FREMP 2006). A portion of the Main Arm splits around Annacis Island, with the Annacis Channel located on the north side of the island. The mouth of the Fraser River joins the Strait of Georgia along a 37 km delta-front from Point Grey to Point Roberts.

The Environmental Management Strategy for Dredging in the Fraser River Estuary developed by FREMP (2006) divided the Main Arm of lower Fraser River into four main channel segments. These segments were developed based on differences in channel morphology, water quality, tidal influences, and dredging requirements. The Main Arm segments include:

- **Sand Heads Channel**—Located west of Steveston to the end of the Steveston Jetty and provides the main access to the Fraser River for shipping.
- **Main Arm Tidal Channel**—Located between Steveston and Dees Island. The main shipping channel runs along the north side of the channel, while the south side has estuarine wetlands and an island complex.
- **Main Arm Meso-Tidal Channel**—Runs from Dees Island along the main shipping channel on the north side of Annacis Island to the eastern tip of the island. Most of this section has industrial activity along its shorelines and is confined by bank protections and training structures.
- **Annacis Channel**—Located along the northern bank of Annacis Island. This section contains combination industrial and residential sections, with extensive channel training works to maintain velocities and minimize dredging requirements.

The proposed outfall location is Annieville Channel, which is located within the Main Arm Meso-Tidal Channel (Figure 1-1). Most of the Main Arm Meso-Tidal Channel has industrial activity along its shorelines and is confined by bank protections and training structures, including the New Westminster trifurcation training structure that serves to split the Fraser River flows down multiple channels, reducing sedimentation and the need for dredging. This segment also includes Gunderson Slough and Tilbury Slough, which are characterized by their shallow bar mouths, and Deas Slough, which is a popular recreational boating area (FREMP 2006). The main shipping channel runs from Gravesend Reach through to St. Mungo's Bend on the south side of Annacis Island and continues upriver through Annieville Channel.

The land area around the new and existing AIWWTP outfalls is mixed commercial and industrial in nature with adjacent sites being Turning Point Brewery and a Sea Span loading area. The new outfall diffuser is proposed to be placed at the edge of the navigational channel to minimize impacts on dredging and shipping.

For the purpose of characterizing the receiving environment for the Stage 1 EIS impact assessment, the Study Area shown in Figure 1-1 was adopted. This Study Area is located within the Main Arm Meso-Tidal Channel and extends from the MV Receiving Environment Monitoring Program (REM) reference station upstream of the Fraser River trifurcation and downstream from the Skytrain Bridge, down to the Environment Canada Gravesend Reach buoy. Existing ambient conditions were characterized based on a compilation of available data and information for this Study Area. Receiving environment uses within the Study Area were also documented as well as current discharges and water withdrawals.

2.1 Physical Setting

2.1.1 Hydrology

The Main Arm of the Fraser River, where the Study Area is located, carries 80 to 85% of the river flow (FREMP 2006), with flows since 2008 ranging from 605 to 11,700 m^3/s (EC Pacific Water Quality Monitoring & Surveillance Program; see CDM Smith [2016] Appendix A for hydrograph depiction of flow rates). Low flows typically occur between September and March, while peak flows occur between April and August in response to freshet and runoff of precipitation.

The river system in the vicinity of the proposed outfall location is a complex estuarine environment due to tidal influences and the encroachment of saline water from the ocean. Flows in the vicinity of the proposed discharge location are subject to tidal influences, which affect water velocity, water depth, and vertical mixing. Salt water migrates up the Fraser River as a result of a combination of density differences between salt and fresh water and rising tides in the Strait of Georgia, and exists as a saline “salt wedge” along the bottom of the river. Fresh water is less dense than salt water and will typically flow out over top of the denser saline waters. The rising tide causes the wedge of salt water to migrate upstream underneath the outflowing freshwater of the Fraser River. Salt water intrusion at Annacis Island is reported to occur only at lower flows (Milliman 1980), as the salt wedge extends upstream to New Westminster during low flows on the Fraser River. During freshet, the salt wedge only migrates up the Fraser River channel as far as Steveston Bend and does not reach the Study Area.

2.1.2 Water Quality

Ambient water quality data for the Project in the vicinity of Annacis Island were obtained from the three data sources described in Table 2-1. The AIWWTP REM and Fraser River Ambient Monitoring Program (FRAMP) datasets represented low river flow conditions collected over a 30-day period during late winter (REM and FRAMP) and late summer (REM). Data from Environment Canada’s Pacific Water Quality Monitoring & Surveillance Program were used to supplement the ambient dataset to better characterize seasonal variability throughout the year in ambient river water quality, including the high flow freshet period. The results from these ongoing water quality monitoring programs have been reviewed, and the data from the years 2011 to 2014 are selected for this analysis because they are representative of recent conditions, and include more analytical chemistry and late summer AIWWTP REM monitoring. Monitoring locations for these three data sources were considered to be close enough to the Study Area to be representative of conditions within the Study Area. Data from the closest upstream Environment Canada station at Hope, several hundred kilometres (km) upstream, were not included because the water quality data were considered to be less representative, there were fewer data, and data were limited for some key constituents such as ammonia.

Data for conventional parameters, including nutrients and metals, were available from all three sources, but data for organic constituents were only available from the FRAMP and REM monitoring stations upstream of the proposed outfall location. For bacteriological constituents, only data from the upstream REM monitoring were used to determine ambient conditions in order to avoid influence from the existing AIWWTP outfall.

Table 2-1: Data Sources for Ambient Water Quality Data Summary (2011 to 2014)

Data Source	Time Period	Sample Type	Sampling Location
Greater Vancouver Regional District Fraser River Ambient Monitoring Program (FRAMP)	February 7, 2011 to March 24, 2014	Grab	Fraser River (Main Arm) off Tilbury Island (FRAMP Site #4)
Metro Vancouver's Annacis Island Wastewater Treatment Plant Initial Dilution Zone Boundary Monitoring Program	February 9, 2011 to October 6, 2014	Grab	Fraser River (Main Arm) off Annacis Island and downstream of the Alex Fraser Bridge
Environment Canada's Pacific Water Quality Monitoring & Surveillance Program	April 15, 2011 to December 15, 2014	Grab and Continuous	Monitoring buoy located in the Fraser River (Main Arm) at Gravesend Reach (near Tilbury Island)

Data were compiled and the following summary statistics were calculated for each parameter measured: number of samples, number of samples less than the method detection limit (MDL), percent of samples less than MDL, minimum, mean or median, 95th percentile, and maximum values[1] (Appendix B). A geometric mean value was calculated for bacteriological constituents such as fecal coliforms.

Seasonal ambient mean concentrations were used in the assessment of monthly water quality predictions (two seasons).

- **Seasonal Ambient Condition:** Data collected between April and August were assigned to the high flow season and data collected between September and March were assigned to the low flow season.

Ambient mean concentrations for conventional parameters grouped by three flow classifications were used in the assessment of instantaneous water quality predictions. Data for conventional parameters were grouped into categories of flow conditions to support the preliminary impact assessment in Section 6.0, recognizing the strong influence of river flow on water chemistry in the Fraser River. The influence of river flow did not always correspond to two seasons, particularly when instantaneous concentrations were considered, therefore, it was appropriate to consider river flow as well as season in characterizing ambient water quality in the lower Fraser River.

- **Ambient Condition by Flow Classification:** Data were divided into three categories based on the measured flows of the Fraser River, regardless of the season when data were collected. The three flow categories were: flow rates greater than 6,000 m^3/s (high), between 6,000 m^3/s and 1,000 m^3/s (moderate), and less than 1,000 m^3/s (low).

Data for organic constituents were more limited, and the number of samples for each parameter was typically less than ten. Therefore for the organic constituents, it was not possible to segregate the dataset by season or flow classification for the calculation of summary statistics.

For bacteriological constituents, summary statistics were calculated for the periods of April to October and November to March because the Fraser River Water Quality Objective (FRWQO) for fecal coliforms is only applicable to the period of April to October based on the protection of livestock and irrigated crops that are only present during that time of the year. Geometric mean concentrations were calculated rather than arithmetic means for bacteriological constituents to correspond with guideline values.

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[1] Minimum, maximum, and median were reported as the MDL when the summary statistic corresponded to a non-detect value. Mean was not calculated for parameters with greater than 50% non-detect values. A median was reported where a mean was not calculated. The 95th percentile was not calculated for parameters with fewer than 10 samples or with more than 95% non-detect values.

Ambient water quality was defined as the mean (or median where no mean was calculated) concentrations for each of the seasonal and flow classifications, or for organics, and data were screened against FRWQOs, BC WQGs, federal Canadian Council of Ministers of the Environment (CCME) guidelines, Environment Canada guidelines for polybrominated diphenyl ethers (PBDE), and Health Canada guidelines (Appendix B). Due to the fluctuation of salinity in the Study Area caused by the salt wedge, variable flow rates and tidal influence, where both marine/estuarine and freshwater screening values were available for a parameter, the more conservative value was applied to the screening.

The lower Fraser River within the Study Area tends to be slightly alkaline and well oxygenated, with relatively low nutrient concentrations. During freshet, total suspended solids (TSS) concentrations are naturally high, and correspondingly, metals such as aluminum, chromium, copper, and iron are also elevated and can exceed FRWQOs as well as federal and provincial WQGs. Dissolved concentrations of these metals tend to be considerably lower, especially under high flow conditions when the downstream transport of sediment peaks. Between 2011 and 2014, geometric mean levels of fecal coliforms were below the FRWQO, but geometric mean levels of the bacteria *Enterococus* (high and low seasonal flows) and *Escherichia coli* (low seasonal flow) were above respective FRWQOs. Bacteriological constituents consistently exceeded the most sensitive long-term BC WQGs protective of livestock, but not recreational guidelines.

Of the subset of organic constituents to be carried through the Stage 1 EIS assessment (Section 4.2.1), polychlorinated biphenyls (PCBs) and 17α-ethinyl-estradiol (EE2) were the only organic constituents reported above applicable guideline values. However, as discussed in Section 6.0, the ambient concentration of EE2 was limited and characterized by variable non-detect values.

2.1.3 Sediment Quality

Sediment quality in the lower Fraser River in the vicinity of Annacis Island and the Study Area has been well characterized in several sampling programs since the 1990s, including the FREMP bi-annual surveys until the mid-90's, the Fraser River Action Plan (FRAP) in 1999, the FRAMP, and the REM for Great Vancouver Regional District's Fraser River WWTPs located in the Fraser River. The FRAMP collects sediment quality every five years. The most recent sample years were 2006, 2011, and 2016. The following overview of sediment quality in the lower Fraser River is based on information provided in Environment Canada (1999a), Bull (2004), Thomas (2007) and Keystone (2011).

River flows serve to transport sediment downstream from the upper and middle reaches of the river into the lower reaches and further into the Fraser River estuary. As described in Section 2.1.1, flows are substantially higher during the freshet season and thus a large proportion of sediment movement occurs during this period.

Fine sediments are transported more readily because less energy is required to mobilize them. Depositional areas of these fine sediments can form within the Fraser River where the current is reduced as a result of the morphology of the river or a physical obstruction to the river flow. The center of the Fraser River channel where current and flow are highest is scoured and substrate consists predominantly of sand with a small quantity of silt. Areas near shore or where eddies in the current form tend to accumulate finer sediment such as clay-silt with a higher proportion of organic matter. The Study Area is similarly structured and the proportion of fine material in sediment tends to decrease from shore towards the center of the channel.

Fine material, both clay and organic, have a higher surface area in comparison to coarse material, and therefore more binding sites where contaminants can adsorb to sediment. In fine sediments, contaminants are typically quantified at a higher concentrations by weight compared to coarse sediments. Determination of the fraction of fine material and organic matter in sediment can assist in interpretation of the degree of contamination of an area.

For many of the Fraser River sediment programs, sediment chemistry data are normalized to organic matter content to facilitate comparisons between sample locations.

Due to the geophysical and geochemical environment of the Fraser River, natural sources of metals (such as weathering of the mineral constituents of the sediment substrate or plant degradation) can be mobilized and travel downstream. Concentrations of metals that are measured at similar concentrations throughout a large area of the Fraser River in recently deposited sediments may be attributed to natural sources. Arsenic, chromium, copper, manganese, iron, and nickel are metals that have been measured at concentrations in sediment that consistently approach or exceed guidelines or objectives throughout the Fraser River (see Table 2-2).

Industrial activities such as manufacturing, shipping, and pulp and paper milling have historically occurred on the lower Fraser River. These activities have released effluents into the environment containing a variety of organic and inorganic contaminants. Because these anthropogenic sources of contamination in the Fraser River are typically released at point sources, detected concentrations of these contaminants are not ubiquitous throughout the river.

Effluent from other sources may load additional contaminants into the environment which could be bound to sediments. The other municipal WWTPs that are active on the lower Fraser River are the Lulu Island and Northwest Langley WWTPs. Runoff from urban areas in the greater Vancouver area may also contribute contaminant loading into the Fraser River because the storm water system releases effluent directly into the Fraser River.

Table 2-2 summarizes the contaminants of historical concern that have been detected at levels approaching or exceeding provincial and federal guidelines or Fraser River Sediment Quality Objectives.

Table 2-2: Contaminants in Fraser River Sediment that have Historically Exceeded Guidelines

Contaminant	Areas of the Fraser River where sediment concentrations have exceeded guidelines or objectives in the last 20 years[a]	Reference
Polycyclic aromatic hydrocarbons (PAHs)	lower Fraser River (Both Arms)[b], upper Fraser River[c], AIWWTP Study Area[d]	Environment Canada 1999a, Thomas 2007, Keystone 2011
Polychlorinated biphenyls (PCBs)	North Arm of Fraser River[e]	Environment Canada 1999a
Pesticides	lower Fraser River (Both Arms)[f]	Environment Canada 1999a
Metals	lower Fraser River Main Arm[g], lower Fraser River North Arm[g,h], upper Fraser[i]	Environment Canada 1999a, Thomas 2007, Keystone 2011, Bull 2004
Polybrominated diphenyl ethers (PBDEs)	lower Fraser River Main Arm	Keystone 2011
Dioxins and furans (total)	lower Fraser River, mid Fraser River	Environment Canada 1999a, Thomas 2007, Keystone 2011
Nonylphenols	no exceedances	Environment Canada 1999a, Keystone 2011
Estradiols and sterols	no exceedances	Keystone 2011

a – Based on CCME, BC MoE guidelines, and Fraser River Sediment Objectives
b – Naphthalene, phenanthrene, fluoranthene, pyrene, benz(a)anthracene, chrysene, benzo(a)pyrene, dibenz(ah)anthracene
c – Retane and other naturally derived polycyclic aromatic hydrocarbons (PAHs)
d – Phenanthrene, benzo(a)pyrene and dibenzo(a,h)anthracene
e – Aroclor 1254 and 1260
f – Lindane and DDT with metabolites
g – Chromium, manganese, iron, arsenic, nickel and copper
h – Zinc
i – Chromium, manganese, iron, nickel and copper

2.2 Ecological Resources

Ecological resources in the lower Fraser River have been the subject of numerous studies and initiatives including the FREMP and the FRAP, as well as other monitoring or research initiatives by government, industry, and academia. Ecological resource information, with respect to the physical habitat characteristics and aquatic resources relevant to the Study Area, was accessed from information sources that included, but were not limited to the following:

- FREMP, an organization jointly established by the provincial and federal governments in the 1980s that closed in 2013
- FRAP
- FRAMP
- Fisheries and Oceans Canada, Pacific Region website
- BC Conservation Data Centre (CDC)
- Government of Canada, *Species At Risk Act* (SARA) Public Registry
- Committee on the Status of Endangered Wildlife in Canada (COSEWIC) status reports for listed marine mammal species
- British Columbia Cetacean Sighting Network (BCCSN)
- British Columbia Species and Ecosystems Explorer
- British Columbia Marine Conservation Analysis (MCA) atlas and public database
- iMapBC (DataBC)
- Relevant peer-reviewed scientific literature and government/ data reports

2.2.1 Fish and Fish Habitat

2.2.1.1 Fish Habitat

The Project is located in the Main Arm Meso-Tidal Channel of the lower Fraser River. The Main Arm of the river separates Annacis Island from the Corporation of Delta mainland by a single channel, identified as the Annieville Channel. Several other names are applied to the Annieville Channel, including City Reach and St. Mungo's Bend. The channel conveys the majority of river flows discharged to the Salish Sea; remaining flows are directed to the Sea by the Middle and North Arms.

Habitat established along the shorelines of the Annieville Channel of the Main Arm has been highly modified. Most habitats along this section of the river comprise either a narrow riparian fringe woodland, intermitted marsh, or mudflat. Substantial flows combined with rock armouring of the South Surrey Interceptor and channel restrictions associated with the Alex Fraser Bridge have resulted in a diverse bathymetry in proximity to the Project. The most notable bathymetric feature includes a deep scour hole extending downstream of the South Surrey Interceptor and past the Project. Other notable bathymetric features include sand waves established within the downstream extent of the scour hole that become increasingly mobile during high freshet flows.

The former FREMP classified the shorelines of the Fraser River based on the relative value of the habitat features (FREMP 2006). FREMP was a cooperative agreement amongst member agencies, including Environment Canada, Fisheries and Oceans Canada, Transport Canada, Fraser River Port Authority, North Fraser Port Authority, BC MoE, and the Greater Vancouver Regional District (Anonymous 2007), and was established in 1985 to coordinate planning an decision-making in the estuary (Water and Land Use Committee 2003). FREMP's Estuary Management Plan integrates habitat management and recreational activities with strategies for water and sediment quality, log management, navigation and dredging, and urban and water related industrial development.

The classification of habitats within the Fraser River estuary during the mid-1980s was one of the first management initiatives of the newly fledged FREMP. The FREMP (2006) colour-coded system classified the overall habitat value of the estuarine shoreline and identified development constraints associated with each classification. The definition of habitat was limited to functional habitat values provided by estuarine environments for fish and wildlife. Development constraints applied to all components of development, including design, construction and operation.

The FREMP (2006) classification system comprised a three tiered colour-coded system: habitats were colour-coded red, yellow or green. Red-coded shorelines sustained highly productive fish and wildlife habitats. Yellow-coded shorelines sustained moderately productive habitats, while green-coded shorelines were characterized by habitats of low productivity. Development constraints were greatest within red-coded habitats, while development within green-coded habitats were constrained the least. Constraints within yellow-coded habitats were intermediate between those for red-coded and green-coded habitats. The FREMP classification system applied only to intertidal habitat and riparian habitat extending up to 30 metres landward of the shoreline. Habitats below local low water, hence below the intertidal zone, were not addressed by the system. This is particularly relevant, as the new outfall will not encounter habitats above local low water (i.e. within the intertidal or upland zones).

FREMP ceased to exist in March 2013. Despite this, the three tiered colour-coded system is still applied as a tool by municipalities (i.e. Richmond and Delta) to assess impacts to fish and wildlife associated with proposed upland developments and related activities within the Fraser River estuary.

The FREMP habitat classifications of the south shoreline of Annacis Island are predominantly high (red) productivity or moderate (yellow) productivity. The high and moderate productivity classifications are largely a function of riparian vegetation and intermittent fringe marsh establishment along the shoreline. Low (green) productivity habitat is reserved for the footing protection structure of the Alex Fraser Bridge north support structure immediately upstream of the Project, and the ship docks at the upstream extent of Annacis Island.

The south shoreline of the Main Arm (i.e. Corporation of Delta shoreline) includes all three habitat classifications. Moderate productivity shoreline is generally more prevalent, interspersed with low productivity shoreline and occasional high productivity habitat. High productivity habitat is more prevalent along the Tilbury Island shoreline.

2.2.1.2 Fish

An estuarine fish assemblage occupies the lower Fraser River to the upper limits of tidal influence at Mission (McPhail 2007). In total, 112 fish species have been documented to utilize the lower reaches of the Fraser River, as summarized in Appendix C. The river sustains nationally important commercial, recreational, and aboriginal fisheries, as regulated by the federal *Fisheries Act*.

The lower river contains a number of euryhaline species, which are adaptable to a range of salinities, (e.g., lampreys, sturgeon, smelts, salmon, and trout); however, there are also purely freshwater species (McPhail

2007). Freshwater species include five minnows [brassy minnow (*Hybognathus hankinsoni)*, peamouth chub (*Mylocheilus caurinus)*, northern pikeminnow (*Ptychocheilus oregonensis)*, longnose dace (*Rhinichthys cataractae*), and leopard dace (*R. falcatus)*)] and three sucker species [bridgelip sucker (*Catostomus columbianus)*, largescale sucker (C. *macrocheilus)*, and mountain sucker (*C. platyhyncus)*]. The fish community of the lower Fraser River is dominated by cyprinids, salmonids, and catostomids (Richardson et al. 2000; Appendix C).

The Fraser River is a significant salmonid-bearing system. Salmonid use of the Main Arm from Steveston to New Westminster is largely confined to upstream adult migration in the fall and downstream juvenile migration and rearing in the spring to midsummer (FREMP 2006). Seven species of salmonids (*Oncorhynchus* spp.) occur within the lower Fraser River, specifically: chinook salmon (*O. tshawytscha*); chum salmon (*O. keta*); coho salmon (*O. kisutch*); cutthroat trout, clarkii subspecies (*O. clarkii clarkii*); pink salmon (*O. gorbuscha*); rainbow trout; and sockeye salmon (*O. nerka*) (Water and Land Use Committee 2006). Adult salmon migrate upriver annually to spawn and hundreds of millions of juveniles migrate downstream to and through the estuary and ultimately to the sea (Rosenau and Angelo 2007).

The Main Arm also supports eulachon (*Thaleichthys pacificus*) during their migration to upstream spawning habitats as close to the Project as New Westminster. The Main Arm also sustains white sturgeon (*Acipenser transmontanus*), as documented by numerous captures of juvenile fish along the south shore of Annacis Island during recent sampling events. Despite having special conservation assessment status (COSEWIC 2003) and provincial conservation priority (CDC), the lower Fraser River white sturgeon population is not included in Schedule 1 of the *Species At Risk Act.*

Out-migrating juvenile salmonids utilize intermittent intertidal marshes established along the Main Arm. The marshes provide rearing habitat for juvenile chinook salmon, chum salmon, coho salmon and white sturgeon (Healey 1991; Salo 1991; Cohen 2012; Nelson et al. 2004). Specific occurrences of species identified by the CDC and iMapBC adjacent to the Project are limited to juvenile white sturgeon. The absence of other documented occurrences in proximity to the outfall is not indicative of species absence, as salmon and coarse fish species have been captured in reaches of the Fraser River upstream and downstream of the outfall.

2.2.2 Fish Health

The historic condition of fish health on the Fraser River was documented in FRAP (1999). Concentrations of legacy contaminants like DDT, organochlorines, dioxins/furans, and metals in fish tissues collected from the river decreased from the 1970's to the late 1990's. Polycyclic aromatic hydrocarbons (PAHs) were observed to increase in fish tissue and further monitoring was recommended. Bull (2004) found that fish sampled on the Main Arm of the lower Fraser River met the Fraser River Objectives to protect human health from concentrations of chemicals in edible fish for dioxins and furans, but results were inconclusive for PCBs because the detection limit for fish tissue was higher than the objective. Total chlorophenols, metals, and PAHs, contaminants historically detected, were not measured in fish tissue in the lower Fraser River by Bull (2004).

A more recent study of the Fraser River conducted in 2012 (ENKON 2014) found that health metrics in fish (largescale sucker and peamouth chub) measured from three sampling areas in the lower Fraser River showed few among-area differences. Lengths, weights, condition factors, and relative reproductive organ size did not differ significantly between these sampling areas. All analyzed fish tissues samples (composites of fish collected) met

Fraser River Objectives for dioxins/furan toxic equivalency quotients (TEQ), total PCBs, and benzo[a]pyrene. A relatively small percentage of fish tissue samples had concentrations that exceeded federal guidelines for at least one of the following parameters: total mercury, dioxin/furan TEQ, PCB TEQ, penta-BDE-99, and DDT. Most samples that exceeded guideline values did so by a margin that was considered essentially equal to the guideline within the limits of analytical precision. Methylmercury was the only parameter that consistently exceeded the federal guideline value.

Sampling that targeted fish health in the vicinity of Annacis Island was conducted in the past. Peamouth chub were collected for an Annacis Island WWTP Pre-discharge Monitoring Study by EVS Environmental in 1996. Cadmium, copper, iron, lead, and zinc were all measured in fish tissue, but there was no apparent pattern of contamination associated with the AIWWTP (EVS 1996).

2.2.3 Benthic invertebrates

A characterization of benthic invertebrate communities in the Main Arm was provided by Swain et al. (1998) based on a study by Northcote et al. (1976). Benthic invertebrates were sampled at stations located along the lower Fraser River in late summer/fall of 1972 and 1973, when the river was characterized by average to high flows and the salt wedge was located closer to the river mouth. The benthic invertebrate community assessment was based on comparison of benthic metrics such as abundance and diversity between stations. The average number of taxa collected from mud and mud-sand substrates and also from sand and sand-gravel substrates in the Main Arm was lower than corresponding estimates from the North Arm; however, diversity was similar between the two arms for both substrate types.

Benthic communities present at the most upstream station in the Main Arm located near Tilbury and Deas islands were composed of oligochaetes, leeches, *Pisidium* clams, crustaceans such as amphipods and isopods, and dipteran insect larvae (non-biting midges). At that time of year (late summer/fall), Swain et al. (1998) suggested that it would be reasonable to expect more freshwater organisms in the Main Arm compared to earlier in the year when the salinity intrusion would be more prevalent with a concomitant increase in more haline or salinity tolerant invertebrates. The downstream stations sampled by Northcote et al. (1976) in the Main Arm were located at the mouth of the Fraser River out of the Main Arm Meso-Tidal Channel segment.

Sediments within the Main Arm Meso-Tidal Channel are dredged annually by a hopper and cutter suction dredge to maintain the shipping channel; infrequent clam shell dredging to maintain vessel access to the sloughs and moorage in small craft harbours also occurs (FREMP 2006). Studies examining the long-term effects of dredging in this segment on benthic invertebrates were not available; however, studies conducted downstream (Anderson et al. 1981) and immediately upstream within the Sapperton Channel Segment (Taylor et al. 2004) indicate that dredging related impacts to the benthic invertebrate communities are limited to entrainment of invertebrates during the dredging process, and that recolonization would be expected in a few months.

2.2.4 Marine Mammals

Three species of pinnipeds (i.e., seals and sea lions) are common in the Fraser River. Table 2-3 summarizes the general seasonal occurrence and listing status of marine mammals near the Study Area. An overview of the biology of each marine mammal species potentially present near the Study Area is provided below.

Table 2-3: Marine Mammal Species that Occur in Fraser River and Southern Strait of Georgia, BC

Common Name (Scientific Name)	Seasonal Occurrence/ Habitat Use[a]	Preferred Diet[a]	Estimated Population Size in BC[a]	SARA Listing[b]	COSEWIC[b]	CDC[b]
Steller sea lion (*Eumetopias jubatus*)	Forage and migrate in area.	Fish (e.g., rockfish, flatfish, salmon) and cephalopods, strongly associated with Pacific Herring in the Study Area.	23,417	SC/Sc1	Special Concern	Red
California sea lion (*Zalophus californicanus*)			1,500 to 3,000	No Status	Not at Risk	Yellow
Harbour seal (*Phoca vitulina*)	Year round resident; forage, mate and rear young in area.	Fish	108,000	No Status	Not at Risk	Yellow

a – Seasonal occurrence based on sighting data from BCCSN (2013), Keple (2002) and DFO (2010) and does not indicate number of individuals per sighting nor number of sightings per season;

b – COSEWIC = Committee on the Status of Endangered Wildlife in Canada; SC1=Schedule 1 of *Species At Risk Act* (SARA 2002); CDC = BC Conservation Data Center (2016)

Steller Sea Lion

The Steller sea lion (*Eumetopias jubatus*) occurs along the coastal rim of the North Pacific Ocean, from California to the Bering Sea and Kurile Islands. They are listed as a species of Special Concern under Schedule 1 of the SARA and by the COSEWIC. The BC population is estimated at 23,417 animals (last assessed in 2010) and has experienced a steady increase in numbers since 1990 (Allen and Angliss 2014). Steller sea lions tend to remain within 45 km of shore, but occasionally occur as far as 130 km offshore (Klinkenberg 2012). In BC, distribution of the Steller sea lion is highly influenced by one of its most important prey species, Pacific herring; they also feed on other small schooling fish (Pacific sardine, Pacific sand lance, and eulachon) as well as Pacific hake, spiny dogfish, and salmon (Edgell and Demarchi 2012; Ford 2014). Steller sea lions occur along the BC coast year-round where they gather on rookeries to breed during summer months. There are seven Steller sea lion breeding locations (known as rookeries) in BC (Williams and Thomas 2007; COSEWIC 2013). None of the identified rookeries fall within or near the Study Area. Stellar sea lion presence in the Study Area should be considered incidental and transient, though a year-round haul-out site can be found downstream at the mouth of the Fraser River at Sand Heads (Bigg 1985; Ford 2014; BCMCA 2011, PNCIMA 2011).

California Sea Lion

The California sea lion (*Zalophus californianus*) occurs along the west coast of North America from Baja California, Mexico to BC. They are considered ‘Not at Risk’ under SARA and COSEWIC with minimum population estimates of the Pacific Temperate individuals to be approximately 153,337 (National Marine Fisheries Service unpublished Data in Allen and Angliss 2014). Although they do not breed north of California, adult males and sub-adults travel into Canadian and Alaskan waters from fall through spring following prey fishes, including salmon, Pacific herring, and eulachon (Edgell and Demarchi 2012; BCMCA 2011). An increase in California sea lions have been observed in a rocky archipelago in southern Vancouver Island, this haul-out is thought to act as a staging area for individuals moving northward and throughout the Strait of Georgia to foraging localities like the mouth of the Fraser River. The timing of California sea lions in this area appears to be tightly correlated with herring spawning and salmon migrations in the Fraser River during the spring (Ford 2014, Bigg 1985). Sand Heads, at the mouth of the Fraser River, has been observed as a frequently used haul-out area for California sea lions. Historical sightings of California sea lions in the Fraser River also suggest that large groups of rafting individuals may travel as far as 50 km up the River (Bigg 1985).

Harbour Seal

The harbour seal (*Phoca vitulina)* is considered to be ‘Not at Risk’ in BC, due to its large and increasing population size (105,000 animals in 2008; Ford 2014; Olesiuk et al. 1990; Baird 2001). Harbour seals are non-migratory and are distributed throughout the Strait of Georgia and surrounding area year-round. They tend to be associated with shallow areas such as tidal flats, shoals, and reefs where they can haul out easily (Ford 2014). Local movements are correlated to tides, weather, season, and food availability. Harbour seals haul out on land and rest on a variety of structures, including rocky shores, mud flats, sandbars, and man-made structures (e.g., floats and docks) (Hoover-Miller et al. 2013). Harbour seals are sensitive to disturbances and will often flee from resting areas into water to avoid interaction, thus reducing valuable resting times and increasing stress. With continued disturbance, harbour seals may abandon haul-out sites. This issue is particularly problematic during birthing and nursing when pups may become separated from their mother and risk abandonment and subsequent starvation (Hoover-Miller et al. 2013). No major haul-out sites (with >200 individuals) are known to exist in the Study Area (Ford 2014), but sightings are a common occurrence year round in southeast Strait of Georgia and in the Fraser River (Keple 2002).

2.2.5 Birds

Historical aquatic bird survey data exists for the Main Arm of the Fraser River from the north end of Annacis Island to the ocean. In 1979, the Canadian Wildlife Services (CWS) conducted a survey of aquatic birds on the south arm of the Fraser River (Blood 1979). A second survey of the Main Arm was conducted in 2009 as part of the Vancouver Airport Fuel Delivery Project (VAFFC 2009). According to these reports, the following bird species groups are common within the Study Area between Tilbury Island and the north end of Annacis Island: Canada goose (*Branta canadensis*), diving ducks (e.g., goldeneye, bufflehead), dabbling ducks (e.g., mallard, widgeon), and herons (e.g., great blue heron [*Ardea herodias fannini*], green heron [*Butorides virescens*]).

The Study Area is situated within the Boundary Bay – Roberts Bank – Sturgeon Bank Important Bird Area (IBA) that consists of a complex of marine, estuarine, freshwater and agricultural areas (IBA 2016). This IBA extends from Boundary Bay to the City of Surrey, west to the Fraser River estuary. The IBA covers most of the Study Area with the exception of the most north east section of the Fraser River, an area between Annacis Island, and the Alex Fraser Bridge. This IBA has been designated because of its importance for large congregations of overwintering waterfowl and shorebirds, colonial waterbirds, and seabirds, as well as numerous species at risk (IBA 2016).

A portion of the IBA (45%) located downstream of the Study Area is protected in conservation management areas such as parks and wildlife management areas. The majority of protected areas are situated around inter- and sub-tidal areas. Two provincial Wildlife Management Areas (WMAs; South Arm Marshes WMA and Roberts Bank WMA), one national wildlife area (Alaksen National Wildlife Area [NWA]), and one national migratory bird sanctuary (George C. Reifel Migratory Bird Sanctuary) occur southwest of the Study Area on the Fraser River-Pacific Ocean delta. These areas were established to protect congregations of overwintering birds, waterfowls, shorebirds, and seabirds. They support critical numbers of North American dunlin (*Calidris alpina*), North American trumpeter swan (*Cygnus buccinator*), North American black-bellied plover (*Pluvailis squatarola*), and also provide habitat for migrating and overwintering bird species like the migrating snow goose (*Chen caerulescens*) and dabbling ducks (e.g., American widgeon [*Anas americana*], northern pintail [*Anas acuta*]; Environment Canada 2016).

2.2.6 Species of Management Concern

Numerous species have been listed by the federal and provincial governments as being of special conservation status. The provincial government assigns a rank or listing of ‘red’ or ‘blue’ to a species based on its status within BC. The rankings or provincial listing categories described below highlight species as well as natural plant communities that require special attention (BC Ministry of Forests, Lands and Natural Resource Operations [MFLNRO] 2007):

- Red - any indigenous species, subspecies or plant community that is extirpated, endangered, or threatened in BC
- Blue - any indigenous species, subspecies or community considered to be vulnerable (special concern) in BC
- Yellow - any indigenous species, subspecies or community considered not at risk in BC

Federally, species ranking is conducted by COSEWIC, established under S.14 of the SARA. COSEWIC is a committee of experts that assesses and designates, under S.15 to S.21 of SARA, which wild species of animal, plant, or other organisms are in danger of disappearing from Canada (Government of Canada 2007). Below is a listing of the status categories used by COSEWIC to rank or list a species:

- Extinct—a species that no longer exists
- Extirpated—a species no longer existing in the wild in Canada, but occurring elsewhere
- Endangered—a species facing imminent extirpation or extinction
- Threatened—a species likely to become endangered if limiting factors are not reversed
- Special concern—a species that is particularly sensitive to human activities or natural events, but is not an endangered or threatened species
- Data deficient—a species for which there is inadequate information to make a direct, or indirect, assessment of its risk of extinction
- Not at risk—a species that has been evaluated and found to be not at risk

COSEWIC rankings are regarded as recommendations to the federal government; the government makes the final decision on whether species will be listed under SARA. Schedule 1 of SARA provides the official list of wildlife species at risk in Canada, including species that are extirpated (extinct in Canada), endangered, threatened, and of special concern. Species listed on Schedules 2 and 3 are not yet officially protected under SARA, but are candidates for protected pursuant with Schedule 1.

A general prohibition under SARA is that “No person shall kill, harm, harass, capture or take an individual of a wildlife species that is listed as an extirpated species, an endangered species or a threatened species” (S.32). SARA also prohibits the damage or destruction of the habitat (“residence”) used by listed species (S.33) unless authorized or permitted (S.73).

To determine if these species have been recorded by the CDC in the areas of interest, the CDC's internet mapping service was accessed. White sturgeon lower Fraser River population (*Acipenser transmontanus pop.4*), provincially red-listed, identified as threatened by COSEWIC, but not included in Schedule 1 of SARA, is the only aquatic faunal species reported by this search.

The BC Species and Ecosystem Explorer database was also accessed. This database contains information on rare and endangered species and ecosystems in BC. Species can be searched by Forest District, Regional District, BC MoE Region, biogeoclimatic zone, and habitat type. Faunal species occurring in the marine and estuary environment of the Coastal Douglas Fir and Coastal Western Hemlock Biogeoclimatic Zones, the zones in which the Project is located, were searched. This area-based (e.g., biogeoclimatic zone) search provides a broad list of regionally occurring species that could potentially occur in the areas.

Listed aquatic faunal species (including birds) with potential to occur in the Study Area based on professional judgement and/or published occurrence reports are summarized in Table 2-4. Other species identified through the BC Species and Ecosystem Explorer may be present in the vicinity of the outfall areas, but have not been validated.

Although expected to be present in the Study Area, barn swallow (*Hirundo rustica*) has been excluded from Table 2-4 as this species is an aerial insectivore and does not forage in water.

Table 2-4: Listed Aquatic Faunal Species of Management Concern Expected to Occur in the Vicinity of the Study Area

Scientific Name	Common Name	Species Group	Provincial Listing	COSEWIC Ranking[a]	SARA Designation[b]
Ardea herodias fannini	Great blue heron *fannini* subspecies	Bird	Blue	SC	1-SC
Butorides virescens	Green heron	Bird	Blue	No Ranking	No Designation
Nyticorax nicticorax	Black-crowned night-heron	Bird	Red	No Ranking	No Designation
Phalacrocorax auratus	Double-crested cormorant	Bird	Blue	Not at Risk	No Designation
Hydroprogne caspia	Caspian tern	Bird	Blue	Not at Risk	No Designation
Acipenser transmontanus pop.4	White sturgeon (lower Fraser River population)	Fish	Red	E/T	No Designation
Eumetopias jubatus	Stellar sea lion	Mammal	Red	SC	1 - SC
Oncorhynchus clarkii	Cutthroat trout	Fish	Blue	No Ranking	No Designation
Salvelinus confluentus coastal lineage	Bull trout South Coast Lineage	Fish	Blue	SC	No Designation
Thaleichthys pacificus	Eulachon,	Fish	Blue	E/T	No Designation
Oncorhynchus kisutch	Coho salmon	Fish	Yellow	E	No Designation
Oncorhynchus nerka	Sockeye salmon	Fish	Yellow	E	No Designation
Oncorhynchus tshawytscha	Chinook salmon	Fish	Yellow	T	No Designation
Oncorhynchus gorbuscha	Pink salmon	Fish	Yellow	No Ranking	No Designation
Oncorhynchus keta	Chum salmon	Fish	Yellow	No Ranking	No Designation
Salvelinus malma	Dolly Varden Char (southern form)	Fish	Yellow	No Ranking	No Designation

a – E= Endangered, T = Threatened, SC = Special concern, NAR = Not at Risk

b – 1-E1 = Endangered Schedule 1, 1-T = Threatened Schedule 1, 1-SC = Special concern Schedule 1.

2.3 Receiving Environment Uses and Relevant Water Quality Guidelines

A desktop review of online databases and websites was undertaken to search for information on known human and environmental uses of the Fraser River relevant to the EIS. Information sources included:

- Fisheries and Oceans Canada, Pacific Region website
- BC MoE - Water Licences Query database
- Metro Vancouver website
- Recreation Sites and Trails BC website
- BC Parks website
- FREMP website

2.3.1 Protected Areas and Parks

Within the Study Area, Don Island (also known as Oikawa Island) and Lion Island (also known as Sato Island) are designated by Metro Vancouver as regional parks. The shoreline on the north side and the downstream tip of Annacis Island is designated as municipal parkland. The upstream tip of Tilbury Island is also designated a municipal park (Metro Vancouver 2015). An inventory of regional and municipal parks located within the Study Area is provided in Table 2-5.

Table 2-5: Parks Located in the Vicinity of the Study Area

Park Name	Area
Regional Parks	
Lion (Sato) Island	Mid-stream Fraser River main channel
Don (Oikawa) Island	Mid-stream Fraser River main channel
Municipal Parks	
Annacis Channel Inlet on North East Side of Annacis Island	Shoreline of Annacis Island
West Patrick Island Development	North Shoreline of Annacis Island
Grosvenor Habitat Park	South-Western Shoreline of Annacis Island
New Westminster Pier Park	Northern shoreline of Fraser River main channel
Tilbury Island Municipal Park Space	Northern tip of Tilbury Island

Downstream of the Study Area and closer to the confluence of the Fraser River with the Pacific Ocean, there are several provincial and federal ecological reserves.

- Two federal management zones, Alaksen NWA and George C. Reifel Migratory Bird Sanctuary, are protected under the *Migratory Birds Convention Act.*
- Three provincial wildlife management areas, South Arm Marshes WMA, Sturgeon Bank WMA, and Roberts Bank WMA, are protected under the *Ecological Reserve Act*.

These protected areas provide wetland habitat for waterfowl and other species and support scientific research and education (IBA 2016).

The value of the Fraser River Estuary area downstream of the Study Area, encompassing Burns Bog, Sturgeon Bank, South Arm Marshes, and Boundary Bay, is recognized through several international designations. This area is designated a Hemispheric Site under the Western Hemisphere Shorebird Reserve Network (WHSRN) and most of the area is a Ramsar Wetland of International Significance.

Several parks have also been identified downstream of the Study Area. Deas Island, a regional park, and a number of municipal parks were identified along the shoreline downstream of the Study Area. A new regional greenway called the Delta-South Surrey Regional Greenway is also in development, which will connect natural areas for both wildlife and people, from Annacis Island to Mud Bay. The greenway currently does not extend into the Study Area, but might in the future (Metro Vancouver 2009).

2.3.2 Fisheries

Fraser River stocks support several commercial aboriginal fisheries, and salmon in particular continue to be important to First Nations for food, social and ceremonial purposes (DFO 2015a). Along with commercial activities, Tsawwassen First Nation, Musqueam First Nations, and other Aboriginal group members may be engaged in activities that have cultural importance in the Study Area.

Aboriginal fisheries are authorized by communal licences issued to individual First Nations organizations by Fisheries and Oceans Canada (DFO) under the Aboriginal Communal Fishing Licences Regulations. First Nations are licenced for two main fishery types which are Food Social and Ceremonial (FSC) fisheries, and fisheries with a sales component including economic opportunity, demonstration, and harvest agreement fisheries. Communal commercial licences are issued annually for First Nation's participation in the commercial fishery and provide detail on fishing areas, methods, allocation and times (DFO 2013a,b).

There are numerous First Nations which are involved in the commercial salmon fishery of the tidal waters of the lower Fraser. Tsawwassen First Nation and seven other Aboriginal groups, the Sechelt, Q'ul-Lhanumutsun, Tsleil-Waututh, Cowichan, Snuneymuxw, Tseycum, and Musqueam hold general commercial licences in Management Area E. As such, they are permitted to conduct salmon gillnetting activities in the section of the Fraser River overlapping the Study Area, from the Port Mann Bridge to the Strait of Georgia, a distance of about 35 km (DFO 2013b). The Tsawwassen First Nation and the Musqueam Indian Band have the most active fisheries on the lower Fraser River (DFO 2014). The preferred location of commercial fishing activity changes depending on seasonal trends and daily movements of salmon within the Fraser River; therefore, specific information regarding fishing activity in the Study Area was not available for the approximately 11.5 km length of the Study Area within this fishing zone. A summary of total reported salmon numbers caught and kept in the 2014[2] First Nation's fisheries in the lower Fraser River below the Port Mann Bridge is provided in Table 2-6.

There are no shellfish harvesting areas within the Study Area or in the South Arm of the river. Shellfish areas along the outer estuary are currently closed to shellfish harvesting and closure is considered permanent (DFO 2016).

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[2] 2014 is the most recent publically available series of catch reports for the Lower Fraser River at the time of publication.

Table 2-6: 2013 First Nations Kept Catches in the Lower Fraser River (below Port Mann Bridge)

Species	Opening	Kept Catch by Band[a]			Total
		Musqueam	Tsawwassen	Other	
Chinook	May - Oct	2,169	1,060	141	3,370
Sockeye	June - Sept	193,199	94,452	10,379	298,030
Chum	Sept - Nov	20,249	8,452	30	28,731
Coho	Sept - Nov	242	159	3	404
Pink	July - Oct	0	7	0	7
Steelhead	-	0	0	0	0

a – Includes FSC and economic opportunity fisheries (DFO 2015b)

2.3.3 Recreational Activities

The lower Fraser River, situated in the urban environment of the Greater Vancouver area, provides many recreational opportunities for the Greater Vancouver population. Day use is often associated with designated parks, wildlife areas, and trails. The broader Fraser River area offers opportunities for hiking, walking, biking, picnicking, wildlife viewing, and nature study (Metro Vancouver 2014). Sport fishing for salmon, trout and other species is also popular in these areas (Forbes 2015). There is minimal swimming activity in the Fraser River, with swimming more prevalent in its smaller tributaries where conditions are more suitable (Swain et al. 1998). No recreational hunting is permitted within the Study Area; however, hunting is permitted on the Fraser River downstream of Deas Island with some restrictions. Waterfowl targeted for hunting include numerous duck species, Canada geese, snow geese, and brant geese (BC MFLNRO 2014).

The Study Area is located in a predominantly industrial and commercial use area of the lower Fraser River with recreational boating and fishing the most probable recreational activities. Although public access to the Annacis Island shoreline is possible in some areas along paved roads in the commercial/industrial area of the island, accessible shoreline is marshy and not generally suitable for recreational use. There is currently no formal trail network along Annacis Island, but the Delta-South Surrey Regional Greenway will cross this island in the future (Metro Vancouver 2009).

Fishing

The Fraser River tidal water area provides many fishing opportunities for angling enthusiasts and is popular for sport fishing, particularly since this activity can be carried out from the shoreline and from boats. Predominantly these popular fishing locations occur outside of the Study Area. Deas Island Park, Steveston area, the termini of shore-line roads in Richmond, the South Arm Marshes and Dow Delta Bar Fishing Park, located at the eastern tip of Tilbury Island, are commonly used for recreational fishing (Moffat and Nichol 2012; Hsu 2014; City of Richmond 2015). The area encompassing the Project, from Deas Island Park to the Port Mann Bridge, is a primarily industrial and commercial area of the Fraser River, and is reported to be unappealing for anglers, with limited public access to the shoreline (Forbes 2015).

Major recreational fish species include salmon, trout, and sturgeon. Sturgeon and wild trout are catch and release, but the recreational fishery for these species is open year round (DFO 2015c). Of the salmon species, sockeye and coho are reported to be the most popular within the Fraser River, although chum is reported to be increasing. Peak fishing season is between July and early September, although fishing does occur year-round. During odd-numbered years, the pink salmon fishery is highly active in September (Hsu 2014).

The provincial government sets specific fishing regulations and catch quotas for Fraser River recreational fisheries. Given the low returns of Fraser River Sockeye between 2007 and 2009, no directed recreational or commercial fisheries were permitted in those years. In 2015, due to drought conditions, fishing for salmon in the tidal waters of the Fraser River was prohibited between July 13 and July 31 (DFO 2015d) and between August 1 and August 31, and daily limits for chinook, pink, and chum were revised with no retention of sockeye salmon permitted (DFO 2015e).

Boating

Recreational boating occurs year round, but highest levels of activity occurring between May and September with lowest levels of activity occurring December to February. Recreational boaters generally exit and enter the Main Arm near Steveston owing to general ease of navigation, but experienced recreational boaters may exit and enter the Main Arm by Canoe Passage. Most recreational boaters limit their movements downstream of the Study Area and remain outside of the main shipping channel, but crossings of the main shipping channel within the Study Area and recreational boating activities do occur.

One marina and boat launch exists within the Study Area: Shelter Island Marina & Boatyard, located near the southern tip of Annacis Island, can accommodate up to 300 vessels and provides additional boatyard and ancillary services (Shelter Island Marina & Boatyard Inc. 2015). Additional marinas are located in Delta and Richmond outside of the Study Area.

2.3.4 Other Uses

The lower Fraser River is also used for industrial, commercial and residential purposes. Seven fish processing plants, a fleet of over 850 fishing boats, five deep sea port terminals, a ferry terminal and over 250 industrial operations are situated within the Fraser River estuary (FREMP 2003). The river provides an important means of transportation for movement of raw materials, including logs, fish, and construction aggregates, as well as finished products (FREMP 2003).

2.3.5 Withdrawals and Discharges

Withdrawals

A summary of licensed Fraser River water withdrawals located within the Study Area is presented in Table 2-7. In comparison to average daily flow (average of 3,888,000 m^3/day for the duration of monitoring efforts, a period of over 100 years) the maximum total withdrawals from within the Study Area represent 3% of the total discharge of the Fraser River.

Table 2-7: Withdrawal Rates to the Fraser River Main Channel between Pattullo Bridge and Tilbury Island.

Company[a]	License No.	Purpose	Maximum Withdrawal
Beedie (Huston Road) Holdings ltd. 3030 Gilmore Diversion Burnaby BC V5G 3B4	C115426	Cooling	4,546.09 m^3/day
Corporation of Delta 4500 Clarence Taylor Cres Delta BC V4K 3E2	C116994	Land Improvement	0 m^3/day total flow (no diversion from the Fraser River)
Corporation of Delta 4500 Clarence Taylor Cres Delta BC V4K 3E2	C116994	Irrigation	29,603,520 m^3/year
Lafarge Canada Inc 7611 No 9 Rd Richmond BC V6W 1H4	C124518	Fire Protection	454.61 m^3/day

Company[a]	License No.	Purpose	Maximum Withdrawal
Lehigh Hanson Materials Limited PO Box 2300 Vancouver BC V6B 3W6	C052514	Fire Protection	9,819.55 m^3/day
Lehigh Hanson Materials Limited PO Box 2300 Vancouver BC V6B 3W6	C052514	Cooling	19,639.11 m^3/day
Maybog Farms Ltd c/o John Ronald May 15411 Cambie Road V6V 1T3	C127913	Frost Protection	236,828 m^3/year
Maybog Farms Ltd c/o John Ronald May 15411 Cambie Road V6V 1T3	C126396	Flood Harvesting	177,621 m^3/year
Maybog Farms Ltd c/o John Ronald May 15411 Cambie Road V6V 1T3	C126396	Irrigation	118,414 m^3/year
Maybog Farms Ltd c/o John Ronald May 15411 Cambie Road V6V 1T3	C126396	Storage-Non Power	24,670 m^3/year

a – Government of British Columbia Water Lot Lease Query, Accessed April 4, 2016 at http://www.env.gov.bc.ca/wsd/wrs/query/licences/

Discharges

A summary of permitted discharges to the Fraser River located within the Study Area is provided in Table 2-8. These discharges are located downstream of the proposed outfall location. There are no discharges within the Study Area located upstream of the proposed outfall location with the exception of the current Annacis outfall (maximum 1,050,000 m^3/day) and two very low volume discharges from Westminster Marine Services Ltd. and Cipa Lumber Co. Ltd. (<30 m^3/day).

Table 2-8: Discharge Rates to the Fraser River Main Channel between Pattullo Bridge and Tilbury Island

Company Name[a]	Permit Number	Authorization Type	Volume of Discharge m^3/day (max)	Average Discharge (m^3/day)	Monitoring Requirements		
					5-day BOD (mg/L)	TSS (mg/L)	Grease and mineral oil (mg/L)
Westminster Marine Services Ltd.	PE-3154	Permit	-	1.14	45	60	-
Cipa Lumber Co. Ltd.	PE-00182	Permit	28	0.8	-	-	-
Greater Vancouver Sewerage and Drainage District	ME-00387	Operational Certificate	1,050,000	-	45	45	-
RMC Ready-mix Ltd.	PE-11217	Permit	15	5	-	-	-
Rempel Bros. Concrete Ltd.	PE-12181	Permit	35	-	-	-	-
Lafarge Canada Inc.	PE-00042	Permit	6,050	1,500	-	75	10
Lafarge Concrete a Division of Lafarge Canada Inc.	PE-2439	Permit	-	1.37	-	75	-
Armtec holdings limited	PE-02976	Permit	120	-	45	60	-
Lehigh northwest cement limited	PE-04513	Permit	18,200	-	-	-	-

a – BC MoE Permit Search, Accessed April 4, 2016 at https://j200.gov.bc.ca/pub/ams/Default.aspx?PossePresentation=DocumentSearch
"-" not applicable

2.3.6 Current and Future Development

A summary of current and reasonably foreseeable projects or activities located on or near the lower Fraser River within 17 km of the proposed AIWWTP new outfall is provided in Appendix E.

2.3.7 Relevant Water Quality Objectives and Guidelines

Water quality guidelines have been developed by BC MoE to be protective of different water uses in both freshwater and marine/estuarine environments, including aquatic life, wildlife, drinking water sources, recreational contact, and agriculture (livestock and irrigation) (BC MoE 2016). These guidelines are applicable across the province and are not site-specific. Two types of guidelines approved by BC MoE are documented in BC MoE (2016).

- Short-term maximum guidelines are intended to protect against severe effects such as lethality to the most sensitive species over a defined short-term exposure period in the receiving environment, such as 96 hours.
- Long-term average guidelines reflective of a 30-day exposure are intended to be protective against sub-lethal and lethal effects on the most sensitive species and life stage indefinitely (Meays 2012, BC MoE 2013a).

Exceeding province-wide guidelines does not imply unacceptable impairment of water uses, but rather that the potential for adverse effects and water use impairment might be increased and should be investigated further. Known receiving environment uses and resources (human and ecological) of the Fraser River within the Study Area have been identified in preceding sections. Given that the lower Fraser River does not represent a drinking water source (Swain et al. 1998), the following environmental uses were identified to determine the most sensitive water use (i.e., the most conservative guideline) for the receiving environment.

- Commercial, recreational, and aboriginal (CRA) fisheries with the exclusion of shellfish harvesting
- Recreational activities such as boating
- Irrigation or livestock watering
- Ecological resources, including fish and other aquatic life and wildlife

For the purpose of the preliminary impact assessment to determine whether the above identified receiving environment uses could be potentially impaired as a result of the proposed effluent discharge, predicted concentrations at the edge of the initial dilution zone were compared to the following objectives and guidelines:

- FRWQOs applicable to the lower Fraser River from the New Westminster Trifurcation to the Banks (Swain et al. 1998)
- Approved BC WQGs for the most sensitive water use; working BC WQGs were used for constituents without approved WQGs (BC MoE 2016)
- CCME WQGs for the most sensitive water use (CCME 2016)
- Environment Canada Environmental Quality Guidelines for PBDEs (Environment Canada 2013)
- Health Canada Guidelines (Health Canada 2014)

For the assessment of recreational water use, relevant guidelines from other jurisdictions such as the US Environmental Protection Agency (US EPA) were used as appropriate where no provincial or federal guidelines were available. More detail on the selected screening guidelines and assessment approach is provided in Section 6.1.

2.3.8 Potential Areas of Concern

Guidance provided by BC MoE for a municipal effluent discharge EIS (BC MELP 2000) recommends that areas of concern be identified in the Stage 1 assessment for consideration with respect to locations where water quality predictions might be made in the Stage 2 EIS. As discussed in preceding sections here is no fish spawning habitat or shellfish harvesting area within the Study Area. The Study Area is primarily located in an industrial area with no recreational beaches or drinking water intakes. Recreational areas are located further downstream and the Fraser River is not a drinking water source. Potential areas of concern identified within the Study Area therefore relate to sturgeon and salmonid rearing habitat located throughout the Study Area (and the Main Arm).

3.0 REGULATORY SETTING

For effluent discharges to aquatic receiving environments in BC, applicable legislation includes the federal *Fisheries Act* that contains a general prohibition against the deposit of a deleterious substance into waters frequented by fish (Section 36), and the provincial EMA that contains a general prohibition against causing pollution. Under the general provisions of the *Fisheries Act*, what constitutes a deleterious substance is a matter of expert opinion; however, for municipal discharges, what constitutes a deleterious substance and when it can be discharged is specifically defined in the Federal Wastewater Systems Effluent Regulation (WSER). The definition of pollution under EMA is discussed below in Section 3.1.2.

To discharge effluent from the new outfall diffuser, MV requires an amendment of Operational Certificate ME-00387 that authorizes MV to discharge effluent from the AIWWTP under the ILWRMP pursuant to EMA. As per the MWR (also pursuant to EMA), an EIS of the effluent discharge is required to identify whether or not receiving water uses could be impaired by the hydraulic upgrade. The EIS is used by the BC MoE in their permitting decisions and is used by the discharger, in this case MV, as part of their due diligence to verify that they meet the requirements of EMA and the ILWRMP.

3.1.1 Integrated Liquid Waste and Resource Management Plan

Within BC, ILWRMPs developed by local governments are authorization mechanisms under EMA. In the absence of an ILWRMP approved by the BC MoE, discharges to the environment within the local jurisdiction may be authorized through other mechanisms that include MWR (Metro Vancouver 2010).

The ILWRMP for the GVS&DD authorizes water, air, and land discharges associated with the management of liquid waste in Metro Vancouver to the environment. Discharges are authorized according to discharge criteria specified in the site specific Operational Certificates for each facility, including the AIWWTP (Metro Vancouver 2010). In May 2011, the integrated plan was approved by the Minister of Environment subject to conditions under the provisions of EMA and has since guided liquid waste management decisions at the AIWWTP.

MV has committed to meeting requirements of the Canada-wide Strategy for the Management of Municipal Wastewater Effluent (CCME Strategy) in its ILWRMP. The CCME Strategy requires that treated municipal effluent discharged into the environment meets the National Performance Standards for wastewater effluent (carbonaceous biochemical oxygen demand [CBOD] and TSS). Based on the CCME Strategy, MV has developed Effluent Discharge Objectives for the AIWWTP with BC MoE (Tri-Star 2015). With respect to the receiving environment, the ILWRMP includes a commitment to meet applicable WQGs or objectives at the edge of the IDZ for the AIWWTP.

3.1.2 Environmental Management Act and the Municipal Wastewater Regulation

EMA is BC’s principal pollution control statute with regulations made pursuant to that Act for more specific regulatory purposes such as the discharge of municipal effluent. EMA prohibits causing pollution, and provides for authorization mechanisms for discharge of waste into the environment. One of such authorization mechanism for municipal facilities that discharge treated effluent is an operational certificate. Other authorization mechanisms under EMA may include regulations. The relevant subordinate regulation for the Project is the MWR that specifies requirements for the discharge of municipal wastewater, including reclaimed water, to receiving environments within BC. The MWR superseded the Municipal Sewage Regulation in 2012 (BC Reg 129/99; OC 507/99).

Under EMA, pollution is defined as "the presence in the environment of substances or contaminants that substantially alter or impair the usefulness of the environment". Common expectations under EMA are two-fold:

- Acutely lethal conditions should not exist within the IDZ or the effluent.
- Chronic sublethal effects should not occur outside of the IDZ. A lack of chronic sublethal effects is (conservatively) predicted when the parameter of concern has a concentration lower than ambient WQGs for BC (BC MoE 2016).

Consistent with the definition provided in the MWR, the IDZ is the three-dimensional zone around the point of discharge where mixing of the effluent and the receiving water occurs. For a large water body, the IDZ is commonly defined as a cylindrical body of water around the outfall, with a lateral radius the lesser of 100 m from the outfall or 25% the width of the body of water and extending upwards to the surface of the water column. The MWR specifies that the discharger must not discharge municipal effluent unless at the edge of the IDZ all WQGs are met. The regulation defines a WQG as: a guideline approved by the minister that applies to BC waters, a water quality objective (WQO) established for a particular body of water, or any other acceptable standard.

As described in Section 3.1.1, BC MoE allows local governments to develop ILWRMPs as part of local liquid waste discharge authorization through EMA. As such, discharges within local jurisdictions are regulated though ILWRMPs and Operational Certificates for each facility, not the province-wide MWR. In the case of the AIWWTP an approved ILWRMP has been in place since May 2011 and so the effluent limits specified in the MWR do not apply to this discharge.

3.1.3 Fisheries Act and the Federal Wastewater Systems Effluent Regulation

With respect to the *Fisheries Act*, a deleterious substance is a substance that, if added to water, would degrade or alter or form part of a process of degradation and would likely be rendered deleterious to fish or fish habitat, or the use by man of fish that frequent that water. The specific properties defining a substance as being deleterious under the parent act are left to interpretation by experts, except where sector-specific regulations have been developed, such as the federal Wastewater Systems Effluent Regulation (WSER SOR/2012-139) that came into effect July 2012. This works-specific regulation was written under the authority of subsection 36(5) and paragraphs 43(g.1), (g,2), and (h) of the *Fisheries Act*. Under the WSER the following classes of substances are prescribed as deleterious substances and their discharge into the environment is authorized in concentrations below the specified limits: CBOD, TSS, TRC, and un-ionized ammonia.

The WSER stipulates maximum effluent concentrations for deleterious substances in the municipal effluent that can be achieved through secondary wastewater treatment and monitoring requirements. Discharge is only permitted if the effluent meets National Performance Standards specified for CBOD, TSS, TRC, and un-ionized ammonia. Discharge can also only occur if the effluent is shown not to be acutely lethal to rainbow trout in accordance with specified standard test methods specified in the regulation.

3.1.4 Port of Vancouver Project Review Process

Under the *Canada Marine Act*, the Port of Vancouver (the Port) is responsible for the administration, management and control of land and water within its jurisdiction. The Port requires that developments meet applicable standards and minimize environmental and community impacts. New developments are also expected to support the Port's land use objectives as described in the Port's land use plan.

The Port is a federal agency that is subject to Section 67 of the *Canadian Environmental Assessment Act* (CEAA) with respect to projects on lands under their administration. The Port has established a review process to address potential effects to environmental and Aboriginal resources as described in the CEAA.

The review process is based on a system of four project categories. In this system, Category A projects are simple, minor works that do not require review by the Port and Category D projects are large complex undertakings that may require extensive review and stakeholder consultation.

4.0 EFFLUENT QUALITY ASSESSMENT

Under the federal Canada-wide Strategy for the Management of Municipal Wastewater Effluent (CCME 2009) and the WSER, the following National Performance Standards exist as minimum performance requirements for effluent quality:

- average concentration of $CBOD_5$ does not exceed 25 mg/L
- average concentration of TSS does not exceed 25 mg/L
- average concentration of TRC does not exceed 0.02 mg/L if chlorine or one of its compounds is used in the treatment process
- maximum concentration of un-ionized ammonia is less than 1.25 mg/L as NH_3-N at 15 ± 1°C

Compliance limits specified in the Operational Certificate - ME00387 (23 April 2004) for the AIWWTP effluent are:

- maximum concentration of $CBOD_5$ does not exceed 45 mg/L
- maximum concentration of TSS does not exceed 45 mg/L
- concentration of TRC to remain below 0.1 mg/L (the required minimum detection limit)

There is also a requirement under the WSER that effluent is not acutely lethal to rainbow trout (median lethal concentration causing mortality in 50% of test organism, LC50 ≥100% v/v), determined on a monthly basis in accordance with Reference Method EPS 1/RM/13 or EPS 1/RM/50 (Environment Canada 2007a, 2008a).

The federal and provincial limits discussed above are minimal compliance requirements, and the assessment of potential impacts carried out herein has been broader, as necessitated by the general provisions of provincial legislation.

4.1 Effluent Discharge Constituents and Potential Effects

This section provides a general overview of the main constituents that are regulated or of interest in municipal wastewater effluent discharges and their potential environmental effects on organisms in the aquatic receiving environment. Whether or not these potential impacts occur will depend on the specific characteristics of the effluent discharge and the receiving environment, in addition to exposure conditions encountered by aquatic organisms in the receiving environment. An evaluation of potential environmental impacts on aquatic organisms in the Fraser River receiving environment is presented in Section 6.0 of this report.

In Metro Vancouver, municipal wastewater is primarily comprised of domestic wastes but also includes minor industrial and commercial inputs. With respect to environmental significance, municipal effluent may contain oxygen-depleting substances, ammonia and other nutrients, pathogenic microorganisms, and surfactants. Although municipal effluent is a complex mixture, there are certain substances and properties that have been associated with known adverse effects or conditions in aquatic environments, particularly when there is limited dilution of the discharge. Some of the key substances and conditions found in municipal effluent are discussed in more detail below.

4.1.1 pH

pH is an environmental factor that affects physiological processes like enzyme activity, ionic regulation, and the chemical speciation of substances present in water. pH is an important exposure and toxicity modifying factor affecting the bioavailability and toxicity of metals and nutrients. In freshwater systems, pH is typically in the range of 6.5 to 9, and values outside this range can disrupt the processes of waste excretion and oxygen uptake across fish gills (McKean and Nagpal 1991). Metals are typically more bioavailable to aquatic organisms under low pH (acidic) conditions and less bioavailable under higher pH (alkaline) conditions.

4.1.2 Total Suspended Solids

There are several reviews on the effects of suspended sediments in freshwater ecosystems (Birtwell 1999; Caux et al. 1997; EIFAC 1964; Newcombe and Jensen 1996; Newcombe and MacDonald 1991). Suspended solids are not usually associated with lethal effects on fish except when the TSS concentration is very high. In studies on the acutely lethal concentrations of TSS on juvenile salmon, it was found that 31,000 mg/L and 17,600 mg/L caused mortality to 50% of juvenile chinook and sockeye salmon respectively over a 96-h test period (Servizi and Gordon 1990; Servizi and Martens 1987). These concentrations are not commonly encountered in waterbodies except under rare circumstances. Suspended sediment also can cause changes in behaviour such as avoidance (Bisson and Bilby 1982; Robertson et al. 2006) and physiological trauma such as gill damage, which has been observed at TSS concentrations on the order of hundreds to thousands of mg/L (Birtwell 1999, Muck 2010, Servizi and Martens 1987).

4.1.3 Carbonaceous Biochemical Oxygen Demand (CBOD)

Municipal effluent contains many substances that can cause depletion of oxygen from surrounding water. Various types of microorganisms that utilize organic wastes as a food material degrade the constituents of the effluent, converting them into energy. This process requires oxygen (O_2) from the surrounding environment, thereby leading to reductions in oxygen available for aquatic organisms. Oxygen can also be removed from the surrounding environment by direct chemical reaction with substances in the waste via a process known as oxidation.

The oxygen-depleting potency of a municipal effluent is measured as CBOD over a 5-day period in a laboratory in which the contribution from nitrogenous bacteria has been suppressed. The extent to which oxygen is removed from receiving waters depends on the dynamics of this process in relation to dispersion and oxygenation of the receiving waters. Waters that are confined and stagnant are more prone to oxygen depletion than waters that are unconfined and well flushed.

4.1.4 Ammonia

Ammonia is a naturally occurring substance, but its concentration in unpolluted waters is typically low and not of toxicological concern. Ammonia is a waste product that is produced by fish and other aquatic organisms to dispose of nitrogenous wastes. Nitrogenous wastes produced by humans and other mammals are excreted in the form of urea. Ammonia can result from the breakdown of urea or the amine portion of amino acids, which make up proteins. While ammonia is a natural substance, it can be introduced into the environment in concentrated amounts from a variety of sources and cause toxic or other effects. The specific characteristics of the effluent and the receiving environment will influence the extent of potential toxic effects.

Ammonia in water exists as two distinct chemical species, un-ionized ammonia (NH_3) and ionized ammonia (NH_4^+, also known as the ammonium ion), in an equilibrium that is influenced by pH, temperature, and in marine waters, salinity (Trussell 1972; Bower and Bidwell 1978). As pH increases (becomes more alkaline), the amount of the more toxic un-ionized form increases. Increased water temperature and decreased salinity also favour increases of the un-ionized form. Water quality guidelines are set on the basis of pH, temperature, and (for marine WQGs) salinity because of the influence of these environmental factors on the toxicity of ammonia.

4.1.5 Nutrient Enrichment

Nitrogen in the form of nitrate (NO_3^-) and phosphorus have relatively low toxicity to aquatic organisms and the effects of these nutrients are usually indirect (Nordin and Pommen 1986). Some nutrient enrichment can improve the productivity of a waterbody by increasing the availability of food; however, beyond a certain point excess nutrient input can lead to a process called eutrophication (Nordin 1985). Excessive nutrient enrichment can cause increased phytoplankton production and result in a phenomenon known as an “algal bloom”. Algal blooms can influence water quality and cause negative impacts to other aquatic organisms via production of toxins (i.e., from cyanobacteria) or from depletion of dissolved oxygen following death and decomposition of algal cells, as well as during diurnal respiration.

4.1.6 Pathogens

Contact with domestic waste has long been recognized as a potential source of infectious disease-causing organisms such as bacteria, viruses, and protozoans (Dadswell 1990). A group of bacteria known as fecal coliforms are present in municipal effluent and are commonly used as an indicator of the presence of effluent and the associated risk of pathogens. *Enterococci* bacteria are also used as an indicator of municipal effluent because they survive longer in the environment than fecal coliforms.

Human health risk from pathogens requires that there be contact with the source of pathogens and humans or harvestable shellfish resources. As noted in Section 2.3, existing and proposed outfall areas are not located adjacent to harvestable shellfish resources, and due to plume trapping the likelihood for significant contact between the plume and human users is low.

4.1.7 Metals

Metals occur naturally in the environment and may enter the aquatic environment from natural weathering processes and anthropogenic sources such as those related to fossil fuel combustion, industrial emissions, discharge of municipal wastewaters, and stormwater runoff from paved surfaces. Certain metals are essential for maintaining good health because of their importance as components of enzymes or proteins, and a shortage of those metals can result in adverse effects. Excess concentrations of essential or non-essential metals can result in toxicity (Chapman and Wang 2000, Campbell et al. 2006). The toxicity of metals to aquatic organisms ranges widely from slight reductions in growth rates to mortality, and may be acute (after a short-term exposure) or chronic (over a longer term). Metal accumulation and toxicity is dependent on metal bioavailability, which is influenced by exposure conditions and toxicity modifying factors such as pH, water hardness, and dissolved organic carbon (DOC), as well as physiological and biological characteristics of aquatic organisms.

4.1.8 Organics

Organic compounds range from the simple molecules to long-chained, multi-ringed, halogenated structures that vary in persistence in the environment and effects on aquatic organisms. The fate and transport of organic compounds in environmental systems is controlled by partitioning between surface water, suspended particulates and sediment, associated organic matter, and biota. The extent to which organic compounds are associated with organic matter is related to a number of factors including molecular weight and the number and position of chlorine atoms in the case of chlorinated compounds.

Organic compounds can have a wide range of effects on aquatic organisms, from reproductive impairment such as reduced fecundity and viability of offspring, developmental impairment such as brain and skeletal deformations and reduced growth, to acute mortality of both adults and juveniles. Of particular concern are persistent, bioaccumulative, and toxic compounds that are hydrophobic and can accumulate in fatty tissues unless the organism has a mechanism for metabolizing and excreting the compound. Organic compounds may be biomagnified up the food chain, resulting in higher concentrations in higher trophic level organisms such as carnivorous marine mammals. Examples of persistent organic compounds present in municipal effluents include PAHs, PCBs, and PBDEs.

4.1.9 Endocrine Disrupting Compounds

Municipal wastewater also contains substances known or suspected to be endocrine disrupting compounds (EDCs), which include some metals (*e.g.,* cadmium), surfactants, plasticizers, and pharmaceutical and personal care products (PPCP) (Anderson 2005; Environment Canada 2007b). EDCs interfere with the endocrine (hormonal) system of animals and may cause reproductive abnormalities.

The presence and ecological significance of EDCs is an area of emerging international science with research being conducted on the fate and behaviour of EDCs in the environment as well as the effectiveness of various wastewater treatment methods (Anderson 2005). In Canada, the need for research and policy directions regarding EDCs such as PPCPs has been recognized and priorities in the areas of effects research and risk management for PPCPs have been identified (Environment Canada 2007b). Research includes the development of analytical methods, as well assessment of the efficiency of treatment of various EDCs, and the presence and effects of EDCs in the aquatic environment (Environment Canada 2008b). One of the compounds that has received attention is EE2, the synthetic hormone in the birth-control pill, and it is the only PPCP for which there is a BC WQG.

4.2 Existing Effluent Chemistry and Toxicity Testing

AIWWTP effluent has been analyzed for wide range of parameters that include the constituents described in Sections 4.1.1 to 4.1.9 (CDM Smith 2016) (Appendix A). Routinely monitored constituents are physical parameters, major ions, nutrients, metals, and bacteriological constituents. Organics, pesticides, and PPCPs have been monitored less frequently. To support the future derivation of Effluent Discharge Objectives as committed to by the ILWRMP, the measurement of organic constituents in effluent discharged by the AIWWTP has been expanded in recent years.

For the purposes of this EIS, AIWWTP effluent quality was characterized based on the following sources: operational plant data, monthly comprehensive monitoring, data reported from the 2011-2014 AIWWTP IDZ boundary monitoring programs (ENKON 2013a,b; 2015b; and unpublished MV data), and Tri-Star (2015). Summary statistics of effluent constituent concentrations were calculated and reported by CDM Smith (2016) in Appendix A for parameters that included those for which there are National Performance Standards, municipal regulations, and receiving environment WQGs.

Based on the effluent characterization by CDM Smith (2016) in Appendix A for the period 2011 to 2014, federal effluent limits were met for CBOD, TSS, and un-ionized ammonia (Table 4-1). TRC was reported below detection limits that exceeded the federal effluent limit, but met the Operational Certificate ME00387 limit equal to a minimum detection limit of 0.1 mg/L. The detection limit for TRC was subsequently improved to <0.02 mg/L in 2014 with a change to the analytical instrument.

Table 4-1: Annacis Island WWTP Effluent Quality Compared to National, Provincial, and Operational Certificate Effluent Limits

Parameter[a]	Units	National Performance Standards	Operational Certificate Limits	Mean Effluent Concentration (2011-2014)[b]	2014 Max Concentration Reported in GVS&DD (2015)
$CBOD_5$	mg/L	≤25 (average)	45 (max)	6.9 (max 28)	20 (Table 3.1 of GVS&DD)
TSS	mg/L	≤25 (average)	45 (max)	8.6 (max 24)	36 (Table 3.1 of GVS&DD)
TRC	mg/L	≤0.02 (average)	0.1	**<0.06 (max 0.1)**	<0.02 (Table 3.1 of GVS&DD)
Un-ionized ammonia	mg/L – as N	1.25 (max) at 15°C	-	max 0.93	0.92 (Table 3.7 of GVS&DD)

nm – not measured
a – $CBOD_5$ – 5-day carbonaceous biochemical oxygen demand; TSS – total suspended solids; TRC – total residual chlorine;- not applicable
b – mean concentration unless specified otherwise, summary statistics reported by CDM Smith (2016) in Appendix A
Bold values exceed federal or operational certificate effluent limits

Effluent quality from the AIWWTP and compliance parameters were summarized in 2011 to 2014 annual wastewater reports (GVS&DD 2012-2015). During this period, effluent quality of compliance parameters was characterized as follows:

- Operational Certificate ME00387 limits for CBOD, TSS, and TRC were met each year.
- Monthly average concentrations of CBOD and TSS met WSER limits each year.
- Monthly maximum concentrations of un-ionized ammonia met the WSER limit in 2013 and 2014; data were not reported for 2011 and 2012.
- Annual maximum concentrations of TRC in 2011 to 2013 were reported as <0.1 mg/L (the minimum method detection limit of the operational certificate), which is above the WSER limit. As a result of a change to the analytical instrument in 2014 with a lower detection limit, the annual maximum concentration of TRC met the federal limit in 2014.
- All reported monthly acute toxicity tests passed (96-h LC50 >100% v/v) each year.
- The estimated concentration[3] of fecal coliforms at the edge of the IDZ met the FRWQO, for each reported month (May through October) of each year.

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[3] Maximum 30-day geometric mean value multiplied by a minimum dilution factor of 40:1 for the IDZ

Based on the most recent characterization of effluent presented in the Stage 1 EIS (i.e., 2014, GVS&DD 2015), the AIWWTP effluent meets WSER limits and is not acutely toxic; therefore, the effluent is not considered a deleterious substance under the federal *Fisheries Act*.

4.2.1 Selection of Organic Compounds

To focus the evaluation of organic compounds reported by MV for the AIWWTP effluent between 2011 and 2014, priority was given to the following criteria:

- Substances for which effluent data were available;
- Substances where environmental water quality criteria were available; and
- Substances that may be exhibiting increasing trends in concentrations in the river within the Study Area between 2011 and 2014, based on ambient water quality data reported by the Annacis REM or the Fraser River Monitoring Programs.

Organic compounds for which preliminary predictions were made are listed in Section 6.0 and include select pesticides (herbicides, insecticides, and fungicides), alkylphenols, PCBs, PBDEs, sterols and hormones, and most PAHs.

4.3 Nutrient Loading

Existing effluent quality data were used to provide preliminary estimates of loading of total nitrogen, total phosphorus and their species of interest to the Fraser River. For Stage 1, mean effluent mass flux and the standard deviation of the effluent mass flux were calculated by CDM Smith (2016) (Appendix A).

An assessment of potential effects on the assimilative capacity of the Fraser River with respect to nutrient loadings, including the cumulative impact of other nearby discharges, will be considered in the Stage 2 EIS.

5.0 RECEIVING WATER QUALITY PREDICTIONS

This section describes the selected preliminary diffuser design and the methodology and results of predicted concentrations at the edge of IDZ to support receiving water quality assessments for the Stage 1 EIS. Details of this design work are provided by CDM Smith (2016) in Appendix A and summarized below.

5.1 Preliminary Diffuser Design

The preliminary diffuser design has the following features:

- The ability to discharge Stage V flows (18.9 m^3/s) at a river level of 103.18 m geodetic datum—the conditions for which this EIS is being evaluated—by gravity without impacting the hydraulic gradeline of the treatment plant. For flows above Stage V, an effluent pump station will be needed to discharge to the Stage VIII (25.3 m^3/s) peak wet weather flow.
- A 240-m long diffuser manifold located just outside the edge of the navigation channel just downstream of the existing outfall (Figure 5-1). The manifold would connect to the main vertical riser from the outfall tunnel at its center.
- The manifold would have 48, 600-mm diameter risers leading to 360-mm diameter ports discharging horizontally toward the center of the river. For Stage V flows, 12 of the ports would be blocked off to aid in increasing dilution leaving 36 active ports. All 48 ports would be open at Stage VIII when peak wet weather flow is 25.3 m^3/s.
- The ports would be fitted with variable orifices (e.g., Tideflex® diffuser valves) to increase exit velocities at low effluent flows. These valves will also reduce sediment entering the diffuser system.
- The diffuser risers would be covered with a conical sleeve or cap to protect them from anchors, ship strikes, and submerged debris. The sleeve needs to accommodate access to the port terminus to permit maintenance of the variable orifices.
- The ends of the manifold would be fitted with bulkheads to facilitate internal access and/or cleaning.

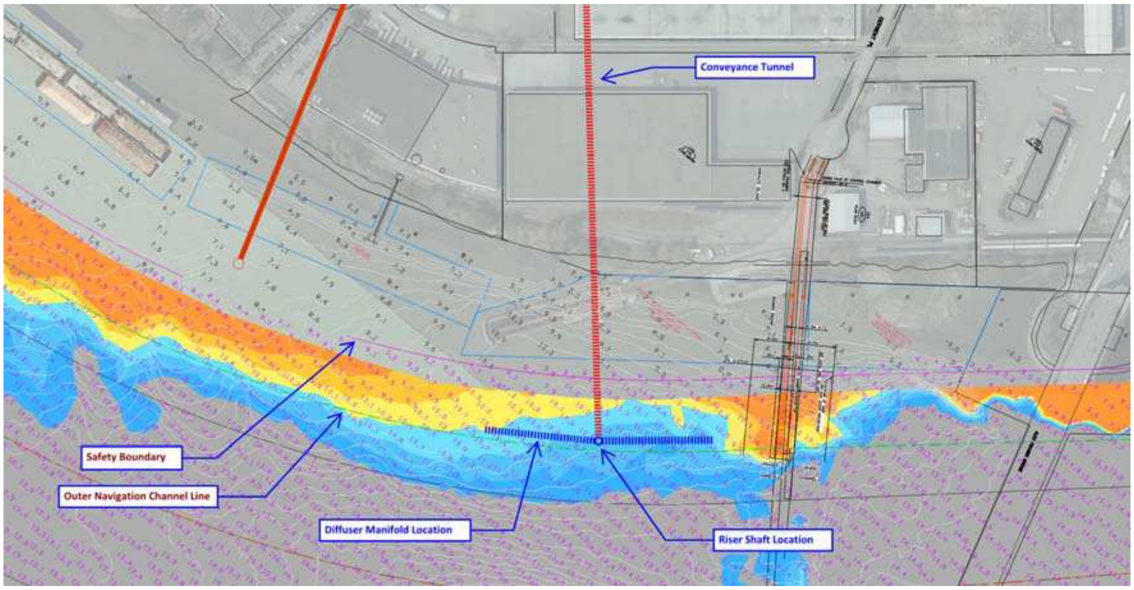

Figure 5-1: Planned Diffuser Location

The proposed location for the diffuser manifold is in the deepest water available in the Study Area, which improves initial dilution. The design of the diffuser in this location results in the top elevation of the diffuser ports at between 9.5 and 9.3 m water depth below Chart Datum. The MWR specifies that the water depth at the shallowest port should be 10 m below Chart Datum. Thus, the proposed diffuser configuration will require a variance of the MWR diffuser depth requirement. The diameter of the ports could be refined in the final design and the actual depth variance required will be determined at that time.

The MWR allows for consideration of mixing with ambient waters in determining compliance with WQGs. The regulations define an IDZ and require that WQGs be met at the edge of the IDZ. The IDZ boundaries for the proposed diffuser for the AIWWTP are shown in Figure 5-2.

5.2 Input Data for the Analysis

The key input data for the prediction of concentrations at the edge of the IDZ are listed below; detailed information is provided in Appendix A.

- Effluent Flow—Daily maximum instantaneous flows from the AIWWTP from 2011-2014 were used as the basis for estimating the future flow distribution; 2011-2014 flows range from 5.5 m^3/s to 12.5 m^3/s. During periods of high flow into the plant, the influent flow is manually throttled and allowed to bypass the plant to prevent the plant from reaching its design capacity of 12.6 m^3/s. The distribution of flows was scaled from present day to Stage V using a future minimum flow of 7.4 m^3/s and a peak flow of 18.9 m^3/s, while maintaining the proportional shape of the distribution.
- Effluent Concentrations—Effluent data were compiled from 2011-2014 records and taken primarily from annual summaries of monthly operating data and effluent samples collected during IDZ monitoring. Selected parameters (un-ionized ammonia, fecal coliform bacteria, TRC, and $CBOD_5$) were taken from daily plant operational records. Statistical summaries of the effluent data are reported in Appendix A; these calculations used the full detection limit when parameters were flagged as either less than a method detection limit or a maximum possible concentration.
- Fraser River Flows—Due to the complexity of the Fraser River estuary, flows measured at the Environment Canada monitoring station at Hope (BC08MF0001) were used to define three river ‘flow classifications’ that describe when the river has uni- or bidirectional currents, is freshwater, or has the possibility of salinity stratification at the Study Area. The three Fraser River flow classifications are $Q > 6{,}000$ m^3/s (high); 6,000 m^3/s > Q >1,000 m^3/s (moderate); and $Q < 1{,}000$ m^3/s (low).
- Fraser River Water Depth—Data from the tide gauge at New Westminster (#7654) were used to define typical low and high water levels at the Study Area.
- Fraser River Current—Current speed is a key input to the initial dilution models; data were taken from the Environment Canada Gravesend Reach buoy (BC08MH0453).
- Fraser River Salinity—River salinity data were taken from a variety of sources and used to define a river flow condition (when $Q < 1{,}000$ m^3/s) when notable salinity stratification is present at the Project Study Area. The shapes of the assumed vertical profile for low and high water levels are shown in Appendix A.
- River-Effluent Seasonal Temperature Differences—Contemporaneous Fraser River temperature data from the Gravesend Reach buoy and effluent temperature were used to define average temperature difference for the three river flow classifications.

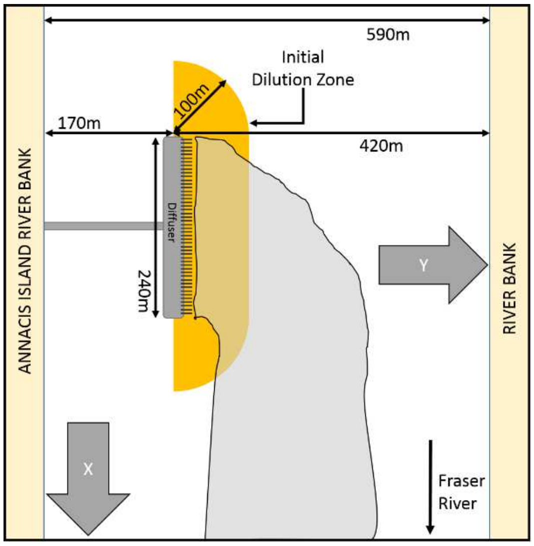

Figure 5-2: Conceptual IDZ

5.3 Predicting Concentrations at the Edge of the IDZ

To determine the extent to which parameters in the treated effluent (C_0) will meet corresponding WQGs requires prediction of the concentration of individual parameters at the edge of the IDZ. The concentration at the edge of the IDZ (C_{IDZ}) is calculated based on the following four components:

- The "instantaneous" contribution from the effluent plume that had just undergone initial dilution (C_N)
- Ambient (background) concentration (C_a)
- Contributions from other significant discharges into the Fraser River that are not adequately captured by the background concentration (C_{other})
- Long-term background buildup of the concentration in the river due to the discharge of the treatment plant itself (C_b)

No significant discharges were noted in the Fraser River between the locations of ambient (background) concentrations, which are the reference station for the REM monitoring program and the Gravesend Reach buoy, so the other sources component (C_{other}) was eliminated (see Section 2.3.5). The remaining three components were combined to predict the concentration at the edge of the IDZ using the following equation:

$$C_{IDZ} = C_a + (C_o - C_a)/S_f + (C_o - C_b)/S_n$$

where: S_f – far-field dilution = $(C_0-C_a)/(C_b-C_a)$

S_n – near-field dilution = $(C_0-C_b)/(C_N-C_b)$

The ambient background water quality data used in the analysis are described in Section 2.1.2.

5.3.1 Far-field Dilution

The presence of background buildup in the Fraser River will reduce the available potential dilution at the edge of the IDZ. For the Stage 1 EIS, a background buildup concentration was calculated as the potential background buildup dilution (S_{BB}) multiplied by the mean effluent concentration. S_{BB} is the ambient flow divided by the projected future effluent flow:

$$S_{BB} = \frac{u_a HW}{Q_{eff}}$$

where the ambient flow can be represented by the product of the ambient velocity as measured at the Gravesend Reach buoy (u_a); the water depth as determined to be the distance between a depth at discharge of 88.4 m (GD+100) and the water surface elevation measured at New Westminster (H); and the river width (W); and the effluent flow (Q_{eff}).

Two estimates of background buildup were derived representing different time-scale processes in the river. A more conservative estimate looked for a critical 12-hour period (a tidal cycle) representing a period of low residual current (when Q <1,000 m^3/s) testing the ability of the river to flush over the course of a tidal cycle. A cumulative frequency distribution of the 12-hour averages was developed and the 5% exceedance value of 250:1 was selected to represent the risk of background buildup for instantaneous predictions. Background buildup concentrations were only considered in the edge of IDZ calculations when bidirectional flow in the Fraser River flow exists (when Q <6,000 m^3/s).

For parameters with long-term average (30-d) WQGs, a cumulative frequency distribution was developed for each of the monthly instantaneous background buildup dilutions and the 50% exceedance value was used to develop estimates of background buildup.

5.3.2 Near-field Dilution

Near-field dilution was determined using either the Shrivastava-Adams equation (unpublished manuscript) when river conditions were unstratified or the UM3 module from the Visual Plumes program (Frick et al. 2003) for stratified conditions.

For parameters with short-term maximum WQGs, near-field dilution was determined for 128 individual model runs representing variation in ambient river conditions and effluent flow rates as shown in Table 5-1.

Table 5-1: Number of Monthly Effluent and Ambient Model Input Parameters

Fraser River Flow Classification	Water Depths	Effluent Flows	Current Speed	Temperature Difference	Density Profile
High flow: Current unidirectional $Q_a \geq 6{,}000\ m^3/s$	2	4	4	1	1
Moderate flow: Current bidirectional $6{,}000\ m^3/s > Q_a \geq 1{,}000\ m^3/s$	2	4	4	1	1
Low flow: Current bidirectional; salinity possible $Q_a < 1{,}000\ m^3/s$	2	4	4	1	2

Representative values for each parameter in Table 5-1 were selected and the percent of time the value occurs was assigned (details of these values and percentages are described in Appendix A). The joint probability of the predicted dilution was calculated from the probabilities of each parameter in Table 5-1. The minimum predicted dilution for each of the three Fraser River flow classifications was applied to the maximum effluent concentration to determine the near-field component of the concentration at the edge of the IDZ.

For parameters with long-term average WQGs, the available data were used to develop monthly average values for each model input parameter to permit calculation of dilution on a monthly basis. For months when salinity can be present, two simulations (stratified and unstratified) were performed and then combined based on the probability of salinity being present. The monthly predicted dilution was then applied to the average effluent concentration to determine the near-field component of the concentration at the edge of the IDZ.

5.3.3 Comparison of the Effect of Effluent Temperature on Ambient Water Temperature

A separate analysis was conducted to assess the BC WQG for temperature protective of aquatic life that limits the temperature change to a +/- 1°C temperature variation at any time, location, or depth in marine and estuarine waters. A conservative analysis was undertaken to evaluate this guideline using the minimum dilutions associated with each Fraser River flow classification using contemporaneous 2011-2014 data on effluent temperature and ambient river temperature measured at the Gravesend Reach buoy. The simplification was justified if the guideline was met in all circumstances, otherwise an assessment of predicted daily dilution would be used.

The differences between effluent and ambient temperature ranged between 0.03°C to 14.3°C. The maximum difference occurred during the winter months when flow was less than 1,000 m^3/s. Based on the minimum predicted dilution for the less than 1,000 m^3/s flow classification, the predicted impact in temperature was 0.8°C and was less than the allowable change in the interim guideline.

5.4 Results of Predicted Concentrations at the Edge of the IDZ

Appendix A provides the results of the predicted concentration at the edge of the IDZ applying the methodology described above. These concentrations were carried forward into the preliminary impact assessment in Section 6.0.

6.0 PRELIMINARY IMPACT ASSESSMENT

The proposed upgrade to the AIWWTP is hydraulic, and so the impact assessment considers water quality predictions made in Section 5.0 that are based on scaling up the existing effluent mass load by the planned flow increase. As appropriate for a preliminary assessment at the Stage 1 level, conservative assumptions were made in the modeling (Section 5) and assessment approaches (Section 6.1). The term “conservative” is used to describe assumptions, conditions, etc. that would result in an assessment that is more likely to over-predict adverse effects than to under-predict them.

The assessment evaluated potential impacts on water uses associated with predicted changes in water quality at the edge of the IDZ. Predicted water quality was compared to FRWQOs and relevant freshwater and marine/estuarine BC and CCME WQGs for the most sensitive water use (between aquatic life, wildlife, and agriculture water uses). A public health evaluation involved comparison to BC WQGs for recreational use or a substituted guideline where a BC WQG was not available (see Section 2.3.7 for more detail).

The preliminary impact assessment followed the approach outlined below.

6.1 Assessment Approach

Predicted constituent concentrations at the edge of the IDZ for the mixed effluent plume were calculated based on expected dilution ratios according to methodology described in Section 5.0. A short list of organic substances of potential concern including select pesticides (herbicides, insecticides, and fungicides), alkylphenols, PCBs, PBDEs, sterols and hormones, and most PAHs, were evaluated in addition to conventional parameters, nutrients, bacteriological constituents and metals.

Predicted concentrations of constituents were screened against WQGs protective of the applicable water uses in the Study Area to identify COPCs. Constituents retained as COPCs were then evaluated in more detail to assess the potential for adverse effects (Section 6.2). The screening methodology is described below for aquatic life, wildlife, and agriculture water uses (Section 6.1.1) and for recreational use (Section 6.1.2).

6.1.1 Aquatic Life, Wildlife, and Agriculture Water Uses

To determine whether aquatic life, wildlife, and agriculture water uses identified within the Study Area in Section 2.3, could be potentially impaired as a result of the proposed effluent discharge, predicted concentrations at the edge of the IDZ were compared to the following objectives and guidelines:

- FRWQOs applicable to the lower Fraser River from the New Westminster Trifurcation to the Banks (Swain et al. 1998)
- Approved BC WQGs for the most sensitive water use; working BC WQGs were used for constituents without approved WQGs (BC MoE 2016)
- CCME WQGs for the most sensitive water use (CCME 2016)
- Environment Canada Environmental Quality Guidelines for PBDEs (Environment Canada 2013)

Aquatic life WQGs were typically the most sensitive guidelines. These guidelines are conservative environmental quality benchmarks with built-in safety factors that represent concentrations that will not result in adverse effects on aquatic resources. Both freshwater and marine/estuarine aquatic life guidelines were considered because the Study Area is within the Main Arm Meso-Tidal Channel and both freshwater and estuarine conditions may be present depending on the location of the salt wedge (Appendix A). As such, a conservative approach was taken where predicted concentrations were screened against the lowest of the provincial and federal freshwater and estuarine/marine guidelines for the most sensitive water use as well as the FRWQOs. A constituent was conservatively identified to be of potential concern if predicted instantaneous or monthly average concentrations were above the lowest applicable guideline or objective, and in the case of monthly predictions, were distinguishable from ambient concentrations (i.e., more than 20% higher than the mean or median ambient river concentration for the appropriate season, as defined below).

With respect to constituents without applicable BC WQGs, a constituent was identified as a COPC if predicted mean monthly concentrations were more than 20% higher than the mean or median ambient river concentration for the appropriate season (i.e., either low or high flow seasons provided in Appendix B). A difference of less than or equal to 20% between predicted concentrations and the average ambient river concentration was not considered to be distinguishable from the ambient river condition and therefore not considered to represent a potential effect to water quality in the receiving environment. A predicted difference of less than or equal to 20% is within the limits of precision associated with both water quality modelling and water quality monitoring. This criterion also is consistent with BC MoE (2013b) where a relative percent difference less than 20% between two duplicate water quality values is not considered to indicate a distinguishable difference between the two values.

The potential for adverse effects on aquatic life and the potential for impairment of wildlife water or agriculture receiving environment uses was further evaluated at the Stage 1 level for those constituents identified as COPCs (see Section 6.1.2.1).

6.1.2 Public Health: Recreational Use

Consistent with the identification of water uses identified within the Study Area in Section 2.3, the public health assessment focussed on comparison of instantaneous and monthly average concentrations to WQGs protective of human health for recreational water use.

The approved BC WQGs for recreational use were selected as the primary screening criteria, when available. For some constituents, the recreational guidelines have been categorized as either primary or secondary contact guidelines. Primary contact includes swimming and other high contact activities whereas secondary contact includes fishing and boating activities with a lower potential for direct contact. Secondary contact guidelines were selected preferentially because primary contact activities do not occur in the Study Area.

Recreational guidelines were only available for a small subset of constituents. Therefore, when a recreational guideline was not available a conservative screening value was derived by multiplying the drinking water guideline by a factor of 10 as recommended by the World Health Organization's Guidelines for Recreational Water Environments (WHO 2003). The WHO (2003) adjustment of 10% of potable water intake is based on a swimming scenario, and is therefore conservative for recreational secondary contact where the recreational user would not be fully submerged in water. Drinking water guidelines were obtained from the approved BC WQGs and Health Canada (2014) with preference given to the most conservative health-based value. Drinking water guidelines based on aesthetic (non-health) considerations (e.g., colour, taste, odour) were not selected for screening. When health-based drinking water guidelines were unavailable from these sources, they were obtained from the US EPA (2016) regional screening levels (RSLs). The US EPA tapwater RSLs are risk-based screening criteria that were derived based on an acceptable hazard quotient (HQ) of 1 for non-carcinogens, and an acceptable incremental lifetime cancer risk (ILCR) of 10^{-6} for carcinogens. Health Canada considers an HQ of 0.2 and ILCR of 10^{-5} to be acceptable thresholds for risk. Therefore, the US EPA RSLs were adjusted (i.e., RSL multiplied by 0.2 for non-carcinogens and RSL multiplied by 10 for carcinogens) to reflect the acceptable target risk levels in Canada.

A parameter was retained as a COPC if the maximum predicted concentration exceeded the selected recreational screening criterion.

6.2 Assessment Results

Instantaneous and monthly average concentrations of constituents predicted at the edge of the IDZ in the Main Arm of the Fraser River are provided in Tables 6-1 and 6-2.

Table 6-1: Screening of Predicted Instantaneous Concentrations of Water Quality Constituents at the Edge of the IDZ of the Annacis Island WWTP Proposed Outfall

Parameter	Units	*Fraser River WQO - Short Term*^{1,2}	Notes		BC WQG Short Term Guideline^{3,2}	Notes		CCME Short Term Guideline^{4,2}	Notes		**Selected Recreational Screening Criterion^{5}**	Notes		IDZ Instantaneous Concentrations		
														High Flow ≥ 6,000 m^3/s	Moderate Flow < 6,000 m^3/s and ≥ 1,000 m^3/s	Low Flow < 1000 m^3/s
Conventional Parameters																
Salinity	ppt													0.083	0.11	0.25
Conductivity	µS/cm													-	150	153
Temperature	°C				±1°C change from background (receiving environment temperature) with an hourly rate of change no greater than 0.5						**30**	R	BC	15	14	4.9
Carbonaceous Biochemical Oxygen Demand (CBOD5)	mg/L													1.4	1.7	1.6
Dissolved organic carbon	mg/L													4.8	3.5	3.1
Hardness, as $CaCO_3$	mg/L													47	52	74
Total Residual Chlorine	mg/L				0.04	M/ES					**0.0006**	DW	EPA	**<0.005**	**<0.006**	**<0.006**
Total organic carbon	mg/L													-	3.1	3.5
Total suspended solids	mg/L				+10 mg/L from background or +10% when background is >100 mg/L	LV								113	28	14
Major Ions																
Fluoride	mg/L				1 - 1.2	H, FS	a				**15**	DW	BC, HC	0.045	0.043	0.05
Sulphate	mg/L													6.6	9.9	17
Calcium	mg/L													14	15	17
Magnesium	mg/L													2.9	3.8	8.2
Nutrients																
Ammonia (un-ionized)	mg-N/L													0.048	0.056	0.055
Total ammonia	mg-N/L	*8.02 - 14*	FS, M/ES, T, pH	a	8.02 - 14	FS, T, pH	b							1.9	2.3	2.2
Total phosphorus	mg-P/L													0.40	0.31	0.28
Dissolved phosphorus	mg-P/L													0.21	0.26	0.25
Nitrate	mg-N/L				32.8	FS		124	FS		**100**	DW	BC, HC	0.034	0.087	0.21
Nitrite	mg-N/L	*0.06 - 0.6*	Cl	b	0.06 - 0.6	Cl	c				**1**	R	BC	0.029	0.028	0.026
Total Metals																
Aluminum	µg/L										**40000**	DW	EPA	2471	585	181
Arsenic	µg/L										**100**	DW	HC	1.1	0.65	0.60
Barium	µg/L										**10000**	DW	HC	41	21	17
Boron	µg/L							29000	FS		**50000**	DW	BC, HC	19	30	48
Cadmium	µg/L				0.12	W, M		0.91 - 1.48	H, FS	a	**50**	DW	HC	0.25	0.25	0.23
Chromium	µg/L										**500**	DW	HC	4.6	1.4	0.65
Cobalt	µg/L				110	FS					**12**	DW	EPA	2.2	0.61	0.23
Copper	µg/L	*3.0*	FS, M/ES, H	c	6 - 9	M/ES					**1000**	R	BC	*8.7*	*4.9*	*3.9*
Iron	µg/L				1000	FS					**28000**	DW	EPA	3728	963	393
Lead	µg/L	*28.6 - 40*	FS, H	d	28.6 - 52.7	H, FS	d				**50**	R	BC	1.6	0.54	0.27
Manganese	µg/L	*100*			1023 - 1322	H, FS	e				**860**	DW	EPA	117	39	23
Mercury	µg/L				2	IR					**10**	DW	BC, HC	<0.003	<0.013	<0.013
Molybdenum	µg/L				50	LV, IR, WI					**2500**	DW	BC	1.3	1.6	1.7
Nickel	µg/L										**780**	DW	EPA	8.8	3.8	2.4
Selenium	µg/L										**100**	DW	BC	0.60	0.69	0.73
Silver	µg/L				0.1	H, FS	f				**188**	DW	EPA	0.070	0.067	<0.063
Zinc	µg/L	*30*			33	H, FS	g				**5000**	R	BC	14	7.1	6.1
Dissolved Metals																
Aluminum	µg/L				100	pH, FS	h				**200**	R	BC	140	48	18
Arsenic	µg/L													0.87	0.94	0.97
Barium	µg/L													13	13	14
Boron	µg/L													18	29	49
Cadmium	µg/L				0.25 - 0.41	H, FS	i							0.12	0.13	0.13
Chromium	µg/L													0.45	0.37	0.37
Cobalt	µg/L													0.16	0.11	0.097
Copper	µg/L													2.6	2.6	2.5
Iron	µg/L				350	FS								160	72	59
Lead	µg/L													0.14	0.093	0.078
Manganese	µg/L													13	11	13
Molybdenum	µg/L													1.4	1.5	1.6
Nickel	µg/L													1.9	2.0	1.8
Selenium	µg/L													0.13	0.14	0.18
Silver	µg/L													0.51	0.60	<0.063
Zinc	µg/L													3.0	3.6	3.8

Parameter	Units	*Fraser River WQO - Short Term*[1,2]	Notes	BC WQG Short Term Guideline[3,2]	Notes	CCME Short Term Guideline[4,2]	Notes	**Selected Recreational Screening Criterion**[5]	Notes		IDZ Instantaneous Concentrations		
											High Flow ≥ 6,000 m^3/s	Moderate Flow < 6,000 m^3/s and ≥ 1,000 m^3/s	Low Flow < 1000 m^3/s
Herbicide													
Linuron	ng/L							**66000**	DW	EPA	<0.075	<0.088	<0.086
Metolachlor	ng/L							**500000**	DW	HC	0.027	0.032	0.031
Triallate	ng/L							**240000**	DW	EPA	<0.004	<0.005	<0.005
Trifluralin	ng/L							**450000**	DW	HC	0.0059	0.0070	0.0068
Insecticide													
Aldicarb	ng/L							**40000**	DW	EPA	<0.025	<0.03	<0.029
Carbaryl	ng/L					3300	FS	**900000**	DW	HC	0.20	0.24	0.23
Carbofuran	ng/L							**900000**	DW	HC	<0.025	<0.03	<0.029
Chlorpyrifos	ng/L					20	FS	**900000**	DW	HC	<0.051	<0.061	<0.059
Deltamethrin	ng/L										<0.146	<0.173	<0.168
Diazinon	ng/L							**200000**	DW	HC	0.071	0.084	0.082
Imidacloprid	ng/L										1.3	1.5	1.5
Lindane (hexachlorocyclohexane)	ng/L							**4200**	DW	EPA	<0.042	<0.05	<0.049
Methoprene	ng/L										<3.2	<3.7	<3.6
Permethrin	ng/L							**2000000**	DW	EPA	1.0	1.2	1.2
Fungicide													
Captan	ng/L							**3100000**	DW	EPA	<0.135	<0.159	<0.155
Chlorothalonil	ng/L							**520000**	DW	EPA	0.0052	0.0062	0.006
Polycyclic Aromatic Hydrocarbons													
Acenaphthene	µg/L			6	M/ES			**1060**	DW	EPA	<0.015	<0.016	<0.016
Acenaphthylene	µg/L										<0.011	<0.011	<0.011
Acridine	µg/L										<0.013	<0.013	<0.013
Anthracene	µg/L							**3600**	DW	EPA	<0.011	<0.011	<0.011
Benz(a)anthracene	µg/L							**1.2**	DW	EPA	<0.011	<0.011	<0.011
Benzo(a)pyrene	µg/L			0.01	M/ES			**0.1**	DW	BC, HC	<0.011	<0.011	<0.011
Benzo(b)fluoranthene	µg/L							**3.4**	DW	EPA	<0.015	<0.016	<0.016
Benzo(g,h,i)perylene	µg/L										0.011	0.011	0.011
Benzo(k)fluoranthene	µg/L							**34**	DW	EPA	<0.011	<0.011	<0.011
Chrysene	µg/L			0.1	M/ES			**340**	DW	EPA	<0.011	<0.011	<0.011
Dibenz(a,h)anthracene	µg/L							**0.34**	DW	EPA	<0.011	<0.011	<0.011
Fluoranthene	µg/L							**1600**	DW	EPA	0.012	0.013	0.013
Fluorene	µg/L			12	M/ES			**580**	DW	EPA	<0.015	<0.016	<0.016
Indeno(1,2,3-c,d)pyrene	µg/L							**3.4**	DW	EPA	<0.011	<0.011	<0.011
1-Methylnaphthalene	µg/L			1	M/ES			**110**	DW	EPA	<0.053	<0.053	<0.053
2-Methylnaphthalene	µg/L			1	M/ES			**72**	DW	EPA	<0.053	<0.053	<0.053
Naphthalene	µg/L			1	M/ES			**12.2**	DW	EPA	<0.053	<0.053	<0.053
Phenanthrene	µg/L										<0.022	<0.022	<0.022
Pyrene	µg/L							**240**	DW	EPA	0.011	0.012	0.012
Quinoline	µg/L							**2.4**	DW	EPA	0.077	0.089	0.086
Alkylphenols													
4-Nonylphenols	ng/L										142	166	162
4-Nonylphenol monoethoxylates	ng/L										81	94	92
4-Nonylphenol diethoxylates	ng/L										194	227	221
Octylphenol	ng/L										<4.5	<4.9	<4.8
Sterols and Hormones													
17 α-Ethinyl-Estradiol	ng/L			0.75	FS						3.3	3.7	3.6
Campesterol	ng/L										569	630	619
β-Sitosterol	ng/L										10685	12387	12082
β-Stigmastanol	ng/L										533	559	554
Polychlorinated Biphenyls													
PCB-77	pg/L			40	FS, M/ES			**280000**	DW	EPA	0.79	0.82	0.81
PCB-105	pg/L			90	FS, M/ES			**400000**	DW	EPA	2.9	3.1	3.1
PCB-126	pg/L			0.25	FS, M/ES			**120**	DW	EPA	<0.81	<0.83	<0.83
PCB-169	pg/L			60	FS, M/ES			**400**	DW	EPA	<0.76	<0.77	<0.77
Total PCBs	pg/L			100	FS, M/ES						222	234	232
Polybrominated Diphenyl Ethers													
Penta-BDE-99	pg/L										259	298	291
Penta-BDE-100	pg/L										53	60	59
Octa-BDE-203	pg/L										22	22	22
Biota[6]													
Coliforms Fecal	MPN/100mL			0	LV			**200**	R	BC	-	-	-
Enterococcus	MPN/100mL			0	LV			**100**	R	BC	-	-	-
Escherichia, Coli	MPN/100mL			0	LV			**385**	R	BC	-	-	-

Notes:

WQO = Water Quality Objectives; H = hardness-dependent guideline; LV = guideline for lifestock; M/ES = marine/estuarine guideline aquatic life guideline; IR = guideline for irrigation; FS = freshwater aquatic life guideline; T = temperature dependant guideline; W = working guideline; pH = pH dependant guideline; Cl = chloride dependant guideline; WI = wildlife guideline; p = guideline is for phototoxicity; mg N/L = milligrams Nitrogen per liter; mg P/L = milligrams Phosphorus per liter; µg/L = micrograms per liter; mg/L = milligrams per liter; ng/L - nanograms per liter; pg/L = picograms per liter; µS/cm = microseimens per centimeter; ppt = parts per trillion; °C = degrees Celsius; –< = reported value is less than method detection limit (MDL); $CaCO_3$ = Calcium Carbonate; MPN/100mL = most probable number of colony forming units per one hundred milliliters of water; IDZ = initial dilution zone; R = Recreational Guideline; DW = Drinking Water Guideline; BC = British Columbia Approved Water Quality Guidelines; HC = Guidelines for Canadian Drinking Water Quality (Health Canada); EPA = Environmental Protection Agency

(1) Water Quality Assessment and Objectives for the Fraser River From Hope to Sturgeon and Roberts Banks First Update, Freshwater, Estuarine or Marine Water Quality Criteria for the Fraser River Main Arm from the New Westminister Triurcation to the Banks. Accessed May 2016. Available online at http://www.dfo-mpo.gc.ca/Library/272539.pdf.
(2) Where freshwater and marine/estuarine guidelines were available, the most conservative values were used for screening.
(3) British Columbia Ministry of Environment Approved Water Quality Guidelines (BC WQG) (2016) for freshwater/estuarine/marine aquatic life. Accessed May 2016. Available at: http://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/waterquality/waterqualityguidesobjs/approved-wat-qual-guides/final_approved_wqg_summary_march_2016.pdf. Where approved guidelines were not available, working guidelines were used for screening. Accessed May 2016. Available at
(4) Canadian Council of Ministers of the Environment (CCME) Water Quality Guidelines for the Protection of Aquatic Life freshwater and marine water quality guidelines. Accessed May 2016. Available online at: http://st-ts.ccme.ca/en/index.html.

(5) Values were preferentially selected from the BC Approved WQG (March 2016) for secondary recreational contact. If no recreational value was available, the drinking water guideline multiplied by 10 was used. Health-based drinking water guidelines were obtained from the BC Approved WQGs (2016) and Guidelines for Canadian Drinking Water Quality (Health Canada 2014), with the most conservative value selected preferentially. The US EPA (2016) tapwater RSLs were used when a BC or Health Canada value was not available. The RSLs were adjusted to reflect an HQ of 0.2 and ILCR of 10-5 (target risk levels for Canada). The BC Approved WQG Summary Report [accessed July 2016] available at: http://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-quality/water-quality-guidelines/approved-water-quality-guidelines. Guidelines for Canadian Drinking Water Quality [accessed July 2016] available at: http://www.hc-sc.gc.ca/ewh-semt/water-eau/drink-potab/guide/index-eng.php. US EPA tapwater RSLs [accessed July 2016] available at: https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables-may-2016.

(6) Due to the temporal restrictions of the Fraser River Objectives for bacteria, ambient water quality data was sorted to align with these parameters. Ambient data were divided by season; high flow season consisted of April to October and low flow season consisted of November to March. To align with screening values, instead of arithmetic means, geometric means were calculated.

Number	Exceeds the most conservative Freshwater/Marine/Estuarine Fraser River WQO protective of aquatic life
Number	Exceeds the most conservative Freshwater/Marine/Estuarine BC WQG Short Term Guidelines protective of aquatic life
Number	Exceeds the most conservative Freshwater/Marine/Estuarine CCME Short Term Guidelines protective of aquatic life
Number	Exceeds the most conservative recreational guideline protective of human health

Equation Notes for Fraser River Short Term Water Quality Objectives
a) pH and temperature dependent ammonia WQO values selected from Table 12 in BC WQO document based on based on mean temperature and pH of the flow scenario.
b) Chloride dependent nitrite guideline: WQO (mg/L) = 0.06 at Cl <2 mg/L; at Cl 2-4 mg/L = 0.12; at Cl 4-6 mg/L = 0.18; at Cl 6-8 mg/L = 0.24; at Cl 8-10 = 0.30; at Cl >10 = 0.6.
c) Hardness dependent Cu WQO (µg/L) = minimum value of [(0.094*hardness)+2] and 3.
d) Hardness dependent Pb WQO (µg/L) = EXP((1.273*(ln(hardness))-1.46).

Equation Notes for BC WQG Short Term Guideline
a) Hardness dependent fluoride guideline: BC max WQG (mg/L) =-51.73+(92.57*log(hardness))*0.01 at hardness ≥ 10; 0.4 mg/L at hardness <10.
b) pH and temperature dependent ammonia guideline: values selected from Table 3 in BC WQG based on mean temperature and pH of the flow scenario.
c) Chloride dependent nitrite guideline: BC max WQG (mg/L) = 0.06 at Cl <2 mg/L; at Cl 2-4 mg/L = 0.12; at Cl 4-6 mg/L = 0.18; at Cl 6-8 mg/L = 0.24; at Cl 8-10 = 0.30; at Cl >10 = 0.6.
d) Hardness dependent Pb guideline: BC max WQG (µg/L) = exp(1.273*ln(hardness)-1.46) at hardness ≥ 8; 3 at hardness < 8.
e) Hardness dependent Mn guideline: BC max WQG (µg/L) = (0.01102*(hardness)+0.54)*1000.
f) Hardness dependent Ag guideline: BC max WQG (µg/L) = 0.1 at hardness ≤100 mg/L; at hardness >100 mg/L = 3.
g) Hardness dependent Zn guideline: BC max WQG (µg/L) = 33+0.75(hardness-90).
h) pH dependent dissolved Al guideline: BC max WQG (µg/L) = 100 at pH ≥6.5, at pH <6.5 = (EXP(1.209-2.426*(pH)+0.286*(pH^2)))*1000.
i) Hardness dependent dissolved Cd guideline: max BC WQG (µg/L) = (exp(1.03*ln(hardness)-5.274)).

Equation Notes for CCME Short Term Guideline
a) Hardness dependent Cd guideline: CCME WQG (µg/L) = 10^((1.016*(log(hardness)))-1.71) at hardness ≥ 5.3 to ≤ 360 mg/L; 0.11 at hardness < 5.3 mg/L; 7.7 at hardness > 360 mg/L.

Table 6-2: Screening of Predicted Monthly Average Concentrations of Water Quality Constituents at the Edge of the IDZ of the Annacis Island WWTP Proposed Outfall

Parameter	Units	*Fraser River WQO - Long Term*^{1,2}	Notes		BC WQG Long Term Average Guideline^{3,2}	Notes		CCME Long Term Guideline^{4,2}	Notes		Selected Recreational Screening Criterion^{4,5}	Notes		IDZ 30-day Concentrations											
														JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Conventional Parameters																									
Salinity	ppt							+10% of baseline	I, M/ES					0.14	0.14	0.14	0.068	0.067	0.066	0.067	0.068	0.14	0.14	0.14	0.14
Conductivity	µS/cm													87	87	88	93	91	89	90	92	87	87	87	87
Temperature	°C							+1°C change due to human activities and +0.5°C/hour	FS, M/ES		**30**	R	BC	9.2	9.2	9.3	14	14	14	14	14	9.2	9.2	9.2	9.2
Carbonaceous Biochemical Oxygen Demand (CBOD5)	mg/L													0.26	0.27	0.28	0.26	0.24	0.22	0.23	0.25	0.26	0.27	0.27	0.26
Dissolved organic carbon	mg/L				± 20% median background	FS								2.5	2.5	2.5	2.5	2.5	2.4	2.5	2.5	2.5	2.5	2.5	2.5
Hardness, as $CaCO_3$	mg/L													59	59	59	51	50	50	50	50	59	59	59	59
Total Residual Chlorine	mg/L				0.002	FS					**0.0006**	DW	EPA	**<0.002**	**<0.002**	**<0.002**	**<0.002**	**<0.002**	**<0.002**	**<0.002**	**<0.002**	**<0.002**	**<0.002**	**<0.002**	**<0.002**
Total organic carbon	mg/L													2.7	2.7	2.8	-	-	-	-	-	2.7	2.7	2.7	2.7
Total suspended solids	mg/L	*+10mg/L from background (<100mg/L); 10% of background (>100mg/L)*			See Table in 2015 BCWG Summary Document8	FS		>5 mg/L from background (30-d) in clear waters; >10 mg/L from background in waters between 25-100 mg/L or >10% when background is >100 mg/L	FS, M/ES					16	16	16	81	81	81	81	81	16	16	16	16
Major Ions																									
Fluoride	mg/L							120	FS		**15**	DW	BC, HC	0.035	0.035	0.035	0.040	0.040	0.040	0.040	0.040	0.035	0.035	0.035	0.035
Sulphate	mg/L				218	H, FS	a							10	10	10	7.3	7.3	7.2	7.3	7.3	10	10	10	10
Calcium	mg/L													15	15	15	14	14	14	14	14	15	15	15	15
Magnesium	mg/L													5.3	5.3	5.3	3.6	3.6	3.6	3.6	3.6	5.3	5.3	5.3	5.3
Nutrients																									
Ammonia (un-ionized)	mg-N/L							0.019	FS	g				0.021	0.021	0.022	0.021	0.019	0.017	0.018	0.020	0.020	0.021	0.021	0.021
Total ammonia	mg-N/L	*1.54 - 1.98*	FS, M/ES, T, pH	a	1.54 - 1.98	FS, T, pH	b	1.03 - 2.85	FS, T, pH	a				1.2	1.2	1.2	1.2	1.1	0.98	1.0	1.1	1.2	1.2	1.2	1.2
Total phosphorus	mg-P/L													0.13	0.13	0.13	0.23	0.22	0.21	0.21	0.22	0.12	0.13	0.13	0.13
Dissolved phosphorus	mg-P/L													0.10	0.11	0.11	0.097	0.091	0.083	0.086	0.094	0.10	0.11	0.11	0.10
Nitrate	mg-N/L				3	FS		3	FS		**100**	DW	BC, HC	0.12	0.12	0.12	0.043	0.043	0.043	0.043	0.043	0.12	0.12	0.12	0.12
Nitrite	mg-N/L	*0.02 - 0.2*	Cl	b	0.02 - 0.2	Cl	c	0.06	FS		**1**	R	BC	0.0047	0.0048	0.0048	0.011	0.011	0.011	0.011	0.011	0.0047	0.0048	0.0048	0.0047
Total Metals																									
Aluminum	µg/L							100	pH, FS	b	**40000**	DW	EPA	254	254	254	1811	1812	1812	1812	1812	254	254	254	254
Arsenic	µg/L				5	FS		5	FS		**100**	DW	HC	0.50	0.50	0.50	0.93	0.93	0.93	0.93	0.93	0.50	0.50	0.50	0.50
Barium	µg/L										**10000**	DW	HC	16	16	16	34	34	34	34	34	16	16	16	16
Boron	µg/L				500-1200	IR, FS, M/ES		1500	FS		**50000**	DW	BC, HC	16	16	16	12	12	11	11	12	16	16	16	16
Cadmium	µg/L							0.08 - 0.12	H, FS	c	**50**	DW	HC	0.027	0.027	0.027	0.066	0.065	0.064	0.065	0.066	0.027	0.027	0.027	0.027
Chromium	µg/L				1	W, V, FS	d	1 [Cr(III)] 8.9 [Cr(VI)]	V, FS		**500**	DW	HC	0.51	0.51	0.51	3.5	3.5	3.5	3.5	3.5	0.51	0.51	0.51	0.51
Cobalt	µg/L				4	FS					**12**	DW	EPA	0.26	0.26	0.26	1.7	1.7	1.7	1.7	1.7	0.26	0.26	0.26	0.26
Copper	µg/L	*2*	FS, M/ES, H	c	2 - 2.8	M/ES; FS at hardness < 50 mg/L CaCO3	e	2	H, FS	d	**1000**	R	BC	*2.2*	*2.2*	*2.3*	*5.9*	*5.9*	*5.8*	*5.8*	*5.9*	*2.2*	*2.2*	*2.2*	*2.2*
Iron	µg/L							300	FS		**28000**	DW	EPA	400	400	400	2738	2738	2737	2737	2739	399	400	400	400
Lead	µg/L	*2*	M/ES		4.4 - 5.4	H, FS	f	1 - 2.05	H, FS	e	**50**	R	BC	0.24	0.25	0.25	1.2	1.2	1.2	1.2	1.2	0.24	0.25	0.25	0.24
Manganese	µg/L				798 - 917	H, FS	l				**860**	DW	EPA	22	22	22	89	89	89	89	89	22	22	22	22
Mercury	µg/L				0.00125-0.002	MeHg, FS, M/ES	g	0.016	I, M/ES		**10**	DW	BC, HC	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012
Molybdenum	µg/L				10	IR		73	I, FS		**2500**	DW	BC	0.79	0.79	0.79	0.62	0.62	0.61	0.62	0.62	0.79	0.79	0.79	0.79
Nickel	µg/L				25	W, FS		25 - 73.6	H, FS	f	**780**	DW	EPA	1.2	1.3	1.3	6.6	6.6	6.6	6.6	6.6	1.2	1.3	1.3	1.2
Selenium	µg/L				2	FS, M/ES, WI		1	FS		**100**	DW	BC	0.13	0.13	0.13	0.13	0.12	0.12	0.12	0.12	0.13	0.13	0.13	0.13
Silver	µg/L				0.05	H, FS	h	0.25	FS		**188**	DW	EPA	<0.026	<0.026	<0.027	0.036	0.034	0.032	0.033	0.035	<0.025	<0.026	<0.026	<0.026
Zinc	µg/L	*14*			7.5	H, FS	i	30	FS		**5000**	R	BC	3.0	3.0	3.0	8.9	8.8	8.7	8.7	8.8	2.9	3.0	3.0	3.0
Dissolved Metals																									
Aluminum	µg/L				50	pH, FS	j				**200**	R	BC	23	23	23	116	116	116	116	116	23	23	23	23
Arsenic	µg/L													0.42	0.42	0.42	0.44	0.43	0.43	0.43	0.43	0.42	0.42	0.42	0.42
Barium	µg/L													13	13	13	14	14	14	14	14	13	13	13	13
Boron	µg/L													17	17	17	11	11	11	11	11	17	17	17	17
Cadmium	µg/L				0.12 - 0.16	H, FS	k							0.02	0.02	0.02	0.025	0.024	0.023	0.024	0.025	0.02	0.02	0.02	0.02
Chromium	µg/L													0.16	0.16	0.16	0.27	0.27	0.27	0.27	0.27	0.16	0.16	0.16	0.16
Cobalt	µg/L													0.057	0.058	0.058	0.12	0.12	0.12	0.12	0.12	0.057	0.058	0.058	0.057
Copper	µg/L													1.2	1.2	1.2	1.5	1.5	1.4	1.4	1.5	1.2	1.2	1.2	1.2
Iron	µg/L													42	42	42	135	134	134	134	135	42	42	42	42
Lead	µg/L													0.042	0.042	0.043	0.097	0.096	0.094	0.095	0.097	0.042	0.042	0.042	0.042
Manganese	µg/L													8.2	8.2	8.2	12	12	12	12	12	8.1	8.2	8.2	8.2
Molybdenum	µg/L													0.82	0.82	0.82	0.76	0.75	0.75	0.75	0.75	0.82	0.82	0.82	0.82
Nickel	µg/L													0.59	0.59	0.59	1.3	1.2	1.2	1.2	1.2	0.59	0.59	0.59	0.59
Selenium	µg/L													0.12	0.12	0.12	0.11	0.11	0.11	0.11	0.11	0.12	0.12	0.12	0.12
Silver	µg/L													<0.026	<0.026	<0.027	0.027	0.025	0.023	0.024	0.026	<0.025	<0.026	<0.026	<0.026
Zinc	µg/L													1.4	1.4	1.4	1.1	1.1	1.0	1.0	1.1	1.4	1.4	1.4	1.4

Parameter	Units	Fraser River WQO - Long Term[1,2]	Notes	BC WQG Long Term Average Guideline[3,2]	Notes	CCME Long Term Guideline[4,2]	Notes	Selected Recreational Screening Criterion[4,5]	Notes		IDZ 30-day Concentrations											
											JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Herbicide																						
Linuron	ng/L			7000	W, FS	7000	FS, I	**66000**	DW	EPA	<0.046	<0.047	<0.049	<0.046	<0.043	<0.038	<0.04	<0.044	<0.046	<0.047	<0.047	<0.046
Metolachlor	ng/L			7800	W, FS	7800	FS, I	**500000**	DW	HC	0.019	0.019	0.02	0.019	0.017	0.016	0.016	0.018	0.018	0.019	0.019	0.019
Triallate	ng/L			240	W, FS	240	FS, I	**240000**	DW	EPA	<0.003	<0.003	<0.003	<0.003	<0.003	<0.002	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Trifluralin	ng/L			200	W, FS	200	FS, I	**450000**	DW	HC	0.0042	0.0043	0.0044	0.0042	0.0039	0.0035	0.0037	0.0041	0.0042	0.0043	0.0043	0.0042
Insecticide																						
Aldicarb	ng/L			150	W, M/ES	150	M/ES, I	**40000**	DW	EPA	<0.019	<0.019	<0.02	<0.019	<0.017	<0.016	<0.016	<0.018	<0.019	<0.019	<0.019	<0.019
Carbaryl	ng/L			200	W, FS	200	FS	**900000**	DW	HC	0.14	0.14	0.15	0.14	0.13	0.12	0.12	0.14	0.14	0.14	0.14	0.14
Carbofuran	ng/L			1800	W, FS	1800	FS	**900000**	DW	HC	<0.019	<0.019	<0.02	<0.019	<0.017	<0.016	<0.016	<0.018	<0.019	<0.019	<0.019	<0.019
Chlorpyrifos	ng/L			2	W, FS, M/ES	2	FS, M/ES	**900000**	DW	HC	<0.038	<0.039	<0.04	<0.038	<0.035	<0.032	<0.033	<0.037	<0.037	<0.039	<0.039	<0.038
Deltamethrin	ng/L			0.4	W, FS	0.4	FS				<0.054	<0.054	<0.056	<0.053	<0.049	<0.044	<0.046	<0.051	<0.053	<0.054	<0.054	<0.053
Diazinon	ng/L					-		**200000**	DW	HC	0.046	0.046	0.048	0.046	0.042	0.038	0.040	0.044	0.045	0.046	0.046	0.046
Imidacloprid	ng/L			230	W, FS	230	FS, I				0.88	0.89	0.91	0.87	0.81	0.72	0.76	0.84	0.86	0.89	0.88	0.87
Lindane (hexachlorocyclohexane)	ng/L			10	W, FS	10	FS	**4200**	DW	EPA	0.017	0.017	0.018	0.017	0.016	0.014	0.015	0.016	0.017	0.017	0.017	0.017
Methoprene	ng/L					90 (target organism management value = 530)	FS				<2.3	<2.3	<2.4	<2.3	<2.1	<1.9	<2.0	<2.2	<2.2	<2.3	<2.3	<2.3
Permethrin	ng/L					0.001	M/ES, I	**2000000**	DW	EPA	0.55	0.56	0.58	0.55	0.51	0.46	0.48	0.53	0.54	0.56	0.56	0.55
Fungicide																						
Captan	ng/L			1300	W, FS	1300	FS, I	**3100000**	DW	EPA	<0.076	<0.077	<0.08	<0.076	<0.071	<0.063	<0.066	<0.073	<0.075	<0.077	<0.077	<0.076
Chlorothalonil	ng/L			180	W, FS	180	FS, I	**520000**	DW	EPA	0.0027	0.0027	0.0028	0.0027	0.0025	0.0022	0.0023	0.0026	0.0026	0.0027	0.0027	0.0027
Polycyclic Aromatic Hydrocarbons																						
Acenaphthene	µg/L			6	FS	5.8	FS	**1060**	DW	EPA	0.012	0.012	0.012	0.012	0.012	0.011	0.012	0.012	0.012	0.012	0.012	0.012
Acenaphthylene	µg/L										<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Acridine	µg/L			0.05	p, FS	4.4	I, FS				0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
Anthracene	µg/L			0.1	p, FS	0.012	I, FS	**3600**	DW	EPA	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Benz(a)anthracene	µg/L			0.1	p, FS	0.018	I, FS	**1.2**	DW	EPA	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Benzo(a)pyrene	µg/L			0.01	FS	0.015	I, FS	**0.1**	DW	BC, HC	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Benzo(b)fluoranthene	µg/L							**3.4**	DW	EPA	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011
Benzo(g,h,i)perylene	µg/L										0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Benzo(k)fluoranthene	µg/L							**34**	DW	EPA	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chrysene	µg/L							**340**	DW	EPA	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Dibenz(a,h)anthracene	µg/L							**0.34**	DW	EPA	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fluoranthene	µg/L			0.2	p, FS	0.04	I, FS	**1600**	DW	EPA	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
Fluorene	µg/L			12	FS	3	I, FS	**580**	DW	EPA	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
Indeno(1,2,3-c,d)pyrene	µg/L							**3.4**	DW	EPA	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
1-Methylnaphthalene	µg/L							**110**	DW	EPA	<0.052	<0.052	<0.052	<0.052	<0.051	<0.051	<0.051	<0.052	<0.052	<0.052	<0.052	<0.052
2-Methylnaphthalene	µg/L							**72**	DW	EPA	<0.052	<0.052	<0.052	<0.052	<0.051	<0.051	<0.051	<0.052	<0.052	<0.052	<0.052	<0.052
Naphthalene	µg/L			1	FS	1.1	I, FS	**12.2**	DW	EPA	<0.052	<0.052	<0.052	<0.052	<0.052	<0.051	<0.052	<0.052	<0.052	<0.052	<0.052	<0.052
Phenanthrene	µg/L			0.3	FS	0.4	I, FS				<0.021	<0.021	<0.021	<0.021	<0.021	<0.021	<0.021	<0.021	<0.021	<0.021	<0.021	<0.021
Pyrene	µg/L			0.02	p, FS	0.025	I, FS	**240**	DW	EPA	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
Quinoline	µg/L			3.4	W, FS	3.4	I, FS	**2.4**	DW	EPA	0.021	0.021	0.021	0.021	0.020	0.019	0.019	0.020	0.021	0.021	0.021	0.021
Alkylphenols																						
4-Nonylphenols	ng/L										51	52	53	51	48	44	46	50	51	52	52	51
4-Nonylphenol monoethoxylates	ng/L										43	43	44	43	40	37	38	41	42	43	43	43
4-Nonylphenol diethoxylates	ng/L										71	72	74	71	67	61	63	69	70	72	72	71
Octylphenol	ng/L										<2.9	<2.9	<2.9	<2.9	<2.8	<2.8	<2.8	<2.9	<2.9	<2.9	<2.9	<2.9
Sterols and Hormones																						
17 α-Ethinyl-Estradiol	ng/L			0.5	FS						1.1	1.1	1.1	1.1	1.0	1.0	1.0	1.0	1.0	1.1	1.1	1.1
Campesterol	ng/L										385	386	392	384	373	357	364	378	382	386	386	385
β-Sitosterol	ng/L										2132	2141	2169	2126	2067	1985	2020	2096	2116	2142	2140	2131
β-Stigmastanol	ng/L										429	430	432	429	426	421	423	427	429	430	430	429
Polychlorinated Biphenyls																						
PCB-77	pg/L							**280000**	DW	EPA	0.70	0.70	0.71	0.70	0.70	0.69	0.69	0.70	0.70	0.70	0.70	0.70
PCB-105	pg/L							**400000**	DW	EPA	2.6	2.6	2.6	2.6	2.6	2.5	2.5	2.6	2.6	2.6	2.6	2.6
PCB-126	pg/L							**120**	DW	EPA	<0.72	<0.72	<0.73	<0.72	<0.72	<0.72	<0.72	<0.72	<0.72	<0.72	<0.72	<0.72
PCB-169	pg/L							**400**	DW	EPA	<0.71	<0.71	<0.71	<0.71	<0.71	<0.70	<0.71	<0.71	<0.71	<0.71	<0.71	<0.71
Total PCBs	pg/L										197	198	199	197	194	190	192	195	196	198	197	197
Polybrominated Diphenyl Ethers																						
Penta-BDE-99	pg/L					3900	6				169	170	174	168	160	148	153	164	167	170	170	169
Penta-BDE-100	pg/L					230	6				35	35	36	35	33	31	32	34	34	35	35	35
Octa-BDE-203	pg/L					170000	6				20	20	20	20	19	19	19	19	19	20	20	20
Bacteria[7]																						
Coliforms Fecal	MPN/100mL							**200**	R	BC	-	-	-	36	38	36	36	36	36	36	-	-
Enterococcus	MPN/100mL							**100**	R	BC	-	-	-	16	16	16	16	16	16	16	-	-
Escherichia, Coli	MPN/100mL							**385**	R	BC	-	-	-	28	28	28	28	28	28	28	-	-

Notes:

WQO = Water Quality Objectives; M/ES = marine/estuarine guideline aquatic life guideline; H=hardness-dependent guideline; IR = guideline for irrigation; FS = freshwater aquatic life guideline; T = temperature dependant guideline; W = working guideline; pH = pH dependant guideline; Cl = chloride dependant guideline; WI = wildlife guideline; MeHg = methyl mercury (MeHg) dependent guideline; I = interim guideline; V = valence dependant guideline; p = guideline is for phototoxicity; mg N/L = milligrams Nitrogen per liter; mg P/L = milligrams Phosphorus per liter; µg/L = micrograms per liter; mg/L = milligrams per liter; ng/L - nanograms per liter; pg/L = picograms per liter; µS/cm = microseimens per centimeter; ppt = parts per trillion; °C = degrees Celsius; -< = reported value is less than method detection limit (MDL); $CaCO_3$ = Calcium Carbonate; MPN/100mL = most probable number of colony forming units per one hundred milliliters of water; IDZ = initial dilution zone; R = Recreational Guideline; DW = Drinking Water Guideline; BC = British Columbia Approved Water Quality Guidelines; HC = Guidelines for Canadian Drinking Water Quality (Health Canada); EPA = Environmental Protection Agency

(1) Water Quality Assessment and Objectives for the Fraser River From Hope to Sturgeon and Roberts Banks First Update, Freshwater, Estuarine or Marine Water Quality Criteria for the Fraser River Main Arm from the New Westminister Triurcation to the Banks. Accessed May 2016. Available online at http://www.dfo-mpo.gc.ca/Library/272539.pdf.

(2) Where freshwater and marine/estuarine guidelines were available, the most conservative values were used for screening.

(3) British Columbia Ministry of Environment Approved Water Quality Guidelines (BC WQG) (2016) for freshwater/estuarine/marine aquatic life. Accessed May 2016. Available at: http://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/waterquality/waterqualityguidesobjs/approved-wat-qual-guides/final_approved_wqg_summary_march_2016.pdf. Where approved guidelines were not available, working guidelines were used for screening. Accessed May 2016. Available at http://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/waterquality/waterqualityguidesobjs/final_2015_wwqgs_26_nov_2015.pdf.

(4) Canadian Council of Ministers of the Environment (CCME) Water Quality Guidelines for the Protection of Aquatic Life freshwater and marine water quality guidelines. Accessed May 2016. Available online at: http://st-ts.ccme.ca/en/index.html.

(5) Values were preferentially selected from the BC Approved WQGs (March 2016) for secondary recreational contact. If no recreational value was available, the drinking water guideline multiplied by 10 was used. Health-based drinking water guidelines were obtained from the BC Approved WQGs (2016) and Guidelines for Canadian Drinking Water Quality (Health Canada 2014), with the most conservative value selected preferentially. The US EPA (2016) tapwater RSLs were used when a BC or Health Canada value was not available. The RSLs were adjusted to reflect an HQ of 0.2 and ILCR of 10-5 (target risk levels for Canada). The BC Approved WQG Summary Report [accessed July 2016] available at: http://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-quality/water-quality-guidelines/approved-water-quality-guidelines. Guidelines for Canadian Drinking Water Quality [accessed July 2016] available at: http://www.hc-sc.gc.ca/ewh-semt/water-eau/drink-potab/guide/index-eng.php. US EPA tapwater RSLs [accessed July 2016] available at: https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables-may-2016.

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(7) Due to the temporal restrictions of the Fraser River Objectives for bacteria, ambient water quality data was sorted to align with these parameters. Ambient data were divided by season; high flow season consisted of April to October and low flow season consisted of November to March. To align with screening values, instead of arithmetic means, geometric means were calculated.

Number	Exceeds the most conservative Long Term Freshwater/Marine/Estuarine Fraser River WQO protective of aquatic life
Number	Exceeds the most conservative Freshwater/Marine/Estuarine BC WQG Long Term Guidelines protective of aquatic life
Number	Exceeds the most conservative Freshwater/Marine/Estuarine CCME Long Term Guidelines protective of aquatic life
Number	Exceeds the most conservative recreational guideline protective of human health
Number	Exceeds the ambient +20 % concentration

Equation Notes for Fraser River Long Term Water Quality Objectives

a) pH and temperature dependent ammonia WQO values selected from Table 11 in BC WQO document based on mean temperature and pH of the flow scenario.

b) Chloride dependent nitrite WQO (mg/L) = 0.02 mg/L at Cl <2 mg/L; at Cl 2-4 mg/l = 0.04; at Cl 4-6 mg/L = 0.06; at Cl 6-8 mg/L = 0.08; at Cl 8-10 mg/L = 0.1; at Cl >10 = 0.2

c) Hardness dependent Cu WQO (µg/L) = minimum value of (0.04*hardness)+2) and 2.

Equation Notes for BC WQG Long Term Average Guideline

a) Hardness dependent sulphate guideline: BC 30-d WQG (mg/L) = 128 at hardness <30 mg/L; at hardness 31-75 mg/L = 218; at hardness 76-180 mg/L = 309; at hardness 181-250 mg/L = 429; at hardness >250 mg/L determine base on site water.
b) pH and temperature dependent ammonia guideline: values selected from Table 4 in BC WQG based on maximum temperature and corresponding pH.
c) Chloride dependent nitrite guideline: BC 30-d WQG (mg/L) = 0.02 mg/L at Cl <2 mg/L; at Cl 2-4 mg/l = 0.04; at Cl 4-6 mg/L = 0.06; at Cl 6-8 mg/L = 0.08; at Cl 8-10 mg/L = 0.1; at Cl >10 = 0.2.
d) Guideline is for Cr(VI).
e) Hardness dependent Cu guideline for FS: BC 30-d WQG (µg/L) = 2 at hardness ≤50 mg/L; at hardness >50 mg/L = 0.04*hardness.
f) Hardness dependent Pb guideline: BC 30-d WQG (µg/L) = 3.31 + exp(1.273*ln(hardness) - 4.704) at hardness > 8 mg/L.
g) Hg BC 30-d WQG (µg/L) = 0.0001/(MeHg/THg), where MeHg is mass (or concentration) of methyl mercury and THg is total mass (or concentration) of mercury in a given water volume. Range is 0.02 µg/L for 0.5% and 0.00125 µg/L for 8% MeHg.
h) Hardness dependent Ag guideline: BC 30-d WQG (µg/L) = 0.05 at hardness ≤100 mg/L; at hardness > 100 mg/L = 1.5.
i) Hardness dependent Zn guideline: BC 30-d WQG (µg/L) = 7.5+0.75(hardness-90).
j) pH dependent dissolved Al guideline: BC 30-d WQG (µg/L) = 50 at pH ≥6.5, at pH <6.5 = (exp(1.6-3.327*(median pH)+0.402*(median pH^{2})))*1000.
k) Hardness dependent dissolved Cd guideline: BC 30-d WQG (µg/L) = (exp(0.736*ln(hardness)-4.943)).
l) Hardness dependent Mn guideline: BC 30-d WQG (µg/L) = (0.0044*hardness+0.605)*1000.

Equation Notes for CCME Long Term Guideline

a) pH and temperature dependent ammonia guideline: values calculated from an equation based on Table 2 in the CCME WQG document where WQG (NH3-N) = (0.019*(1/(1/(1+(10^((0.0901821+(2729.92/(273.15+temperature)))-pH))))))*0.8224 where mean pH and temperature of the flow scenario were used for the calculation.

b) pH dependent Al guideline: CCME WQG (µg/L) = 5 at at pH < 6.5; 100 at pH ≥ 6.5.

c) Hardness dependent Cd guideline: CCME WQG (µg/L) = 10^((0.83*(LOG(hardness))-2.46) at hardness ≥ 17 to ≤ 280 mg/L; 0.04 at hardness < 17 mg/L; 0.37 at hardness > 280 mg/L.

d) Hardness dependent Cu guideline: CCME WQG (µg/L) = 0.2*(EXP((0.8545*(LN(hardness)))-1.465) at hardness ≥ 82 to ≤ 180 mg/L; 2 at hardness < 82 mg/L; 4 at hardness > 180 mg/L.

e) Hardness dependent Pb guideline: CCME WQG (µg/L) = EXP((1.273*(LN(hardness)))-4.705 at hardness > 60 to ≤ 180 mg/L; 1 mg/L at hardness ≤ 60 mg/L; 7 at hardness > 180 mg/L.

f) Hardness dependent Ni guideline: CCME WQG (µg/L) = EXP((0.76*(LN(hardness)))+1.06) at hardness > 60 to ≤ 180 mg/L; 25 mg/L at hardness ≤ 60 mg/L; 150 at hardness > 180 mg/L.

g) Un-ionized ammonia values are calculated using the equation: un-ionized ammonia = total ammonia x 1/(1 + 10 (pKa-pH)) where pKa is: 0.09018+2729.92/temperature, mean temperatures and pHs are used for the mean un-ionized ammonia calculation and maximum temperature and pH are used for the maximun un-ionized ammonia calculation.

6.2.1 COPCs for Aquatic Life, Wildlife, and Livestock Uses

The predicted instantaneous and monthly average concentrations at the edge of the IDZ are below the BC and CCME WQGs for most constituents for which these guidelines are available, indicating that adverse effects of these constituents on aquatic life and potential impairment of wildlife and agriculture environmental uses are not expected. Instances where predicted concentrations are above the lowest WQG for the most sensitive end use are discussed below.

Ammonia

Predicted instantaneous and monthly concentrations of total ammonia are below the FRWQO and both provincial and federal WQGs for the protection of aquatic life.

Predicted un-ionized ammonia concentrations are either below (June and July) or approximately equal to the CCME WQG (all other months), with maximum predicted concentrations exceeding the CCME WQG by up to 1.1 times. The un-ionized CCME WQG of 0.019 mg/L is equivalent to the lower 95% confidence interval concentration predicted by Environment Canada (1999b) for an ecological risk criterion of 0.041 mg/L associated with a 20% reduction in growth or reproduction in the most sensitive 5% of species in the aquatic community. The upper 95% confidence interval was 0.063 mg/L. The most sensitive toxicity benchmark for un-ionized ammonia included in the guideline derivation was a 5-year chronic lowest-observed-effect-concentration (LOEC) of 0.04 mg/L for rainbow trout reported by Thurston et al (1984), as cited in Environment Canada (1999b).The CCME WQG can therefore be considered to be conservative in the assessment of potential adverse effects on aquatic life, with effects on sensitive species such as rainbow trout more likely to occur at concentrations closer to 0.04 mg/L, higher than the range of predicted un-ionized ammonia monthly concentrations (0.017 to 0.0215 mg/L).

This preliminary assessment of conservatively derived ammonia predictions indicates that adverse effects on aquatic life would not be expected at the edge of the IDZ. Ammonia will be assessed in further detail in the Stage 2 assessment in consideration of the final outfall design and additional effluent and ambient data, as well as additional site-specific pH and temperature data.

Metals

Measured concentrations of total metals in water include metals adsorbed to particulate matter, whereas measured concentrations of dissolved metals do not because the particulate matter is filtered out of the sample prior to analysis. As discussed in Section 4.1.7, metal accumulation and the potential for toxicity to an aquatic biota is dependent on metal bioavailability under the specific exposure conditions. The dissolved metal fraction (per operational definition of <0.45 µm-filter) provides a truer measure of bioavailability than the overall total measurement that is compared to WQGs for most BC and CCME WQGs. This means the comparison of total predicted concentrations against WQGs can be conservative, especially for large river systems such as the Fraser River that are characterized by considerable sediment transport downstream.

For the majority of metals, predicted monthly concentrations are below FRWQOs and the lowest WQG. Predicted monthly average concentrations of dissolved aluminum, total chromium, lead, and zinc from April to September, and total aluminum, iron, and mercury concentrations for all months are greater than FRWQOs or the lowest WQG, but are not distinguishable from the relevant ambient river condition.

With respect to instantaneous metal concentrations, some total metals are above the FRWQO or the lowest WQG, but according to the following rationale adverse effects on aquatic would not be expected.

- **Iron**: The total iron concentration for the high flow scenario is above the maximum BC WQG, but dissolved iron is below the dissolved guideline, indicating that no adverse effects on aquatic life are expected when bioavailability for uptake by aquatic life is considered.
- **Cadmium**: Total cadmium concentrations are above the working marine WQG, but dissolved concentrations are below the approved freshwater dissolved guideline. The approved freshwater dissolved WQG better represents the fraction of cadmium in the water that is available for uptake by aquatic biota and therefore adverse effects due to cadmium exposure would not be expected. Furthermore, the working marine WQG was adopted from the long-term exposure CCME WQG of 0.12 µg/L and so is more reflective of longer term exposure not short-term instantaneous exposure. Predicted mean monthly total cadmium concentrations are below 0.12 µg/L.

Predicted instantaneous concentrations of total copper at the edge of the IDZ are above the FRWQO and the lowest total WQG under the three river flow classifications, and are distinguishable from the ambient river condition (i.e., more than 20% higher than the ambient mean value). Mean monthly concentrations predicted at the IDZ are also above the FRWQO and the lowest total WQG, but can only be distinguished from the ambient river condition during low flows from September to March. However, predicted instantaneous and mean monthly concentrations of dissolved copper at the IDZ are below the total copper WQG, indicating that a proportion of predicted total concentrations would not be expected to be bioavailable for uptake by aquatic biota. At this preliminary Stage 1 level of assessment, adverse effects to aquatic life would not be expected, but the assessment will be refined in the Stage 2 EIS based on the final design, an expanded effluent and ambient water quality dataset, refined water quality modeling procedures, and further consideration of copper bioavailability under site-specific conditions in the receiving environment.

Organics

PBDEs and PAHs

Predicted concentrations of all PBDEs and all PAHs except benzo(a)pyrene are below the short and long-term WQGs protective of aquatic life, indicative of no potential for adverse effects at the edge of the IDZ.

Instantaneous and monthly predictions for benzo(a)pyrene are not considered to indicate a potential for adverse effects because both effluent and ambient data inputs were measured at a detection limit equal to the BC and CCME WQG of 0.01 µg/L, and non-detected values were included in calculations as the detection limit. As a result, predicted concentrations range from 0.01 to 0.014 µg/L, approximately equal to the BC and CCME WQGs. However, these values are likely overestimates of true mean concentrations. Also, these concentrations are lower than acute and chronic toxicity values used to derive the BC and CCME WQGs (Nagpal 1993, CCME 1999), indicating that effects on aquatic life would not be expected.

Prior to undertaking the Stage 2 assessment, both effluent and ambient river water should be analysed at a detection limit lower than the provincial and federal WQG of 0.01 µg/L to reduce uncertainty in the impact assessment.

Polychlorinated biphenyls (PCBs)

Predicted instantaneous and monthly concentrations of total PCBs are higher than the maximum BC WQG for the protection of aquatic life by up to 1.5 times, although the BC WQG was derived to protect consumers of PCB-contaminated foods rather than the protection of aquatic biota from toxicity related effects. The four samples used to characterize the ambient river condition are also above the BC WQG. Predicted monthly concentrations (190 to 199 pg/L) are above the mean ambient concentration of 155 pg/L by 1.3 times; within the range of analytical precision specifically reported for PCBs in water (i.e., relative percent difference of 30%; OMOE 2011). The predictions do however have some associated uncertainty because they are based on effluent quality characterized by only six samples and a mean ambient river concentration based on only four samples. The Stage 2 assessment will consider a larger effluent and ambient dataset for PCBs.

A CCME aquatic life WQG for total PCBs is not recommended (CCME 2016). The original WQG published by CCREM (1987) has now been withdrawn because exposure to PCBs in the aquatic environment is primarily via bottom sediments and tissue media, for which CCME guidelines are available (CCME 2016). BC MoE (Bull et al. 2004) and the Fraser River Monitoring Program (Thomas 2006, Keystone 2011) reported total PCB concentration in Main Arm bottom sediments to be well below the FRWQO and the federal guideline, indicating no potential concern regarding biomagnification in the food web. Concentrations have also remained stable in recent decades (Keystone 2011). As discussed in Section 2.2.2, the evaluation of PCB concentrations in fish tissues is more uncertain than the sediment evaluation due to reliance on fish tissue data with detection limits above relevant guidelines or values that approximated guideline values.

In consideration of the above preliminary assessment, impairment of aquatic life, wildlife or agriculture water uses due to predicted concentrations of PCBs is not expected. The inclusion of additional effluent and ambient data in the more definitive Stage 2 EIS is expected to reduce uncertainty in the evaluation.

Endocrine Disrupting Compounds

17α-ethinyl-estradiol (EE2), a synthetic derivative of the natural hormone estradiol, is the only hormone for which there is a regulatory guideline (BC WQG; BC MoE 2016). Toxicity-related effects on aquatic biota from exposure to EE2 are sublethal and manifest over longer chronic time periods rather than lethal effects over the short-term; therefore the assessment focused on predicted monthly concentrations.

Predicted instantaneous and monthly concentrations of EE2 are above the BC WQG. Predicted monthly concentrations (1.0 to 1.1 ng/L) are approximately equal to the LOEC of 1.0 ng/L for reproduction in fathead minnow (*Pimephales promelas*) and rainbow trout, upon which the 30-day BC WQG is based (with a safety factor of two applied) (Nagpal and Meays 2009). However, EE2 predictions are based on effluent and ambient river data characterized by non-detect values over a wide range of method detection limits (i.e., <2 to <49 ng/L in the effluent; <2 to <9 ng/L in the ambient data). Therefore, the predicted monthly concentrations are likely overestimates of true mean concentrations.

Uncertainty associated with the EE2 predictions should be addressed for the Stage 2 EIS by review of more recent monitoring data with respect to sampling and analytical procedures employed. As recommended by Tri-Star (2015), this hormone is being measured in the AIWWTP effluent, but the feasibility of obtaining consistent, low detection limits should be evaluated further. Data collected in 2015 and 2016 will be carried forward to the Stage

2 EIS where a more in depth technical assessment of predicted water quality will be undertaken based on the final design, an expanded effluent and ambient water quality dataset, and refined water quality modeling procedures.

Other sterols and hormones selected for evaluation in the Stage 1 EIS (i.e., campesterol, β-Sitosterol, β-Stigmastanol) do not have WQGs for comparison, but predicted concentrations are distinguishable from ambient river concentrations. However, as with EE2, there is uncertainty associated with these predictions due to limited effluent and ambient datasets comprised primarily of variable, non-detect values.

Temperature and Salinity

With respect to the evaluation of the potential for adverse effects on aquatic life due to an increase in river temperature at the edge of the IDZ, an increase in temperature of 0.8°C at the IDZ was predicted for a 'worst case' scenario of minimum dilution and low river flows[4] in Section 5.3.3. This incremental increase is within the BC WQG and CCME maximum incremental change of ±1°C change from natural ambient background in marine and estuarine waters (BC MoE 2016, CCME 2016). These guidelines are based on natural ambient conditions so that temperatures are similar to regimes which organisms have adapted through evolutionary processes (BC MoE 2016).

Predicted salinity concentrations are within the variable range documented in Appendix B for the Fraser River within the Study Area. Salinity is particularly variable in this section of the river due to the influence of the upstream migration of the salt wedge, as described by CDM Smith (2016) in Appendix A.

6.2.2 COPCs for Public Health

Predicted instantaneous and monthly average concentrations at the edge of the IDZ were below their respective recreational criteria for all parameters with the exception of chorine (TRC). An assessment of TRC is provided below.

Total Residual Chlorine

The predicted IDZ concentrations for TRC exceeded the selected recreational screening criterion. The maximum predicted TRC concentration was based on non-detected concentrations in effluent (and the detection limit was subsequently improved in 2014) and is therefore considered a conservative prediction.

The screening criterion for TRC was based on the US EPA Regional Screening Levels (RSLs) for tapwater. The US EPA tapwater RSLs are risk-based thresholds that are protective of ingestion of water, dermal contact, and inhalation of volatiles. As chlorine is a volatile substance, its RSL (0.0006 mg/L after adjusting for an HQ of 0.2 and a factor of 10 for recreational use) is largely driven by the inhalation pathway. However, the inhalation pathway considered for tapwater is based on exposure from showering, which is not relevant for secondary contact recreational use which does not occur in an enclosed environment. The dermal exposure route is considered to be more relevant for secondary contact recreational use. Thus, the predicted chlorine concentrations were screened against the US EPA ingestion RSL of 4 mg/L (after adjusting to HQ=0.2 and applying a factor of 10 for recreational use). The maximum predicted concentration of TRC (<0.006 mg/L) was well below the US EPA dermal RSL screening value. In addition, Health Canada (1999) and the WHO (2006) guidance for safe swimming pool

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[4] Based on the minimum predicted dilution for the less than 1,000 m^3/s flow classification, the predicted impact in temperature was 0.8°C and was less than the allowable change in the interim guideline.

use have reported acceptable levels of TRC in swimming pools in the 1 to 3 mg/L range, which provides additional evidence that the predicted TRC concentrations would not be associated with adverse health effects. Therefore, the predicted concentrations of TRC are not expected to pose a risk to human health.

6.3 Preliminary Impact Conclusion

Overall, the Stage 1 assessment based on conservative assumptions and preliminary IDZ predictions indicated that pollution as defined by EMA is unlikely to occur as a result of the hydraulic upgrade to the AIWWTP and resultant treated effluent discharge; specifically:

- Adverse effects on aquatic life and impairment of other receiving environment uses identified for the Study Area (i.e., secondary recreational contact, wildlife use, agricultural use) are not expected based on a preliminary assessment of predicted concentrations at the edge of the IDZ in the Fraser River.
- Secondary treated whole effluent at the point of discharge is not expected to be acutely lethal to aquatic life and conditions within the IDZ would likewise not be expected to be acutely lethal to aquatic life. Chronic toxicity is not expected beyond the IDZ boundary. While existing effluent has been tested and found to be non-acutely lethal, the potential for acute lethality must also consider effluent quality based on the permit conditions being applied for. When the new effluent outfall is commissioned, toxicity testing will be carried out to confirm these predictions and is expected to be a condition of the amended Operational Certificate.

Based on the most recent characterization of effluent presented in the Stage 1 EIS (i.e., 2014), the AIWWTP effluent meets National Performance Standards (i.e., WSER limits and it is not acutely toxic); therefore, the effluent is not considered a deleterious substance under the federal *Fisheries Act*.

7.0 UNCERTAINTY ASSESSMENT

The Stage 1 EIS conducted herein was a predictive exercise, with the objective of identifying whether or not the proposed effluent discharge could potentially result in adverse effects on aquatic life or impairment of other uses identified for the receiving environment. Accordingly, it is not possible to make direct environmental measurements in the receiving environment and assess impact directly. Assessing impact before discharge requires the use of various predictive tools such as effluent dilution modeling. While these tools are useful and provide a reasonable and commonly used prediction of likely conditions, it is appropriate to identify the main uncertainties associated with a predictive assessment and to consider the implications of these uncertainties on predictions made. Finally, if the findings of the EIS and the analysis of uncertainties provide confidence that the discharge can proceed to final outfall design then the identification of uncertainties will assist in focusing a pre-discharge monitoring program to support the Stage 2 Assessment based on the final outfall design. The main uncertainties are summarized in Table 7-1.

Table 7-1: Identified Uncertainties in the Stage 1 Environmental Impact Study for the AIWWTP Proposed Outfall Diffuser

Assumption	Section	Uncertainty	Under/over Estimate of Impact	Rationale
Stratification in the Fraser River is stronger or occurs more frequently.	Section 5: Receiving Water Quality Predictions	Medium	Under	Stratification generally reduces dilution. Available data to characterize stratification at the project site are limited. River flow during additional data gathering in late winter 2016 was not sufficiently low to have stratification reach the project site.
Current speed observed at the Environment Canada Gravesend Reach buoy is representative of the current speeds at the proposed diffuser location (approximately 6-7 km upstream of the buoy).	Section 5: Receiving Water Quality Predictions	Medium	Neutral	Available data to characterize the current speed at the proposed diffuser location in the Fraser River are limited. The analysis predicted the lowest dilutions to occur when the current speed is near zero during slack tide and the dilutions typically increase with higher current speeds.
The Shrivastava-Adams equation adequately represents dilution during unstratified conditions for the proposed diffuser design.	Section 5: Receiving Water Quality Predictions	Low	Unknown	Shrivastava-Adams (draft manuscript) derived an equation to predict dilution based on experimental results from Seo et al. (2001) of a tee (unidirectional) diffuser in shallow water with a crossflow. The experimental conditions are similar to the Annacis outfall diffuser preliminary design, but not exactly the same. Planned scaled physical modeling may result in updating the equation used for the Stage 2 EIS.

Assumption	Section	Uncertainty	Under/over Estimate of Impact	Rationale
Use of full detection limits to calculate both ambient and effluent concentrations	Sections 4, 5, and 6	Low for most parameters; Medium for others such as organic constituents	Over	The use of full detection limits in statistically characterizing ambient and effluent water quality results in conservatively high predicted concentrations at the edge of the IDZ. The degree of conservatism depends on the percentage of samples for each parameter that have non-detected values (more non-detects results in greater over-prediction of true values).
Use of limited data (sample size) and data reported at varying detection limits equal to or higher than WQGs	Sections 4, 5, and 6	Low for most parameters; Medium or high for others like organic compounds (EE2, PCBs, pesticides)	Over	The ability to adequately characterize effluent and ambient conditions is limited for some organic constituents by sample size, varying detection limits, and detection limits equal to or higher than corresponding WQGs. This results in uncertainty in the inputs to the IDZ predictions and therefore uncertainty in predicted IDZ concentrations.
Interaction of constituent mixtures will not result in effects greater than estimated through the use of WQG.	Section 6: Impact Assessment	Low	Neutral	The impact assessment has examined the constituents individually; however, in reality they are discharged in a mixture. Although additive interactions among constituents are more common, it is possible that more-than-additive (synergistic) or less-than additive (antagonistic) interactions may occur. Toxicity testing considers these interactions because the effluent is a mixture. Tests on existing effluent have shown no acute lethality to rainbow trout.

8.0 CONSIDERATIONS FOR MONITORING TO SUPPORT THE STAGE 2 ASSESSMENT

The potential need for pre-discharge monitoring was determined in consideration of provincial EIS guidance by BC MELP (2000) and in consultation with BC MoE. These discussions determined that pre-discharge monitoring to support the Stage 2 EIS would mainly focus on the collection of supplemental water and sediment quality data, with the collection of some benthic invertebrate data during the sediment quality survey. Supplemental monitoring was subsequently undertaken in late summer/fall 2015 (water) and late winter 2016 (water, sediment, benthic invertebrates) in advance of submission of this Stage 1 EIS. These data were not intended to be included in the Stage 1 EIS, but rather were to be reported separately and included in the Stage 2 EIS.

Supplemental monitoring to support the Stage 2 EIS was undertaken so that data would be collected during the appropriate season, thus mitigating the potential for delay in preparation of the Stage 2 EIS. Effluent and ambient Fraser River data were collected within the Study Area for the following components:

- Water quality data downstream of the proposed outfall location in late summer/fall (2015—conventional parameters, metals, nutrients, bacteriological constituents, nonylphenols, and PAHs).
- Water property vertical profile data (late winter 2016—depth profile measurements of pH, dissolved oxygen, salinity, conductivity, temperature, and turbidity).
- Addition of select organic constituents to the late winter 2016 IDZ monitoring program for effluent, IDZ, and reference locations (2016—PAHs, PBDEs, PCBs, pesticides).
- Sediment quality data and preliminary benthic invertebrate data (late winter 2016).

Further monitoring is currently being considered for fall 2016 to provide additional supplemental data for the Stage 2 EIS, most notably:

- Inclusion of a comparable organic parameter suite (nonylphenols, sterols and hormones, PAHs, PBDEs, PCBs, pesticides) as for the late winter 2015 IDZ program in late summer/fall 2016 monitoring at the reference location to better characterize ambient concentrations of these parameters in the Fraser River.
- Inclusion of a comparable organic parameter suite (nonylphenols, sterols and hormones, PAHs, PBDEs, PCBs, pesticides) in concurrent effluent monitoring to better characterize effluent concentrations.
- Detailed in situ pH and temperature monitoring near the proposed outfall location, outside of the zone of influence of the existing effluent, to better characterize pH conditions over a range of river flow and tidal conditions. The in situ pH and temperature data will be used for a detailed ammonia assessment in the Stage 2 EIS.
- Additional depth profile data at both the reference and IDZ monitoring stations to better characterize the vertical temperature and conductivity/salinity structure of the Fraser River near the proposed outfall location to be collected during late summer/early fall 2016 when the river is at low flow (preferably <1,000 m^3/s, but consideration of sampling could occur if flows were <2,000 m^3/s) and predicted tide levels are favorable for migration of the saltwater wedge up the river.

The 2015/2016 pre-discharge monitoring described above, that has already been undertaken or is currently being scheduled, serves to address both EIS guidance and a substantial proportion of the uncertainties identified in this Stage 1 EIS. Based on the evaluation of 2011 to 2014 data by this Stage 1 EIS, the following should also be considered to support the Stage 2 EIS.

- The short-list of organic parameters considered for the Stage 1 EIS should be reviewed in consideration of the additional effluent and ambient data collected in 2015 and 2016. This should then form the basis of the short-list of organic parameters considered for the Stage 2 EIS.
- The list of parameters monitored in effluent and the ambient environment between 2011 and 2016 (subject to data availability) should be reviewed to confirm that parameters have been monitored in both media.
- Some parameters such as EE2 and pesticides in the effluent and ambient environment were reported at MDLs higher than corresponding WQGs. This is a source of uncertainty in IDZ predictions based on these values and the resulting water quality impact assessment. It is recommended that recent chemistry data (2015-2016) be reviewed with respect to sampling and analytical procedures employed and the need for sampling in addition to that described above.

9.0 CLOSURE

We trust that this report provides sufficient information for your present needs. If you have any questions, please do not hesitate to contact the undersigned at 604-296-4200.

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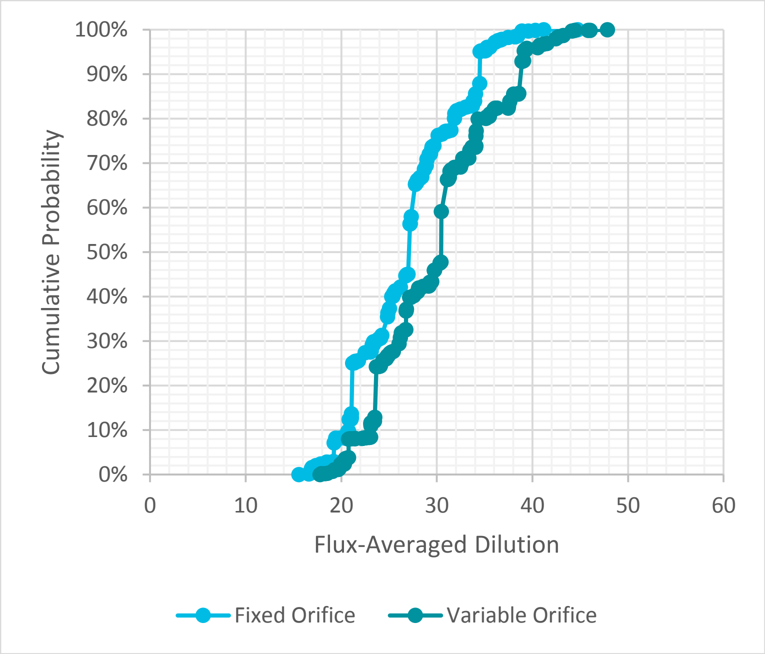
APPENDIX A

Multiport Diffuser Design and Initial Dilution Modeling Report (CDM Smith 2016)

Multiport Diffuser Design and Initial Dilution Modeling

Annacis Island WWTP
Transient Mitigation and Outfall Project

CDM Smith Canada ULC



Prepared for:

metrovancouver
SERVICES AND SOLUTIONS FOR
A LIVABLE REGION

July 29, 2016

CDM Smith

A Report Prepared for:

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Multiport Diffuser Design and Initial Dilution Modeling
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Section 1

Introduction

1.1 Purpose

This draft report presents a preliminary multiport diffuser design and initial dilution modeling for the terminus (diffuser) of the outfall system for the Annacis Island Wastewater Treatment Plant (AIWWTP) for the purpose of identifying what can be achieved in terms of dilution and mixing within the physical constraints identified in the preliminary concept development (Black and Veatch, 2015).

Early modeling of the diffuser system made it evident that the project's dilution objectives could not be achieved using a gravity outfall system, particularly for the maximum future (Stage VIII plant expansion) effluent flow combined with the 200-year flood stage on the Fraser River. Since future plant capacity expansions, beyond the current Stage V expansion project, are anticipated to only be required several decades in the future, CDM Smith recommends the preliminary diffuser design be optimized for Stage V flows using the majority of available gravity head. The diffuser would still be designed such that it could be modified to accommodate higher future flows. Initial dilution modeling was then performed using this preliminary design to estimate achievable dilution and mixing in the Fraser River. Under this scenario, future plant capacity expansions are likely to require pumping to augment the available hydraulic head.

This draft report describes the physical constraints, regulatory requirements, preliminary diffuser design, Fraser River and effluent data used as inputs for the diffuser modeling, and initial dilution modeling results. It also describes how the diffuser system would be expanded for future Stage VIII flows, estimated pumping requirements, and presents preliminary dilution modeling for these future flows.

1.2 Project Background

1.2.1 Outfall Project

Metro Vancouver (MV) is currently implementing Stage V improvements to the AIWWTP that will increase the peak wet weather capacity of the plant from 12.6 m^3/s to 18.9 m^3/s, and has future (Stage VIII) plans to further increase the peak wet weather capacity to 25.3 m^3/s. A new outfall/diffuser system is needed because the current outfall does not have sufficient hydraulic capacity to discharge planned flow increases at high river levels, and is not able to provide sufficient dilution and mixing.

The design of outfall/diffuser system has the following main objectives:

- To provide an outfall system with a total capacity of 25.3 m^3/s (i.e., Stage VIII peak wet weather flow) at a river level of 103.18 m GD without impacting the hydraulic gradeline of the treatment plant.
- To achieve a minimum dilution ratio of 20:1.

1.2.2 Scope of Work

Conceptual design and preliminary concepts development for the outfall project were completed by others (Black and Veatch, 2015). CDM Smith was retained by Metro Vancouver to review the previous work and complete preliminary level activities to refine design concepts and perform options analysis to select the best option to achieve the project objectives (Phase A – Pre-Design) prior to proceeding with detail design (Phase B – Detail Design). Phase A also includes fluvial geomorphological, geotechnical, environmental and archaeological services (and obtaining all necessary permits and approvals associated with the field investigations).

Specific to the outfall system, the Phase A scope of work includes:

- An options analysis to look at various options for conveying effluent to the river (one or routes), diffuser arrays in the river (single or multiple), and pumping (now or in future).
- Preliminary design for the recommended outfall system option, including dilution modeling to confirm that the outfall design meets all relevant regulations and guidelines pertaining to ammonia at the initial dilution zone.
- An Environmental Impact Study (EIS) conducted for the recommended outfall system pursuant to the Environmental Management Act and the Municipal Wastewater Regulations.

1.2.3 Environmental Impact Study

British Columbia's Municipal Wastewater Regulations require an EIS before expanding or making a material change to a wastewater treatment facility. The EIS includes provisions for controlling environmental impacts during the construction and operation of the wastewater facility considering:

- Potential cumulative effects of the discharge on the receiving environment
- Additional municipal effluent quality requirements if necessary to protect public health or the receiving environment
- A receiving environment monitoring program
- Demonstration that the system and its discharges will not adversely affect public health or the receiving environment
- Impact on the receiving environment both when the effluent quality requirements are met and when effluent quality is degraded

Golder Associates, as a subcontractor to CDM Smith, is leading the EIS preparation in stages per provincial guidance that includes a Stage 1 assessment of available data and a pre-discharge monitoring program (if required), followed by a Stage 2 refined evaluation of potential effluent-related impacts on the receiving environment and public health. For the Stage 1 EIS, conservative assumptions are made to result in an assessment that is more likely to over-predict adverse effects than to under-predict them.

The results of the preliminary diffuser design and initial dilution modeling presented in this report will be utilized for the Stage 1 EIS. Refinements to the diffuser design and updated dilution modeling reflecting the final design configuration will be utilized to complete the Stage 2 EIS.

1.3 Concept Design Development

MV's project definition and the preliminary outfall system concept development (Black and Vetch, 2015) established various physical parameters and constraints that were used in CDM Smith's options analysis and preliminary diffuser design.

1.3.1 Outfall and Diffuser System Location

The new outfall is to be located opposite the AIWWTP in the Fraser River. The general area is in the Annieville Channel of the main arm of the Fraser River lying south of Annacis Island and west of the Alex Fraser Bridge as shown on **Figure 1-1**. At this location, the Fraser River is a complex tidal estuary located approximately 20 km upstream from the mouth at the Georgia Strait. At the mouth at Georgia Strait, the river drains approximately 230,000 km^2 of British Columbia.

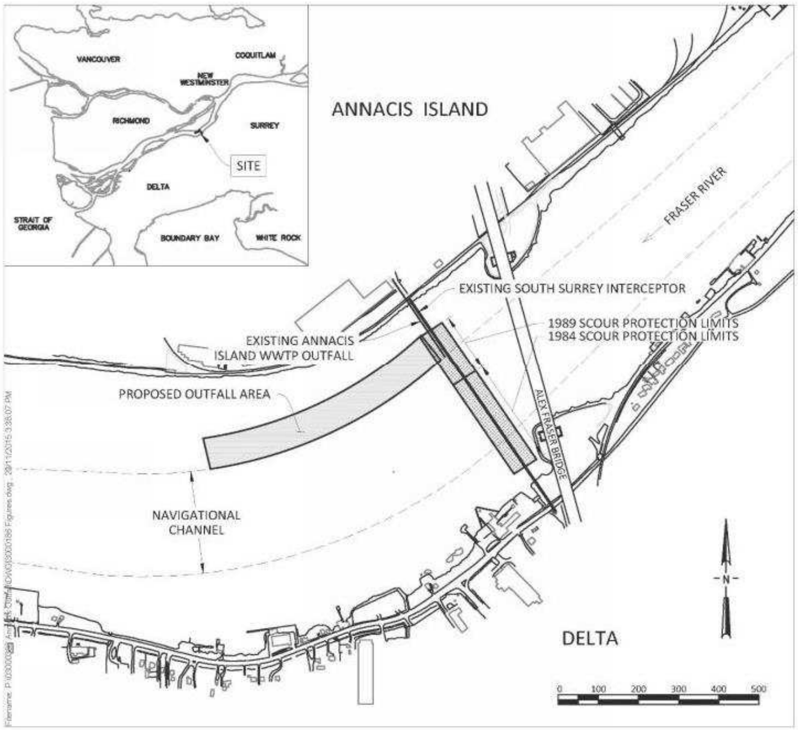

Figure 1-1. Site Map (NHC, 2015)

During the preliminary concept development, a decision was made to locate the diffuser system outside the Fraser River Navigation Channel to minimize dredging and shipping impacts. To maximize the diffuser depth and separation from the shoreline, the diffuser ports need to be located immediately adjacent to the edge of the shipping channel. Considering various possible routes for the effluent conveyance to the river, the general area where the outfall diffuser can be located is highlighted on **Figure 1-1.**

1.3.2 Elevations and Bathymetry

Hydraulic and riverbed elevations that control or constrain the outfall diffuser design were also established in the preliminary concept development as summarized in **Table 1-1**.

Table 1-1. Outfall Design Elevations

Item	Elevation GD + 100 (m)	Chart Datum	Description
Chlorine Contact Tanks	105.70	7.29	Maximum Stage VIII water surface elevation in CCTs[1]
Design River Stage w/ SLR	104.18	5.77	Design river level + 1.0 m for sea level rise
Design River Stage	103.18	4.77	Design river level, 200-yr peak winter flood level
High Water	102.00	3.59	High water datum at Alex Fraser Bridge
Geodetic Datum (GD)	100.00	1.59	CVD28GVRD Geodetic Datum
Chart Datum	98.41	0.00	Per Port of Vancouver, varies +/- 0.01 m across area
Dredging Grade	87.51	-10.90	Navigation channel dredging elevation +/- 0.01 m
Dredging Subgrade	85.56	-12.85	Maintenance dredging elevation +/- 0.16 m

[1] Record drawing CCT surface elevation of 106.01 m less historic and predicted settlement through 2067 of 0.31 m

For the Design River Stage, the available hydraulic head for effluent flow under gravity conditions is 2.52 m (105.70-103.18) assuming a freshwater ambient river condition. This available head is reduced by 0.11 m when a salt wedge is present during winter flow water levels.

A bathymetric survey was performed in 2013 as part of the preliminary concept development (Fugro, 2014) with contours shown on a GD + 100 m datum. Bathymetric surveys of the Fraser River are conducted on a regular basis by the Canadian Coast Guard (CCG) based on a Local Low Water Datum, which is used for navigation charts (Chart Datum). CCG surveys of the navigation channel typically extend to safety setback lines established by Port of Vancouver and occasionally closer to the shore. An image of the most recent (January 2016) bathymetric survey is shown in **Figure 1-2**. The Fugro 2013 elevation contours can be seen as light grey lines in the figure.

A fluvial geomorphology study for this area of the Fraser River was performed for this project by Northwest Hydraulics Consultants (NHC, 2016). This study indicates that the ship protection peninsulas built for the Alex Fraser Bridge and armor rock placed over the existing Annacis WWTP Outfall and South Surry Interceptor pipelines have created an area of sediment scour immediately downstream of these features. This scour prevents or minimizes the formation of sand waves, which develop during Freshet river flows, in the eastern portion of the study area. It is possible that existing, vertical diffuser discharge may also have an effect on sedimentation immediately downstream of the diffuser by adding to turbulence there; this effect is believed to be secondary. The sediment shadow effect is evident for several hundred metres downstream of the existing outfall. However, sand waves up to 1-m high have historically developed in this area. Further downstream sediment accumulates in the river bottom on the north side of the navigation channel. Port of Vancouver reports they have to dredge the inside of the river bend in this area every two years due to sediment accumulation of up to 2 m or more.

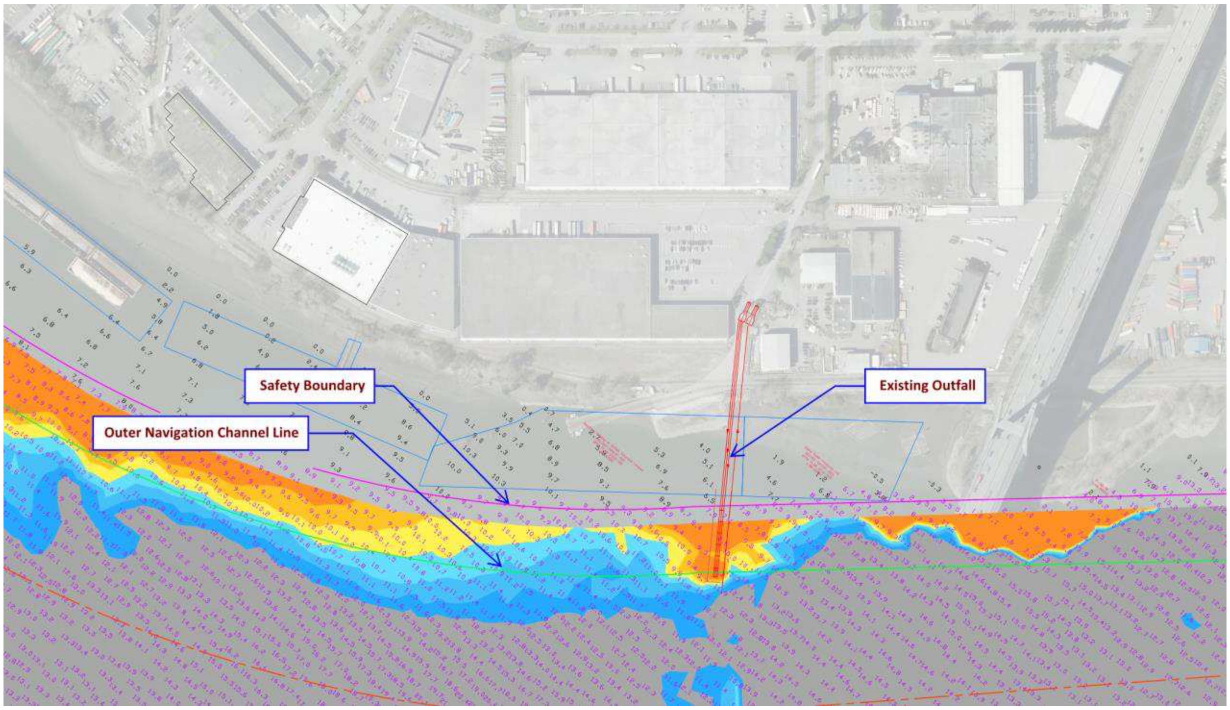

Figure 1-2. Project Study Area with January 2016 CCG Bathymetric Survey Chart

1. Magenta Line is Safety Boundary
2. Green Line is Edge of Dredged Navigation Channel
3. Contour shading is at 0.5 m intervals with blue greater that 10.5 m below Chart Datum

The colour shading on **Figure 1-2** highlights the fact that: (1) the river bottom elevation in January 2016 between the Outer Navigation Channel Line and the Safety Area (proposed outfall area) is shallower than the Dredging Grade except for a localized area west of the existing outfall and near the channel line and (2) dredging deeper than the Dredging Grade for the new diffuser would create a depression that would quickly fill with sediment.

1.3.3 Diffuser Layout

Preliminary concept development (Black and Veatch, 2015) suggested that two separate diffuser sections ("two outfalls") near the west and east limits of the proposed diffuser area might result in better overall dilution and diffusion of the effluent into the river. The validity of this concept was part of the dilution modeling studies carried out during the outfall system options analysis as described in this report (**Section 5.2**).

1.4 General Approach and Limitations

The general approach used for the preliminary diffuser design and initial dilution modeling presented in this report is as outlined below:

1. Identify regulatory requirements the project must meet that affect the design of the AIWWTP outfall/diffuser system (**Section 2**), which include:
   a. Municipal Wastewater Regulations (MWR) including those of dilution ratio, IDZ boundaries, municipal effluent quality requirements, and outfall design requirements, and
   b. Provincial water quality guidelines (WQGs) and site-specific water quality objectives (WQOs).
2. Review and analyze available data to support the analyses including Fraser River ambient conditions (flow, tide, current, temperature, salinity, and ambient background concentrations) and effluent data for the AIWWTP (**Sections 3 and 4**).
3. Develop a conceptual design for the diffuser system(s) that optimizes initial dilution for the Stage V flows using the available gravity hydraulic head at the Design River Stage (**Section 5**).
4. Define an approach to determine the concentration at the IDZ boundary including selecting of an initial dilution model, establishing input parameters for modeling and perform initial dilution simulations to determine dilutions used to assess regulatory endpoints (**Section 6**).
5. Present the initial dilution modeling results for both the optimized gravity flow design for Stage V flows and a pumped flow design for Stage VIII flows (**Section 7**).

This report does not address the following items. These are addressed in the Stage 1 EIS or will be addressed through subsequent analysis, including the Stage 2 EIS, after physical modeling is performed and the diffuser system design is completed.

- Dredging volumes, predicted sedimentation rates, and maintenance dredging and other diffuser inspection and maintenance requirements.
- Calculations of ambient (Fraser River) background concentrations for individual constituents is being completed as part of the Stage 1 EIS and are presented in that report.
- The back-calculation of allowable ammonia concentrations as defined in the Municipal Wastewater Regulations, which will be done concurrently with the diurnal ammonia analysis.

Section 2

Regulatory Requirements

2.1 Municipal Wastewater Regulations

2.1.1 Calculation of Dilution Ratio

According to the Municipal Wastewater Regulations, Part 1 (1) (2) (2): "The dilution ratio is calculated by dividing the 2-year return period 7-day low flow in the receiving stream by the maximum weekly (7-day) municipal effluent flow… "

Daily stream flow records are not available at the project site; however, long-term daily flow records since 1912 are available for the Fraser River at Hope (described further in **Section 3.4**). Hope is about 130 km upstream of the project study area adjacent to Annacis Island. Downstream inflows to the river between Hope and Annacis Island add to the total flow, even during low flow conditions at Hope (based on Northwest Hydraulic Consultants (NHC) Fraser River flow models). A conservative, initial estimate of outfall dilution ratio was calculated using the Hope flow data.

Using the entire record of flow at Hope (1912-2015), the 2-year return period 7-day low flow (7Q2) was calculated using the US Environmental Protection Agency (USEPA) DFLOW 3.11. DFLOW uses daily stream flow records and calculates hydrologically-based design flows. The calculation is based on a climatic year of April 1 through March 31 and yields a 7Q2 flow for the Fraser River of 652 m^3/s at Hope. The AIWWTP outfall will discharge into the Annieville Channel of the Fraser River, the main arm of the river downstream of the trifurcation above Annacis Island. Seventy-eight percent (78%) of the river flows through the Annieville Channel (NHC, 2008). Therefore, the 7Q2 flow in the Annieville Channel is 78% of 652 m^3/s, or 509 m^3/s.

Using the 2001-2014 AIWWTP record of average daily flow, a maximum weekly flow of 9.8 m^3/s was calculated by taking the maximum of the running averages of seven daily average flows. Therefore, the current minimum dilution ratio is 51.9 (509 m^3/s divided by 9.8 m^3/s). The actual dilution ratio would be somewhat higher due to inflows downstream of Hope. Future minimum dilution ratios were estimated by assuming the maximum weekly municipal effluent flow as a proportion of the peak wet weather flow (PWWF) remains consistent (at 78%) with future plant expansions. These minimum dilution ratios are shown in **Table 2-1**.

Table 2-1. Estimated Dilution Ratio

Expansion	PWWF (m^3/s)	Max. Weekly Flow Proportion	Max. Weekly Effluent Flow (m^3/s)	Min. 7Q2 River Flow at Annacis Is. (m^3/s)	Minimum Dilution Ratio
Stage IV	12.6	78%	9.8	508.6	51.9
Stage V	18.9	78%	14.7	508.6	34.6
Stage VI/VII	22.1	78%	17.2	508.6	29.6
Stage VIII	25.3	78%	19.7	508.6	25.8

---

[1] http://www.epa.gov/waterdata/dflow

Part 6 (1)(94) (4) indicates that a director may approve the use of secondary treatment if there is a minimum dilution ratio of 20:1 and Part 6 (1)(94) (5) prohibits discharge if the dilution ratio is less than 10:1. The AIWWTP effluent discharge into the Fraser River meets these criteria for all projected future flows.

2.1.2 Initial Dilution Zone (IDZ)

The Municipal Wastewater Regulations at Part 6 (1) (91) (1) define the IDZ as:

- The 3-dimensional zone around the point of discharge where mixing of the municipal effluent and the receiving waters occurs.

Water quality guidelines must be met at the edge of the IDZ. For guidelines that protect from the potential for short-term toxicity impacts, the objectives must be met at all times. For those that protect from the potential for long-term average impacts, the guidelines must be met at monthly average conditions.

In addition, the edge of the IDZ must be at least 300 m away from recreational areas, shellfish harvesting areas, domestic or agricultural water intakes, or other sensitive areas requiring protection. None of these areas are located within 300 m of the project study area as defined in **Section 1.3**.

The key clauses relating to the spatial extent of the IDZ are found in Section 93(1): "For the purpose of calculating the initial dilution zone for a stream, river or estuary, all of the following, measured from the point of discharge and from mean low water, apply:

(a) the height is the distance from the bed to the water surface;
(b) the width, perpendicular to the path of the stream, is the lesser of
  (i) 100 m, and
  (ii) 25% of the width of the stream or estuary;
(c) the length, parallel to the path of the stream, is the distance between a point 100 m upstream and a point that is the lesser of
  (i) 100 m downstream, and
  (ii) a distance downstream at which the width of the municipal effluent plume equals the width determined under paragraph (b)."

The regulations also state the initial dilution zone must not extend closer to shore than mean low water. Following these regulations, a conceptual IDZ for a multiport diffuser at the project site is shown **Figure 2-1**. Therefore, for the purpose of these analyses, the target initial dilution will be determined at the edge of an IDZ located 100 m in all directions from any edge of the diffuser, since 100 m is less than 25% of the river width at this location (147.5 m).

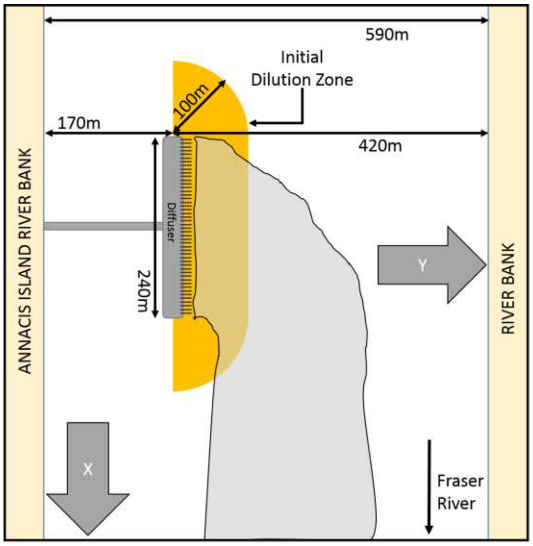

Figure 2-1. Conceptual Initial Dilution Zone

2.1.3 Municipal Effluent Quality Requirements

Part 6 (1) Sections 94-97 defines the municipal effluent quality requirements. Those relevant to the AIWWTP discharge include:

- Section 94 defines end-of-pipe limits for the following parameters: biochemical oxygen demand (BOD_5), total suspended solids (TSS), pH, total phosphorus and orthophosphate, and Section 96 defines edge-of-the-IDZ limits on coliform bacteria. These limits are evaluated in the main report of the Stage 1 EIS.

- Section 95 requirements are in effect if the maximum daily effluent flow is greater than 50 m^3/day, which is the case for the AIWWTP discharge. Subsection 6 requires analysis related to the design of the diffuser, and states:

  "A discharger must determine the maximum allowable municipal effluent ammonia concentration at the "end of pipe" by a back calculation, from the edge of the initial dilution zone that considers:

  (a) the ambient temperature and pH characteristics of the receiving water, and
  (b) water quality guidelines for chronic ammonia."

2.1.4 Outfall Design and Minimum Depth Requirement

Sections 99 and 100 include requirements that define important design considerations for any outfall/diffuser system. These include that the outfall/diffuser system must meet initial dilution requirements; prevent air entrapment; is adequately weighted to prevent movement; is protected from corrosion, wave, boat and marine activity; is located at sufficient depth to maximize the frequency of trapping the plume; intercept the predominant current and avoid currents that move the plume to the shoreline; and is designed to achieve maximum dilution where most of the water flows in the water body.

Additional requirements specific to siting an individual outfall/diffuser system include:

- 99(2)(c)(i) and (ii): "Each diffuser section will provide at least a 10:1 dilution with the IDZ" and "Outside the IDZ the discharge does not cause water quality parameters to fail to meet water quality guidelines."

- 99(3)(b)(ii): "A qualified professional must ensure that outfalls are located at a depth of at least 10m below mean low water in estuaries."

- 100(1) and 100(2), which confirm that the minimum 10m depth below mean low water level applies to the shallowest diffuser port.

- 89(2)(a) "'mean low water' means, for marine waters, the datum provided on the most recently published marine chart published by the Canadian Hydrographic Service for the location."

2.2 Water Quality Guidelines and Objectives

The Municipal Wastewater Regulations stipulate that the discharger must not discharge municipal effluent unless, at the edge of the IDZ, applicable WQGs are met. For this project, Fraser River WQOs also need to be met at the edge of the IDZ. The Stage 1 EIS screens against applicable guidelines (listed below) from all relevant jurisdictions.

- Fraser River WQOs;
- Approved BC WQGs;
- Working BC WQGs;
- Canadian Council of Ministers of the Environment (CCME) WQGs or Health Canada Guidelines; and[2]
- Relevant guidelines from other jurisdictions such as the USEPA Water Quality Criteria.[3]

Most of the comparisons to WQGs and WQOs are performed in the main report of the Stage 1 EIS. The calculations for comparison to the interim guideline for temperature (to protect aquatic life that limits changes in the river to a +/- 1°C temperature variation at any time, location or depth in marine and estuarine waters) is included in **Section 7.6**.2

2.3 Port of Vancouver Requirements

Discussions with Dave Hart, Dredging Specialist, Operations for Port of Vancouver, indicated they would have the following conditions for placing the diffuser in the Fraser River at the project study area:

- A diffuser could be placed between the boundary of the navigation channel and the safety setback lines.
- A diffuser in the above area should not have any infrastructure extend above 6 m water depth at MLW (Chart Datum).

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[2] https://www.ec.gc.ca/ese-ees/default.asp?lang=En&n=05DF7A37-1 accessed November 4 2015

[3] http://water.epa.gov/scitech/swguidance/standards/criteria/current/index.cfm#altable accessed November 4, 2015

2.4 Summary of Regulatory Requirements

The following is a summary of the regulatory requirements and their application to the proposed outfall/diffuser system design for the AIWWTP discharge.

- A dilution ratio greater than 20:1 determined from the 7Q2 flow and maximum weekly effluent flow is met for the current effluent discharge and all anticipated future effluent flow rates.
- The project study area can accommodate a diffuser location and its IDZ does not overlap with the shoreline.
- The diffuser should be located at a depth of at least 10 m (measured at the shallowest port), and achieve a minimum dilution of 10:1 with the IDZ.
- The discharge from the diffuser should not cause water quality parameters outside the IDZ to fail to meet water quality guidelines or objectives.

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Section 3

Fraser River Data

3.1 Available Monitoring Data

Data from several monitoring stations along the Fraser River inform this study. **Table 3-1** describes the data used to understand ambient conditions in the Fraser River and as input data for initial dilution modeling. The stations are shown on **Figure 3-1**.

Table 3-1. Monitoring Data Considered in this Study

Station	Data Available	Data Frequency	Coverage	Approximate River km from Mouth
Fraser River Water Quality Buoy at Gravesend Reach	Temperature, pH, conductivity, current speed, water quality	Continuous Hourly	4/2008 – 2014	13.1
		Grab Samples	9/2001 – 12/2015	
AIWWTP	Flow and water quality	Described in Section 4		20.1
AIWWTP Receiving Environmental Monitoring (REM)at the IDZ	Effluent and river water quality	Grab Samples for Winter and Summer Season	2011-2014	20.1
Fraser River at New Westminster	Tide Elevation	Hourly	1970 – 2014	26
Upstream Reference Station for AIWWTP REM Monitoring	Water quality	Grab Samples for Winter and Summer Season	2011-2014	26.3
Fraser River at Hope	Flow, water quality	Daily	1912 – 2015	151

The remainder of this section presents a summary of the data that were considered. The data are used in two ways: (1) input data for initial dilution modeling and (2) to characterize the parameters measured in treated effluent (**Section 4.0**) and the Fraser River to predict concentrations at the edge of the IDZ.

The initial dilution model requires input data on the effluent, ambient river conditions and the diffuser configuration:

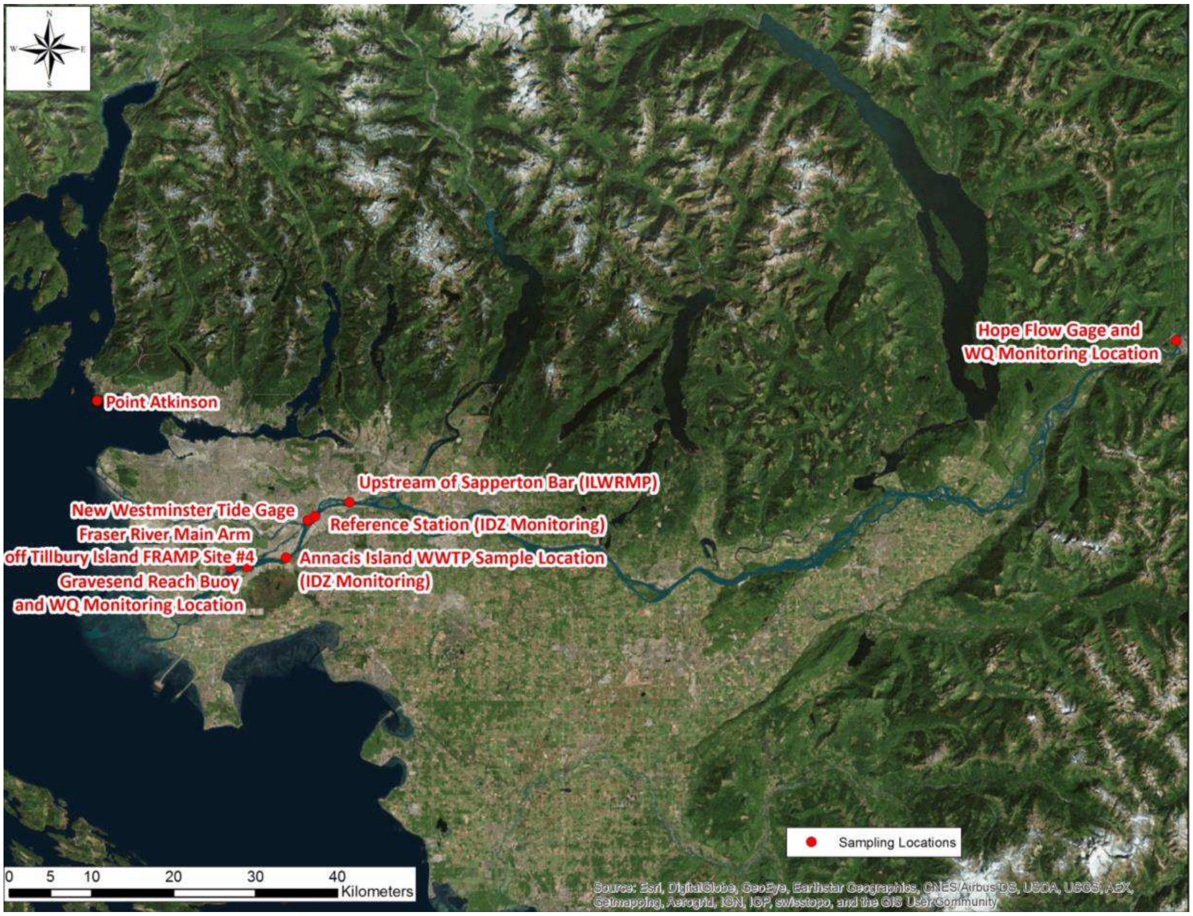
- Effluent – flow and density (temperature)
- Fraser River – water depth, current speed, and vertical density structure (temperature and salinity)
- Diffuser – length and orientation of manifold; and number, diameter, orientation and spacing of ports

Section 6.3 describes how the data are used to develop input parameters for the initial dilution model. **Section 5.0** describes the development of conceptual diffuser designs.

Water quality data used to calculate the concentration at the edge of the IDZ are:

- Ambient background concentrations –the REM monitoring's reference area station, supplemented with data collected at the water quality buoy at Gravesend Reach and FRAMP Tilbury Island data (see Stage 1 EIS for calculations).

- Effluent – 2011-2014 effluent dat9



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 3-1. Locations of Monitoring Stations along the Fraser River

3.2 Gravesend Reach Data

3.2.1 Temperature

Ambient river temperature in the Fraser River varies seasonally. **Figure 3-2** depicts temperature at the Gravesend Reach water quality buoy about 7 km downstream of Annacis Island. The readings at the buoy are taken at 1 m below the surface, and thus, do not provide a representation of vertical variation in the water column, which is an important input parameter for initial dilution modeling. These data are used in **Section 6** to develop average temperatures for three river flow conditions as input to the initial dilution.

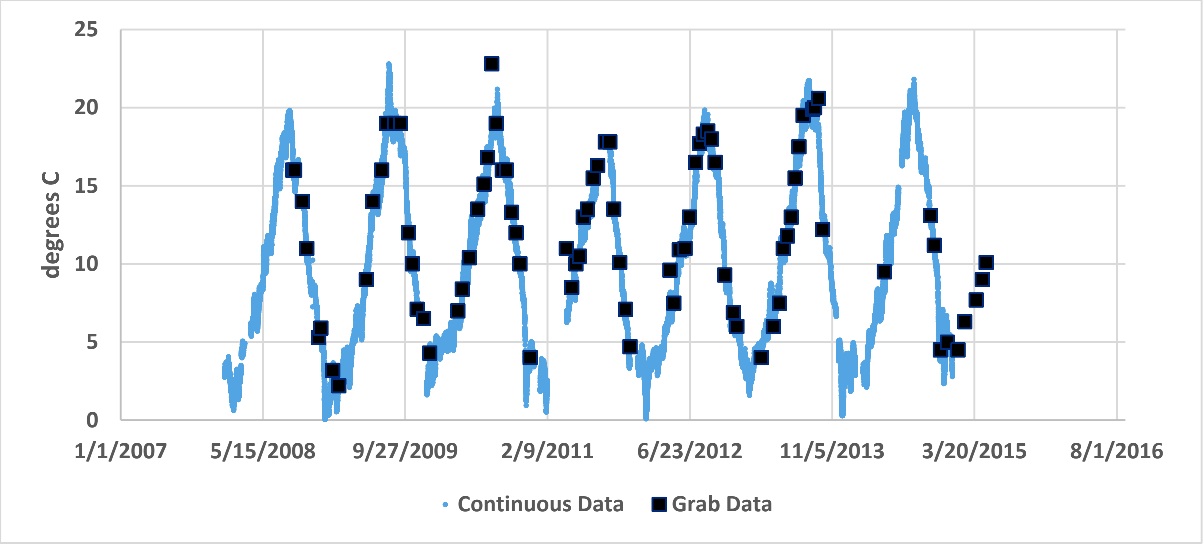


Figure 3-2. Time Series of Water Temperature (2008-2015) at Gravesend Reach Buoy (BC08MH0453) in the Main Arm of the Fraser River

3.2.2 pH

The Gravesend Reach water quality buoy also measures pH at 1 m below the water surface. **Figure 3-3** is a time series graph of the available grab data for 2010. The buoy record does not contain a continuous observation of pH, and the data quality appears questionable (it is unclear if QA review was completed). While the data is between 7 and 8.5, consistent with expectations for potential ranges in seawater, unexplained linear shifts in observations occur, as well as spurious data points (those well out of expected bounds were removed from this graph). Other sources of pH data will be sought prior to completing diurnal dilution calculations for ammonia.

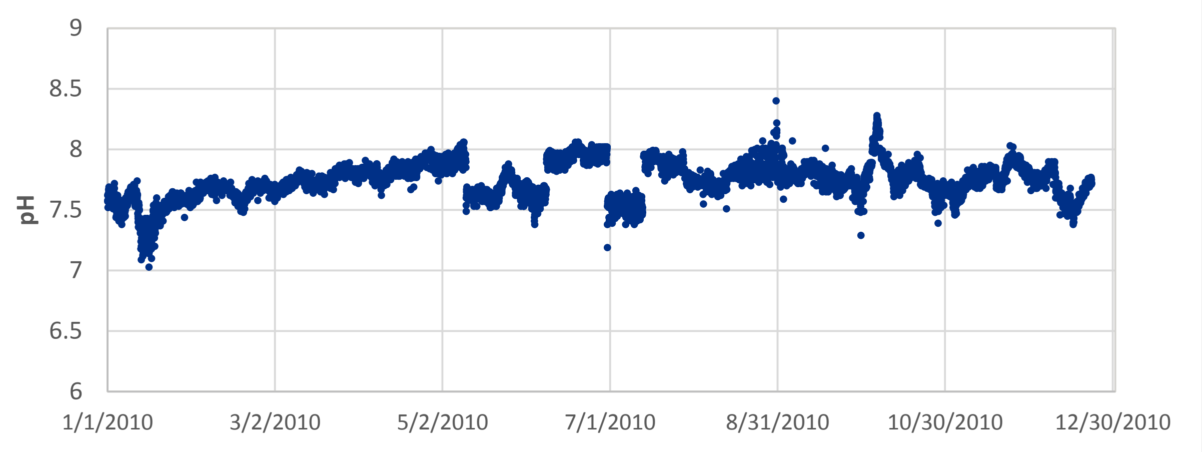


Figure 3-3. Time Series of pH Measurements at the Fraser River (Main Arm) at Gravesend Reach Buoy

3.2.3 Conductivity / Salinity

Conductivity is measured at the Gravesend Reach buoy at a depth of 1 m. Conductivity and temperature were converted to salinity using a Microsoft Excel based spreadsheet[4]. When present, the average salinity was 5 psu with maximum observations of 18 psu. These data, along with other observations of salinity, are used in **Section 3.7** to develop a conceptual understanding of the occurrence of salinity near Annacis Island.

Observations at the buoy indicate that salinity (>1 psu) can be present at this location when river flows are less than 1,000 m^3/s, and occurs in both flood and ebb tidal cycles. **Figure 3-4** is a time series plot comparing conductivity against water surface elevation showing the transient nature of the salt front. Included on the figure is the river flow as measured at Hope. **Figure 3-4** is indicative of the complex nature of this estuary. The semidiurnal mixed tide carries the salt water up the Fraser River when the river is in low flow conditions, but the salt wedge does not completely leave the system on the ebbing tide as indicated in **Figure 3-5**. Some residual salt is present in the Fraser River under more conditions other than just flood tide.

While conductivity can be observed at Gravesend Reach, it is not accurate to directly apply it as representative of the conditions at Annacis Island. Water density is influenced by salinity levels such that more saline water is denser than freshwater. This results in salt water moving up the Fraser River along the bottom, while freshwater from the entire drainage basin travels at the surface; so the observations of salinity of 18 psu at a depth of 1 m is quite unusual.

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[4] http://nest.su.se/mnode/Methods/spreadsheets/cond to sal converter.xls

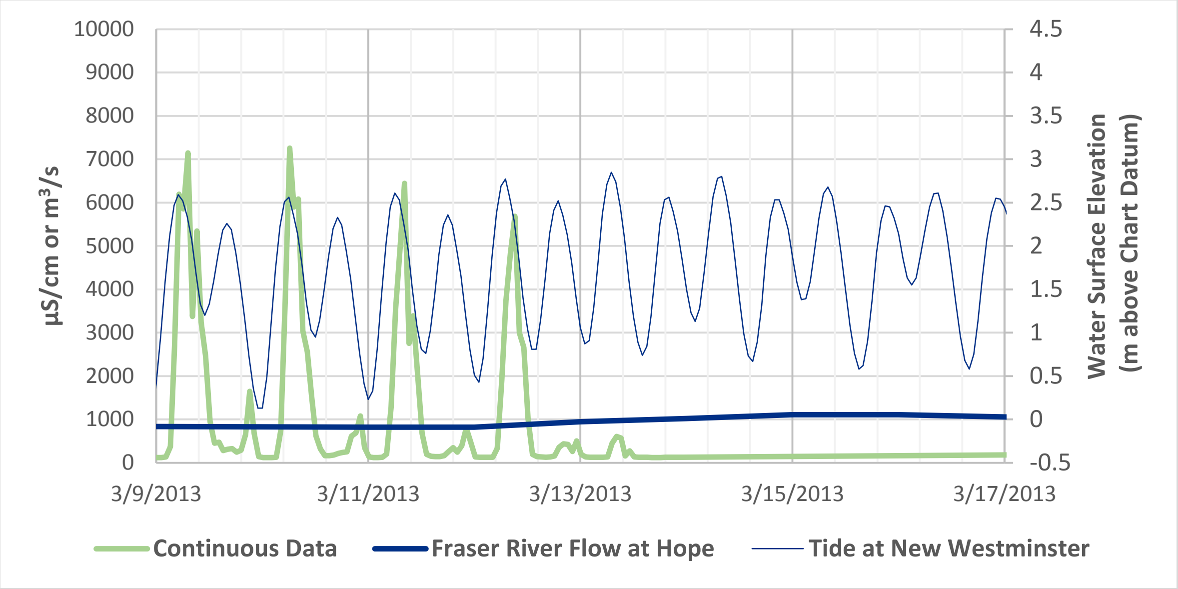

Figure 3-4. Time Series of Conductivity at Gravesend Reach, Water Surface Elevation at New Westminster, and Fraser River Flow at Hope Indicating Transient Nature of Salt in the Fraser River and the Dependence of Fraser River Flow on the Presence of Salt

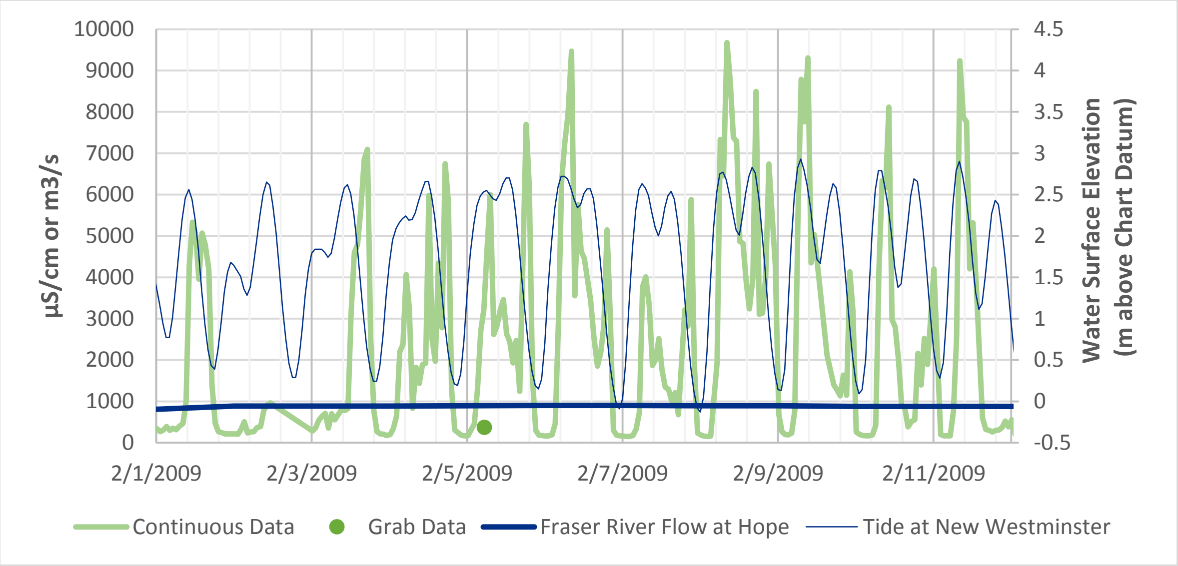

Figure 3-5. Time Series of Conductivity at Gravesend Reach, Water Surface Elevation at New Westminster, and Fraser River Flow at Hope Indicating Residual Salinity on Ebb Tides

3.2.4 Fraser River Currents

River currents on the Fraser River are measured at the Gravesend Reach buoy. Current speed and current direction are also measured at 1-m below the water surface. The hourly data record used for this project begins in April 2008 and ends in mid-December 2014 with some periods of missing data. Although the buoy is located some distance downstream of AIWWTP, the measurement conditions along the banks of the Fraser River provide a reasonable analog to a similar behavior near the proposed outfall/diffuser system. Thus, the Gravesend Reach current data is used to develop inputs for the initial dilution model (**Section 6.3**).

From the buoy data, the Fraser River appears to exhibit a tidal current reversal during periods of lower discharge when the direction of measured current is typically bidirectional (**Figure 3-6**, left panel with current direction [top] and current speed [bottom]; current direction >180° is flow discharging to the mouth of the river; current direction <180° is upstream flow). During higher flows in the freshet period, flow in the Fraser River is primarily unidirectional (**Figure 3-6**, right panel). The period of time of unidirectional vs. bidirectional flow varies from year to year and is a function of freshwater flow and tides in the Fraser River; as a general guide, unidirectional flow occurs when river flow at Hope exceeds 6,000 m^3/s. When bidirectional flow occurs, the upstream flow period is typically 5-6 hours in a day, and thus is often only associated with the highest high tide of the day. Some days, however, experience two periods of reversing tide.

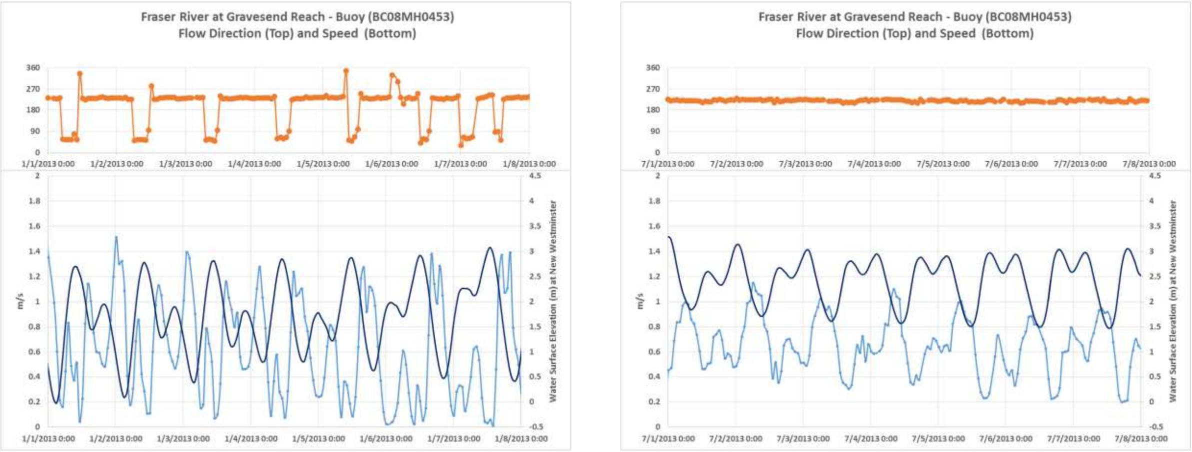

Figure 3-6. Current Speed and Direction for Low (left panel) and High (right panel) Periods of River Discharge

3.2.5 Ambient Background Water Quality Data

Additional water quality data is measured at the Gravesend Reach buoy, which include nutrients, major ions and metals. These data are used to supplement water quality data from the reference station of the REM monitoring program to define ambient background levels in the river as the measurements could be influenced by the discharge from the AIWWTP. Interestingly, observational comparison of the ambient background levels at this location and the reference sampling site used by Metro Vancouver during the IDZ monitoring indicate concentrations are quite similar at the two sites, suggesting the signature of the AIWWTP is not seen at the Gravesend Buoy. As the samples are not contemporaneous, a more rigorous statistical analysis was not performed.

3.3 Fraser River Water Surface Elevation at New Westminster

Canadian Hydrographic Service, Department of Fisheries and Oceans maintains a record of tidal water surface elevations at New Westminster (#7654)[5]. Hourly observations are available from 1970-2014, with the reported water surface elevation as height in m above the chart datum. **Figure 3-7** presents the tide observation at New Westminster for the 2012 calendar year. The tide signal exhibits a mixed semidiurnal tide with two high tides and two low tides occurring each day, but the twice daily high and low tides have different and irregular amplitudes. The year cycle also indicates the influence of the river flows on the tidal signal. During the freshet and high flow summer months, the low tide observations are almost 2 m higher than during low flow periods. Daily water surface excursions during low flow conditions are generally 2.5-3.5 m, yet during high flows, these daily excursions can be reduced to approximately 1 m. The complexity of the semidiurnal mixed tide and large seasonal variation in Fraser River flows results in a very complex hydrodynamic situation at the project site.

Along with the observations of water surface elevation, the Department of Fisheries and Oceans provides a table that compares the water surface elevation at Point Atkinson against water surface elevations at Stevenson, Deas Island, and New Westminster based on the discharge at Hope. These data for Point Atkinson and New Westminster are presented in **Table 3-2**.

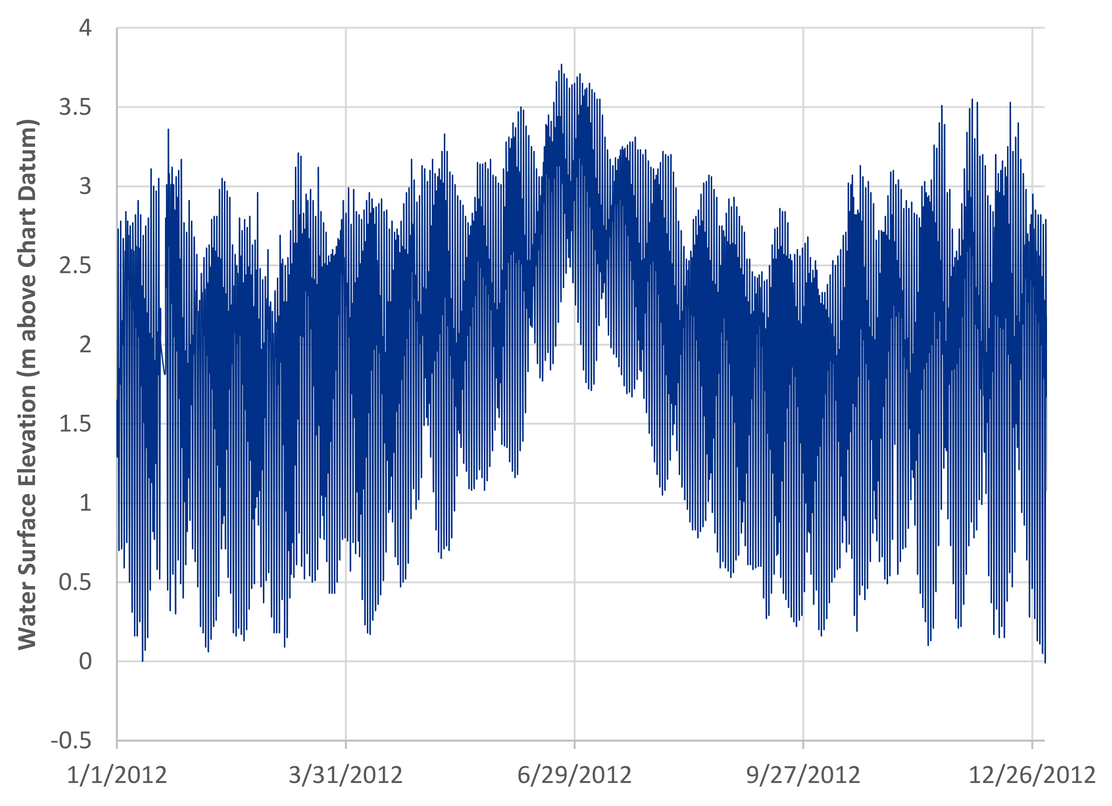

Figure 3-7. Time Series of Water Surface Elevation at New Westminster for Calendar Year 2012

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[5] http://www.waterlevels.gc.ca/eng/station?type=1&date=2016%2F02%2F05&sid=7654&tz=PST&pres=0

Table 3-2. Water Surface Elevation at Point Atkinson and New Westminster based on the Discharge at Hope

Point Atkinson [m]	New Westminster [m]			
	700 m^3/s	2,800 m^3/s	5,700 m^3/s	8,500 m^3/s
5.0	3.2	3.4	3.5	3.5
4.5	2.7	3.0	3.1	3.2
4.0	2.4	2.6	2.8	3.0
3.5	1.9	2.2	2.4	2.7
3.0	1.6	1.8	2.1	2.5
2.5	1.2	1.5	1.8	2.3
2.0	0.8	1.1	1.5	2.1
1.5	0.4	0.7	1.3	1.9
1.0	0.2	0.4	1.1	1.8
0.5	0.0	0.2	1.0	1.7
0.0	-0.1	0.1	0.9	1.6

3.4 Monitoring of the Fraser River Upstream of Sapperton Bar

As part of the Integrated Liquid Waste Management and Resource Management Plan (ILWRMP), Metro Vancouver has an ambient monitoring program "in areas where water quality (as indicated by water quality objective criteria) is potentially affected by wastewater and/or stormwater" (e.g., ENKON, 2014). The water quality monitoring program repeats on a 5-year cycle with water quality monitored in every year, while sediment sampling and of fish tissue/fish health survey are conducted in one year of the cycle. The water quality monitoring program has been in place since 2003; the most current cycle began with monitoring in 2013. Seven sites are monitored as part of the ILWRMP. Sampling is designed to collect during periods of low flows in the Fraser River with 5 surveys conducted at one week intervals for compliance with average water quality objectives (5 samples within a 30-day period).

For the purpose of understanding ambient background concentrations, this project considered data from Site 3 – Upstream of Sapperton Bar. This location about 6.2 km upriver of the AIWWTP discharge. The water quality monitoring includes laboratory testing for bacteriological parameters, nutrients, ions, physical parameters, dissolved oxygen, total and dissolved metals, total and reactive silica, and nonylphenol + octylphenol and nonylphenol ethoxylates. Field measurements consist of pH, conductivity, dissolved oxygen, temperature, salinity, and turbidity.

The Sapperton Bar data is not used to characterize the ambient background as there is sufficient low flow data at the reference area location from the REM program. The pH data, however, will be reviewed as part of the ammonia analysis to determine its usefulness in augmenting the pH data at the Gravesend Reach buoy.

3.5 Monitoring of the Fraser River at Hope

3.5.1 Fraser River Flow

Discharge in the Fraser River varies considerably from year to year and from season to season. Snow-melt, which contributes approximately two-thirds of the total runoff, begins in April and increases to a maximum in late May and early June. By late August, the flows have diminished, and the lowest flows of the year generally occur in winter (January-February).

Measured upstream of Annacis Island at Hope, BC, the flow record starts in 1912 and thus extends more than 100 years. The minimum daily flow of 340 m^3/s on record was documented on January 8, 1916. More recently, a minimum daily discharge of 470 m^3/s occurred on December 17, 2000. The average daily discharge over the entire data record is approximately 2,700 m^3/s. The maximum recorded daily discharge was 15, 200 m^3/s on May 31, 1948.

Hope is about 130 km upstream of the AIWWTP outfall adjacent to Annacis Island. As discussed in **Section 2.1.1**, downstream inflows to the river between Hope and Annacis Island can add to the total flow, even during low flow conditions at Hope, based on NHC Fraser River flow models. However, flow data at Hope was considered representative of the Fraser River flows at Annacis Island for the purposes of characterizing when the river current is high enough to overcome tidal currents.

The flow data at Hope was combined with current data at Gravesend Reach to elucidate the relationship of flow and current at the project site. **Figure 3-8** depicts time histories of two representative years (2009 and 2013) where complete, contemporaneous current direction and flow data exist. Note that current data from the buoy were filtered and limited to 2 m/s based on what appears to be meter drift or periods of instrument maintenance.

This figure shows that when the Fraser River flow at Hope is greater than 6,000 m^3/s, the current is predominately unidirectional. When flow is less than 6,000 m^3/s, the current is bidirectional. The direction of the current during the tide cycle determines whether a local buildup effluent occurs (called background buildup) that will reduce instantaneous dilution predicted by the initial dilution model. The 6,000 m^3/s value becomes a threshold, and is used in **Section 6.0** to establish one of the flow classifications for the complex estuary.

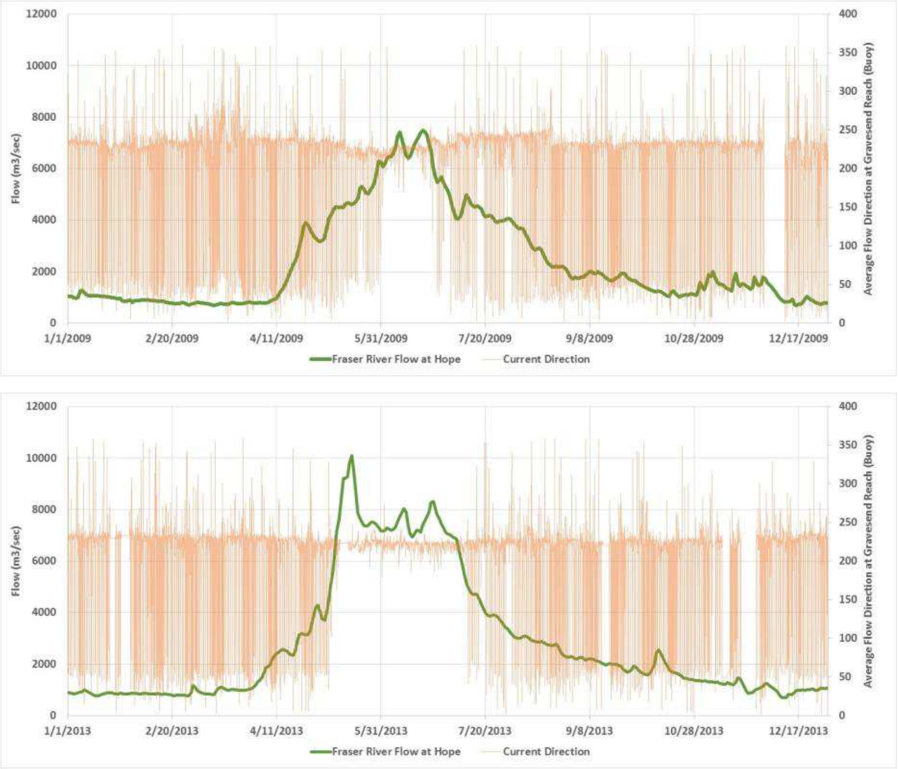

Figure 3-8. 2009 and 2013 Time Histories of Fraser River Flow at Hope and Current Direction at Gravesend Reach Buoy

3.5.2 Fraser River Water Quality Data at Hope

Water quality samples are collected at the Federal-Provincial monitoring station at Hope, located about 130 km upstream of Annacis Island; the data record begins in July 1979. Hope is the farthest downstream of five long-term monitoring stations on the Fraser River. Samples are collected twice monthly and analyzed for physical parameters, major ions, nutrients (nitrogen and phosphorus), dissolved, extractable and total metals.

The water quality data at Hope were not used as part of this project. They were reviewed for use in establishing ambient background concentrations, but were found to vary significantly for some parameters when compared to MV monitoring data upstream of the project site.

3.6 MV Receiving Environment Monitoring Program

Metro Vancouver conducts a (REM) program to assess the potential for impacts from the AIWWTP on the receiving environment. Water column monitoring has been conducted at the IDZ boundary annually since 2003. For this project, we have considered the data collected from 2011 to 2014 (Smith, A., 2013a 2013b, 2015; data from the 2014 monitoring program were provided digitally by Metro Vancouver).

Since 2011, Metro Vancouver has collected data twice a year to assess compliance of the discharge of the AIWWTP with site-specific WQOs and provincial WQGs. Winter sampling occurs during low flow in February-March, while summer sampling targets summer low flow conditions in September. For each sampling period, five surveys are conducted at one-week intervals to determine compliance with 30-day water quality objectives; when needed a sixth survey is added. Sampling dates and times are selected for each sampling period to reflect specific tide conditions at the IDZ boundary. Each week, samples are collected from within the effluent plume at the edge of the IDZ boundary and at the reference area located above the New Westminster trifurcation. The location of the plume is determined in the field using an onboard colour video sounder. **Figure 3-9** (left) shows the extent of the IDZ boundary and the sampling sites for slack tide on September 26, 2011. The locations of the reference area stations are shown in **Figure 3-9** (right).

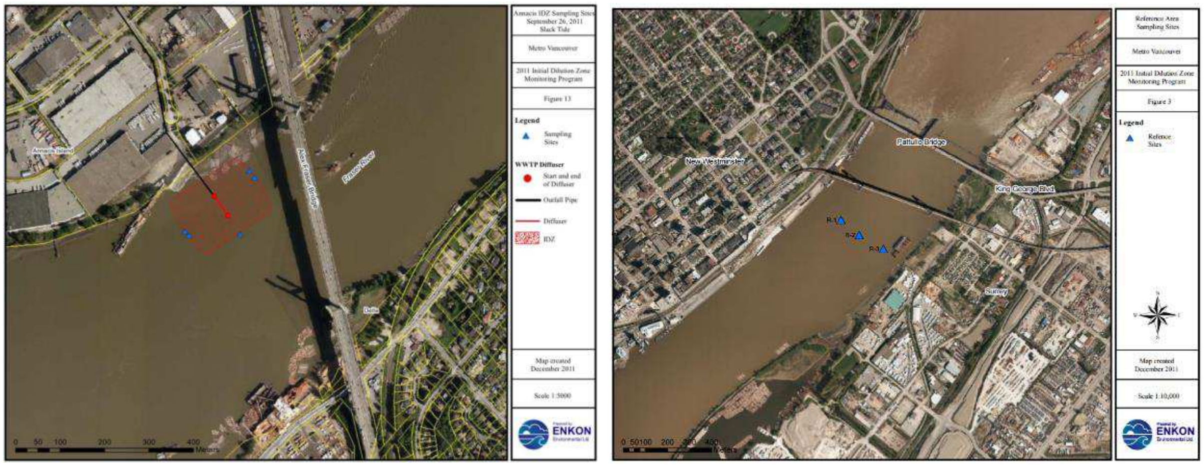

Figure 3-9. IDZ Monitoring Locations for Sampling Conducted in September 2011 (left panel) and Reference Area Stations (right panel)

In March 2013, a special sampling event was conducted to analyze variation in dilution with tidal cycle. High frequency samples were collected over a day at the IDZ boundary and of plant effluent and were analyzed for fecal coliform bacteria, *E. coli*, enterococci and ammonia.

Field measurements are taken for pH, temperature, dissolved oxygen, conductivity, and salinity. Grab samples are sent to the laboratory for bacteriological analyses (fecal coliform bacteria and enterococci) as well as pH, conductivity, total ammonia, nitrate, nitrite, and total phosphorus. If a sample is confirmed to have been collected from the effluent plume (by having elevated the fecal coliform bacteria counts or elevated ammonia levels, if the effluent is disinfected), the sample is further analyzed for chloride, total Kjeldahl nitrogen (TKN), total and dissolved organic carbon (TOC and DOC), total suspended solids (TSS), volatile suspended solids (VSS) and low-level total and/or dissolved metals by ICP-MS (NB: additional parameters vary by year). Additional organic parameters have been analyzed at a subset of both IDZ and reference sampling stations; not all parameters are analyzed for each sampling period with more samples from the winter period being analyzed for these organics: alkylphenols, 4-nonylphenols, nonylphenol, mono- and diethoxylates, octylphenol, polycyclic aromatic hydrocarbons (PAHs), pyrethoid pesticides, polychlorinated biphenyls (PCBs), and polybrominated diphenyl ethers (PBDEs), and/or selected hormones and sterols.

The Stage 1 EIS describes the approach used to develop ambient background water quality data for use in the predictions of concentrations at the edge of the IDZ, and includes a statistical summary of the ambient water quality monitoring data.

3.7 Additional Data on Occurrence of Salinity

The presence of salinity at the project site and its distribution with depth will have a significant influence on the predicted initial dilution from a submerged diffuser. Typically, ambient temperature and salinity observations are used to develop density profiles as an input to the initial dilution modeling. Density profiles are of critical importance to the initial dilution calculations because the amount of salinity influences the buoyancy flux impacting dilution, and the shape of the density profile will influence how high the effluent plume will rise before it is trapped. While salinity can increase dilution through buoyancy flux, a trapped effluent plume can lower dilution by limiting the volume of water that can be entrained.

Limited data on conductivity/salinity, however, exist at the project site, and the available data are insufficient to derive a comprehensive understanding of the occurrence, magnitude and variation with depth of salinity. This section uses the available data to develop a conceptual understanding of salinity that is then used as input to the initial dilution modeling.

3.7.1 Previous Studies with Salinity Data

This dilution analysis is informed by observations presented in Ages and Woolard (1976) with respect to the presence of the salt water wedge in the area of Annacis Island. They report that during periods of low flow in the Fraser River (typically during the winter), the salt wedge associated with the flood tide has been recorded to reach Annacis Island and in close proximity to the project site as shown in **Figure 3-10**[6]. Ages and Woolard performed their study during a period of low flow, when flow in the Fraser River was approximately 850 m^3/s.

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[6] This salinity intrusion study was completed before the increase in dredging operations near the project site in the early 1980s. A deeper, dredged channel may allow for the salt wedge to penetrate further upstream.

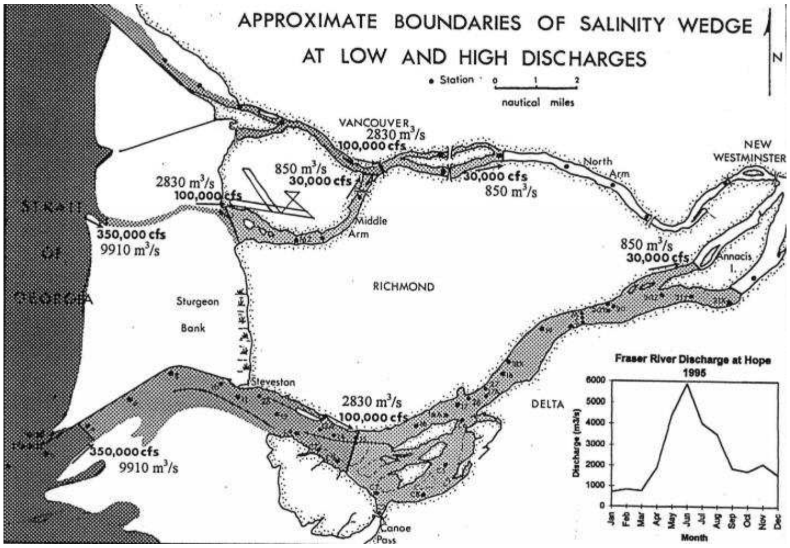

Figure 3-10. Approximate Boundaries of Salinity Wedge at Low and High Tide (Ages and Woolard, 1976)

Vertical profiles of temperature and salinity are presented in the ***Annacis Island Wastewater Treatment Plant Pre-Discharge Monitoring Dilution/Dispersion Study*** (LWMP Environmental Monitoring and Assessments Technical Committee, 1997). During a detailed field survey in November 1995, the Fraser River flow was sufficiently high such that the salt wedge was held below the AIWWTP.

Profiles of temperature and salinity were also measured through the flood cycle on February 13 and 14, 1996 when the Fraser River flow at Hope on those two days were 865 and 922 m^3/s, respectively [NB: the location of the profiles are not recorded, but are assumed to be in the navigation channel near Annacis Island). **Figure 3-11** presents the temperature and salinity profiles from the beginning of the salt water intrusion (top) and at the fullest intrusion (bottom). The vertical profiles indicate that the water column is stratified with a surface layer of freshwater extending down 4 to 6 m, and then a linearly increasing salinity level extending below the freshwater 'lens' with maximum observed salinities of 6 to 12 psu at the bottom.

Figure 3-12 presents salinity data measured at the IDZ boundary from Metro Vancouver's REM program from 2007 to 2014. Sampling occurs during low flow periods in February-March and August-September. Measurements are summarized in yearly IDZ monitoring reports (e.g., Smith, 2013a). As the measurement program consists of a grab sample at depth and is designed to capture the effluent plume, the samples do not represent ambient river conditions. Therefore, we can only use these data to determine whether salinity was present at Annacis Island and at what concentration. The grab samples were collected from depths ranging from 10 m to nearly 20 m below the water surface, depending on the location along the IDZ boundary and the sampling time period (winter vs. summer, ebb vs. slack vs. flood). Nearly 80% of the recorded measurements report less than 1 psu of salt in the water column during either of the summer or winter sampling periods with a maximum concentration of 6.41psu (**Figure 3-12**). When salt was measured at levels greater than 1 psu, the river flows were less than 1,000 m^3/s.

Metro Vancouver also collected vertical profiles of temperature and salinity just downstream of the IDZ near the western boundary of the project's study area during the 2015 summer low flow REM program. These profiles did not indicate the presence of saline water. The river flow as measured at Hope was above 1,000 m^3/s.

The study of Ages and Woolard (1978) indicates that salt water intrusion can occur as far up the Fraser River as Annacis Island and potentially influence dilution. The periodic presence of salt at the AIWWTP is further supported by both the LWMP (1997) dilution/dispersion study and data collected for the IDZ monitoring reports. The data from the IDZ monitoring program provide specifics as to the level of salinity near AIWWTP but are not representative of ambient conditions, and lack the vertical profile information necessary to define input for dilution modeling. The LWMP study contains vertical profiles that indicate freshwater to a depth of 6 m followed by a salty layer of increasing salinity with depth to the riverbed. This information, along with the continuous record of salinity at the Gravesend Reach buoy, is used as the basis for an assumed vertical profile of salinity as an input parameter to the initial dilution modeling.

3.7.2 Monitoring for Stratification: March-April 2016

Because the vertical density structure in the river is an important input parameter to the near-field dilution analysis, additional conductivity, temperature, and depth data was collected during March-April, 2016 (**Figure 3-13**) (Golder Associates, 2016). Two data collection efforts occurred:

- Continuous monitoring of temperature and salinity from March 9-April 13, 2016 at a location near the north shore of the study area; two meters were deployed but only the bottom meter, located just above the river bottom at water depths ranging from about 3 to 5 m provided usable data, and

- Water column profiling using acoustic backscatter at select tidal conditions during March 22-23, 2016.

The goals of the program were to obtain temperature and salinity information at low flow to support the hypothesis that salinity only occurs at low river flow and obtain additional information on the vertical density differences. Data from the bottom-moored meter are presented in **Figure 3-13.** During the deployment, average flow in the Fraser River at Hope during this time was 1,450 m^3/s, which is above the low flow of 1,000 m^3/s where the salt wedge has the potential to reach Annacis Island. The results show several instances where salinity briefly rose to above 0.1 psu, with a peak value of about 1.8 psu, and 6 hours as the longest duration of salinity above 0.1 psu. The data suggest salinity occurrence at the project site is driven by complex interactions of multiple cycles of strong asymmetrical tides followed by a strong flood tide. While the conceptual model used for the modeling in this analysis uses 1,000 m^3/s as the highest flow when notable salinity stratification occurs at the site, the more recent data indicate that very weak stratification occurs at flows up to 2,000 m^3/s.

A CTD instrument and an acoustic Doppler current profiler (ADCP) were used to collect data on the vertical structure of salinity in the river on March 22-23rd.. On the dates of the survey, no salinity was found at the project site as river flow and tidal conditions were suitable. The survey team traveled down river and located the inward extend of the salt wedge near Tilbury Island.

Vertical profile data collected there showed both the magnitude and vertical character of the stratification were similar to the profile used for initial dilution modeling (**Section 6.3.7**).

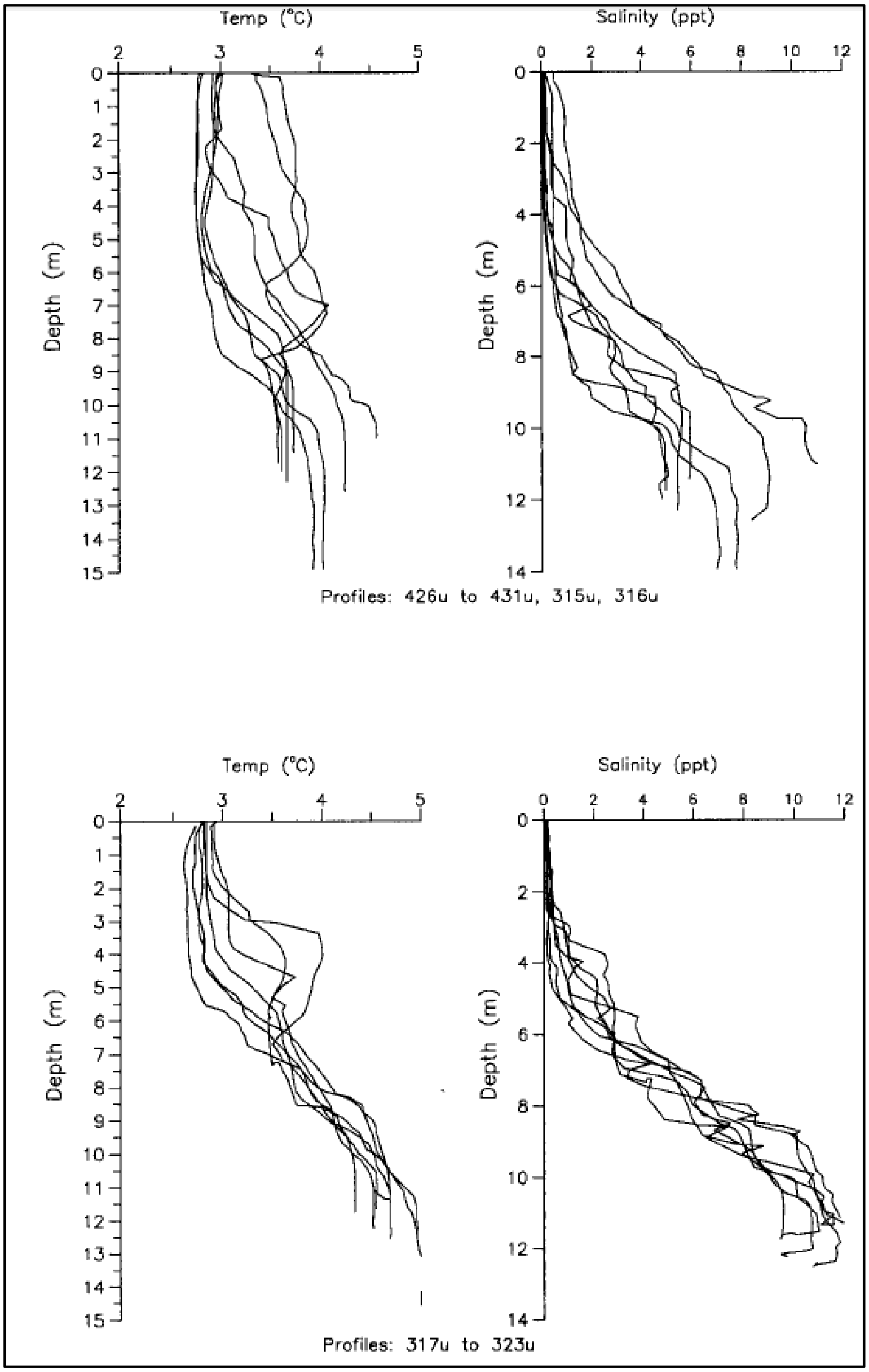

Figure 3-11. Vertical Profiles of Temperature (left) and Salinity (right) at the Beginning of Saltwater Intrusion (top) and at the Fullest Extent of Intrusion (bottom) (LWMP, 1997)

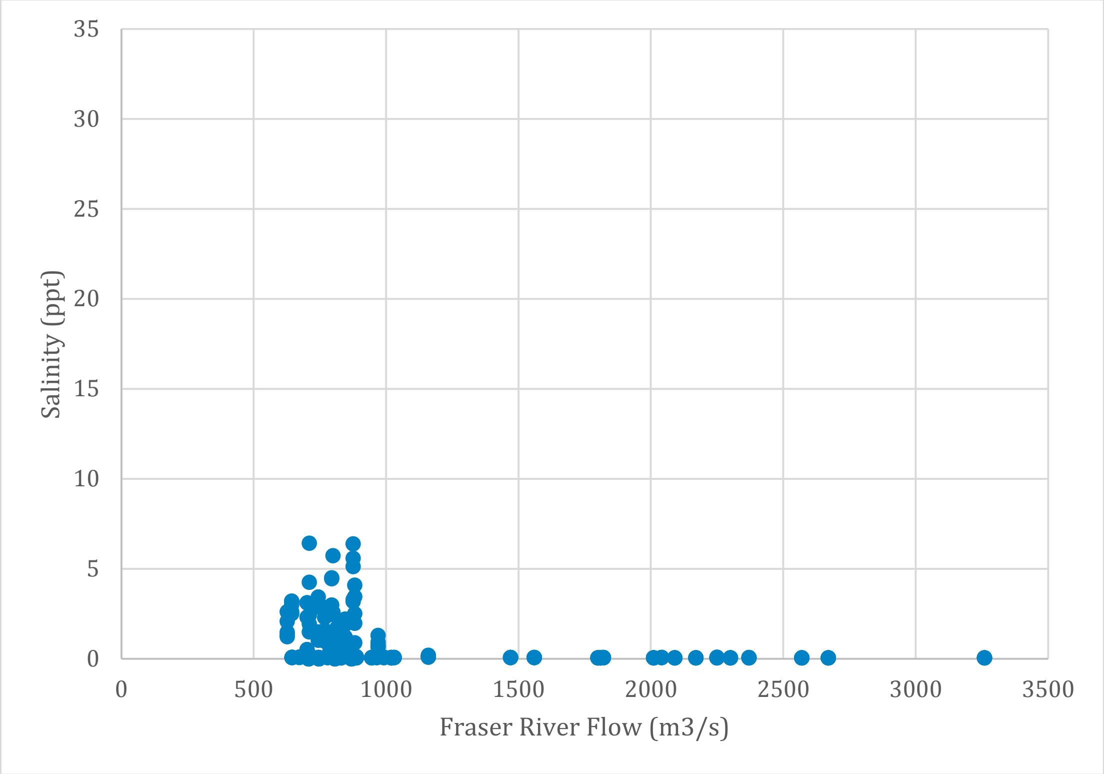

Figure 3-12. Salinity Measurements from the Annacis Island WWTP IDZ Monitoring Program (2007-2014)

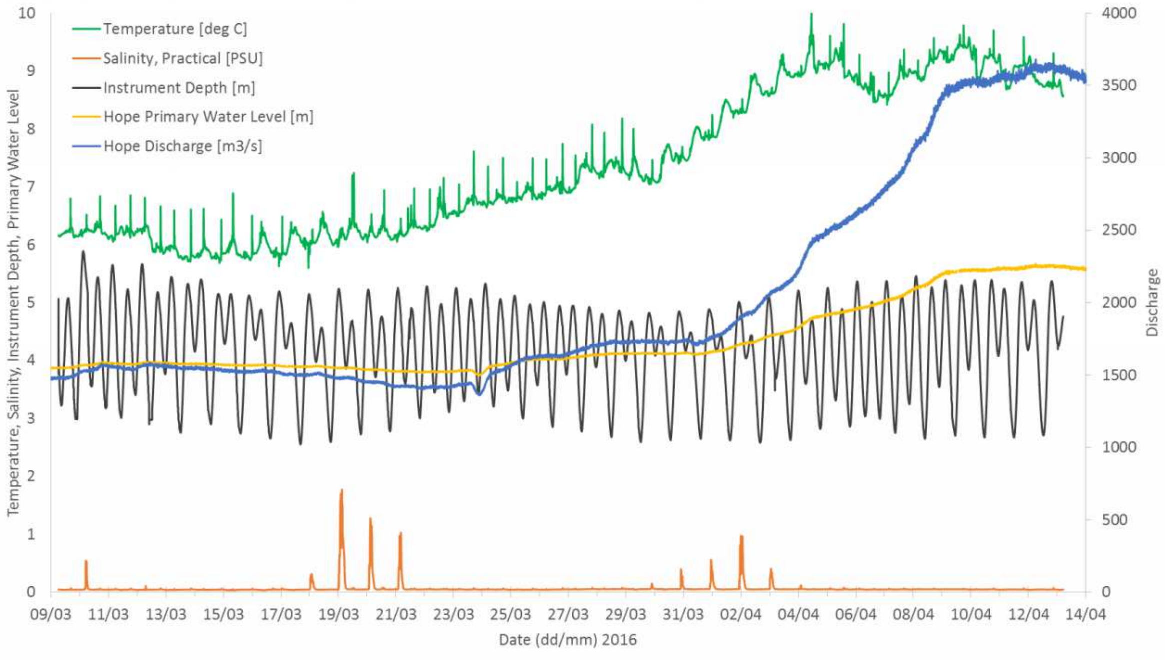

Figure 3-13. Time Series of Temperature, Salinity, and Instrument Depth near AIWWTP Measured (March-April 2016) (Golder Associates, 2016)

Section 4

Effluent Quality

4.1 Annacis Island Wastewater Treatment Plant Flows

The Annacis Island Wastewater Treatment Plant (AIWWTP) provides secondary treatment to wastewater for over one million residents in 14 municipalities, treating about 175 billion litres of wastewater every year.

Currently, the plant is undergoing a Stage V expansion project to increase its secondary treatment capacity by over 25% to an average dry weather flow of 637 MLD (7.4 m^3/s). The peak wet weather flow (PWWF) for Stage V is 18.9 m^3/s; the ultimate plant buildout is Stage VIII, which will have a PWWF of 25.3 m^3/s. The timing of the flow increases is currently being evaluated. Based on aggressive growth projections (**Figure 4-1**), capacity increases beyond Stage V could occur as early as 2024.

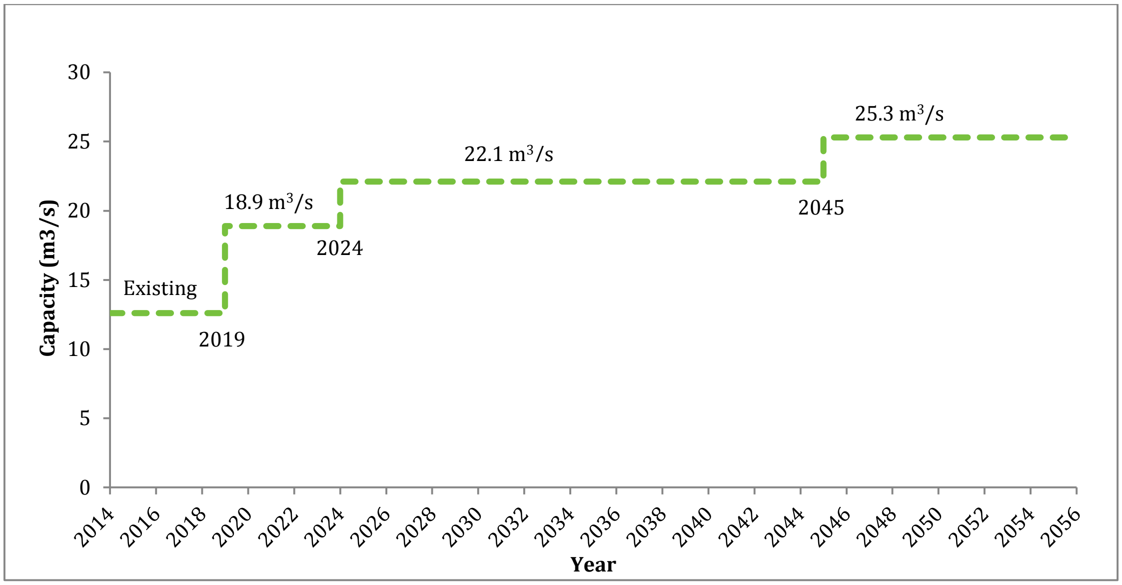

Figure 4-1. Possible Timing of Capacity Requirements for the Annacis Island WWTP based on Aggressive Growth Projections

Figure 4-2 presents a time history of the daily maximum instantaneous effluent flow at the AIWWTP from 2011 through 2014. The data range from 5.5 m^3/s to 12.5 m^3/s. During periods of high flow into the plant, the influent flow is manually throttled and allowed to bypass the plant to prevent the plant from reaching its design capacity of 12.6 m^3/s. Thus, the upgrades to the plant would allow all of the incoming flow to be treated with added capacity for other system wide improvements.

Section 6.3.4 discusses how the current range of flows was scaled up to create a predicted distribution of flows at Stage V, and how this distribution was segmented as input into the initial dilution modeling.

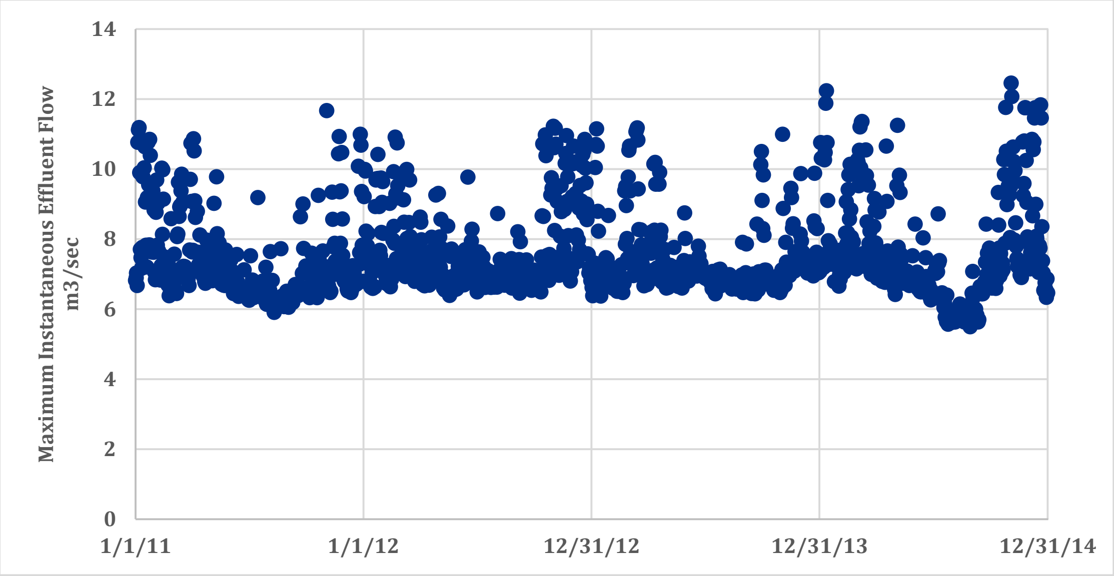

Figure 4-2. Daily Maximum Instantaneous Effluent Flow at the Annacis Island WWTP (2011-2014)

4.2 Effluent Quality

Effluent quality data are available from the following sources: operational plant data, data from monthly comprehensive effluent monitoring, data gathered in conjunction with the existing outfall IDZ monitoring program, and water quality data reported in the *Potential Effluent Discharge Objectives for the Annacis Island Wastewater Treatment Plant* (EDO) report (Tri-Star Environmental Consulting, 2015).

Effluent quality data are available for many parameters including conventional parameters (e.g., carbonaceous BOD, TSS, residual chlorine, un-ionized ammonia, pH, phosphorus and fecal coliform levels) and potentially toxic parameters (e.g., metals and various organic substances).

The existing effluent data is used as the basis for characterizing future effluent quality. As the proposed Stage V upgrade to AIWWTP is to improve hydraulic capacity, it is reasonable to expect that future effluent quality can be predicted by scaling up the existing effluent mass load by the planned flow increase (i.e., effluent concentrations will remain the same).

The available effluent water quality data from 2011 through 2014 were compiled (**Appendix A**) and evaluated. In general, data for conventional and nutrient parameters were taken from the annual summaries of effluent data by month, while data for potential toxic parameters were taken from the IDZ monitoring program and the EDO report. Data for un-ionized ammonia, total residual chlorine and CBOD, which are not included in the annual summaries are taken from plant operational data. When data were sufficient to the development of summary statistics, the following values were determined: count, minimum, mean, maximum, standard deviation, and

95% percentile concentrations. When sample concentrations were below the method detection limit, the whole value of the detection limit was used for the statistical calculations. Other data quality flags, such as those indicating maximum possible concentrations, were assessed and the whole value concentration were also used for statistical calculations. In addition, the mean effluent mass flux and the standard deviation of effluent mass flux are calculated in **Appendix B**.

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Section 5

Preliminary Diffuser Design

5.1 Overview

This section develops design considerations for the outfall/diffuser system, and recommends a preferred diffuser design for the AIWWTP discharge.

An outfall system typically comprises three main components:

1. The outfall headworks facilities discharge the plant effluent, by gravity or by pumping, against the various tidal conditions in the receiving waters. The headworks provide the necessary hydraulic head to ensure the effluent reaches the desired discharge site.
2. The conveyance facilities transport the effluent from the outfall headworks to the discharge site.
3. The outfall terminus is the point at the end of the outfall system where the effluent enters the receiving water. The terminus can range from a simple open pipe to a multiport diffuser, with the latter being common when a project's goals are to increase mixing or probability of submergence.

The diffuser design evolved from a previous diffuser design concept (Black and Veatch, 2015) and was advanced and refined through numerous iterations of the hydraulic analysis described in this section and initial dilution modeling as described in **Section 6** and **Section 7**.

5.2 Previous Diffuser Design Concept

Black and Veatch (2015) modeled the dilution of several different outfall/diffuser system design cases (existing outfall, 1 new outfall, 1 new outfall and maintain existing outfall, 2 new outfalls), and recommended that 2 independent outfall/diffuser systems with independent IDZs would best achieve regulatory requirements.

The need for two diffusers was based on analyses using both a far-field model (RMATRK) and an initial dilution, jet-plume model (VISJET). RMATRK is an advection-dispersion model that accounts for potential plume interactions at the diffuser locations as well as dealing with the potential for returned effluent on tidally reversing currents. However, RMATRK does not account for any buoyant or momentum mixing that is important with the initial dilution calculations. VISJET was used to model the jet plume mixing. However, VISJET neither accounted for tidally reversing effluent entrainment nor the presence of the second diffuser. Also, the VISJET model does not provide for a dilution solution beyond the plume reaching the surface, which was often before the edge of the IDZ. The reported dilutions at the edge of the IDZ in the report are quite disparate as RMATRK results indicated an IDZ dilution of 22:1 to 44:1, while VISJET reports a dilution at the surface of 246:1. The difference between these two results is not adequately defined to aid in the concept design decisions.

After performing additional dilution modeling as described in this report, the recommendation to use two new diffusers was discounted, and further design evaluations focused on a single diffuser. Key factors considered in discounting the two new diffuser concept include:

- Initial dilution modeling was performed assuming the water column during winter (low flow) conditions was uniform in its salt content at 10 psu and the river was unbounded. Several lines of evidence exist to indicate that most of the time the Fraser River is fresh throughout the water column at Annacis Island, and that saline water is only intermittently present. When present, the salinity is typically less than 10 psu, and is confined to the bottom layer of the river. The inclusion of a fully saline receiving water leads to over prediction of initial dilution because (1) it creates additional mixing due to buoyancy of the fresh water effluent discharging to a salty ambient that does not exist, and (2) allows the discharging effluent to be mixed into the entire water column when the vertical variation in salinity (salty water being present in the bottom of the river) can cause the plume to trap at depth and reduce dilution.

- There was no consideration of reduction in dilution from the presence of an up-current diffuser. Thus, the initial conceptual design did not adequately account for plume overlap, which would increase the required dilution at the downstream diffuser as a result of entraining upstream diluted effluent. The Risk Assessment Results (AECOM, 2015) also identified this deficiency in the initial estimation of the dilution at the IDZ and determined that dilution at the downstream diffuser would be reduced by 27% as a result of entrainment from the upstream diffuser.

5.3 Diffuser Design Criteria

In a typical diffuser design, an attempt is made to maximize pipe velocities while maintaining head losses within limits determined by available hydraulic head to support gravity flow or pump selection in coordination with attaining the maximum initial dilution possible. As described in **Section 1.2.1**, design criteria for outfall/diffuser system is to:

- To provide an outfall system with a total capacity of 25.3 m3/s at a river level of 103.18 m GD without impacting the hydraulic gradeline of the treatment plant.

- To achieve a minimum dilution ratio of 20:1.

For this project, the diffuser needs to convey both the Stage V (18.9 m^3/s) and projected Stage VIII (25.3 m^3/s) flows. This goal can be achieved by developing a design for the ultimate peak flow, and then determining the number of ports that need to be blocked off to allow the diffuser to also achieve the maximum dilution at the lower Stage V flows.

Additional criteria that must be considered in the diffuser design are the presence of bed waves in the Fraser River, protecting the diffuser ports from anchor and ship strikes, and providing for a bulkhead or gate on the diffuser manifold.

- ***Bed Waves*** – The Fraser River is geomorphologically active. During periods of high discharge, beds waves, comprised of sand, travel down the river bed and vary in height based on local water depth. These waves can be 5-m high in the deep navigation channel, but are thought to be about 1-m high at the edge of the channel where the diffuser is proposed to be located (NHC, personal communication). For the purpose of this analysis, it is assumed that the height of the diffuser risers between the river bed and the bottom of the diffuser port is 1 m to minimize the potential for the ports being covered by bed waves.

- ***Protection for the Diffuser Ports*** – The proposed diffuser will be located in a region of the river with heavy boat and ship traffic. Using risers protects the diffuser manifold from ship damage by allowing it to be fully buried. The disadvantage of risers is that they are subject to damage by ships, anchors and possibly other debris (e.g., sunken logs). Design of a conical sleeve or cap to place over a riser pipe should significantly reduce the potential for damage and is included in the concept design.

- ***Manifold Bulkheads*** – Given the high sediment load carried by the Fraser River, it is likely that over time some sediment will enter the diffuser. The diffuser manifold should be fitted with a bulkhead at the downstream end to facilitate access. Consideration should be given to extending the end of the manifold piping to the riverbed and providing bulkhead at each end to facilitate cleaning.

5.4 Diffuser Location and Layout

5.4.1 Location within Study Area

The discharge of effluent through a diffuser system creates an interaction of the plume with ambient currents and density stratification to provide initial dilution. Proper placement of the diffuser (location and orientation) creates proper plume formation and maximum dilution.

For the AIWWTP four factors determine the potential location for the diffuser: (1) the project study area boundaries and its bathymetry (defined in **Section 1.3**), (2) achieving the maximum depth below Chart Datum (discussed in **Section 1.3.2** and **Section 2.1.4**), (3) dredging activities at and near the study area, and (4) the presence of bed waves that migrate down the river during the freshet season. Ideally, the siting of the diffuser would also be able to take account of other potential projects in the Fraser River that could affect the diffuser location (e.g., widening or deepening the navigation channel following replacement/removal of the George Massey tunnel), but these projects are not currently sufficiently defined to be included.

Bringing these factors together, the optimal location for a diffuser would be in the deepest water available, outside of the actively dredged areas, where the effects of passage of sand waves can be minimized. This leads to placement of the diffuser at the eastern end of the study area.

5.4.2 Bathymetry and Dredging Constraints

Figure 1-2 shows the 2016 bathymetry and the edge of the navigation channel (dashed green line). The dredging depth constraint at the project site is the Dredge Grade maintained by Port of Vancouver at 10.9 m below Chart Datum. Based on the most recent bathymetric survey done by CCG in January 2016, a 100-m portion of the study area along the navigation channel nearest the existing outfall is currently below the Dredging Grade (-10.9 m Chart Datum or elevation 87.51 m GD + 100), while the next 200 m portion further downstream is up to 0.5 m above the Dredge Grade. As described in **Section 1.3.2**, sediment deposition in the 300+ m river reach downstream of the existing outfall is limited and Port of Vancouver does not need to do routine maintenance dredging in this area. Therefore, the area just outside the navigation channel within 300 m of the existing outfall was determined to be the best location for the diffuser in terms of water depth (and resulting dilution) and limited requirements for future maintenance dredging due to the lower height of the sand waves.

5.4.3 Diffuser Orientation

Two diffuser orientations were considered, perpendicular and parallel to the shoreline. A diffuser manifold oriented perpendicular to the shoreline has the advantage of more readily intercepting river flow as it crosses against the predominant river current direction , which aids in increasing dilution.

A perpendicular manifold is difficult to fit into the project study area, particularly given the depth/dredging constraints and the upwardly sloping bottom towards shore. These constrain a perpendicular manifold to being on the order of the length of the existing diffuser. Review of the time history of bathymetry by the Canadian Coast Guard indicates that the maximum length for the diffuser manifold would be about 60 m, avoiding shallow water and the navigation channel dredging practices. Preliminary initial dilution runs using CORMIX for a perpendicular diffuser with 3.5 m port spacing, maximizing exit velocity using the available head, and both a coflowing diffuser (90° ports to the manifold in the dominant direction of river flow) and a staged diffuser (similar to coflowing but with the ports on both sides oriented offshore) provide a dilution of greater than 20:1 for 15% of the time, with dilutions of less than 10:1. This dilution is less than that for the parallel orientation. Given these factors, a diffuser manifold perpendicular to the shore is considered impractical.

Accordingly, the selected diffuser orientation is parallel to the shoreline along with the diffuse manifold located a few metres outside the edge of the navigation channel to take advantage of the deeper water. The distance between the edge of the navigation channel and the shoreline is approximately 175 m, which is sufficient to allow for the IDZ to be located shoreward of the diffuser without impinging on the shoreline. **Figure 5-1** shows a preliminary alignment selected for the conveyance tunnel and diffuser manifold.

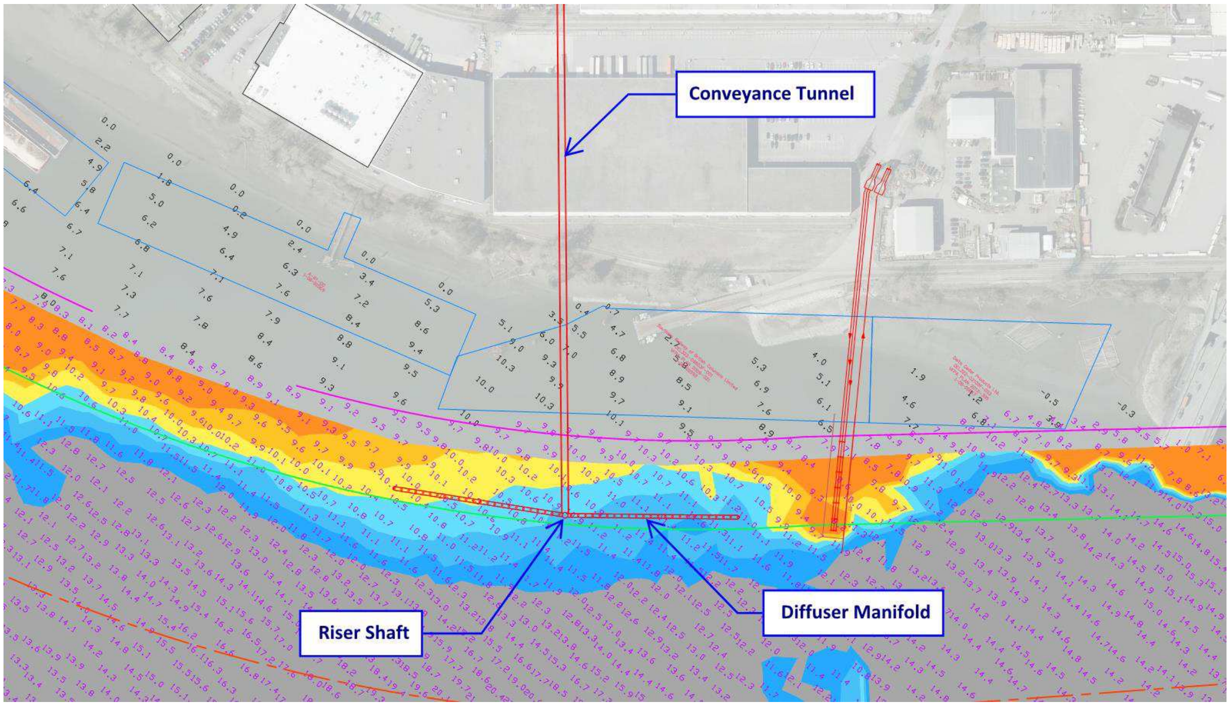

Figure 5-1. Planned Diffuser Location

5.4.4 Diffuser Length

Diffuser length can be a significant parameter contributing to initial dilution of treated effluent. Length, however, is a less sensitive term in dilution analysis with the diffuser concept for the AIWWTP – parallel to shore with unidirectional ports. Length, in the case of locating the Annacis diffuser within the project study area, is constrained by available water depth and the field of bed waves in the western end of the area. Given these constraints and the fact that construction of a new diffuser cannot impinge on the location of the existing diffuser, the maximum length of a diffuser is about 300 m.

The diffuser length needs to be sufficiently long to allow for good mixing dynamics, but not too long to increase head loss. Preliminary diffuser lengths can be estimated using the theoretical equation for dilution for a unidirectional diffuser in quiescent water body and unbounded waters.

$$L = (S^2 * 2 * Q)/(u_o * H)$$

where L is length (m), S is the target dilution, Q is effluent flow (m^3/s), u_o is port exit velocity (m/s) and H is water depth (m).

The results of these calculations for a target dilution of 20:1, two water depths (10.9 and 14.4 m), the Stage V and VIII peak flows, and typical project site velocities are shown in **Table 5-1**.

Table 5-1. Estimated Diffuser Length using Mass Flux Considerations

Port Exit Velocity (m/s)	Diffuser Length for Stage V Flow (18.9 m³/s)		Diffuser Length for Stage VIII Flow (25.3 m³/s)	
	Low Tide	High Tide	Low Tide	High Tide
1	1,387	1,050	1,857	1,406
2	694	525	928	703
3	462	350	619	469
4	347	263	464	351
5	277	210	371	281

These results are expected to be conservative because they do not include river velocity. For this project, it is desirable to have a shorter diffuser length to both fit into the available deep water at the project site and minimize head loss in the diffuser manifold.

Simulations of initial dilution were made for preliminary alternatives examining length and port spacing, using the available head which resulted in port velocities around 4 m/s. Two lengths were tested: 240 m and 300 m; the latter being the longest diffuser that could be placed given project constraints. The results of these runs are described in **Section 7**. They indicate that the 300-m long diffuser predicts only nominally higher dilution than a 240-m long diffuser. Thus the decision was made to proceed with a 240-m long diffuser as the design basis; this may be refined in future phases, if a physical model is used to assist with verifying site-specific dilution predictions.

5.4.5 Port Orientation

Diffusers create dilution of the discharged effluent by entraining ambient river water into the plume. Dilution results from entrainment due to momentum and/or buoyancy. In the Annacis Island case, the majority of the time the treated effluent will discharge into freshwater, resulting in momentum being the only source of entrainment flux. Momentum is created by the discharge velocity at the diffuser ports. Thus, a goal of the diffuser design is to select small ports to achieve high discharge velocity while staying within available hydraulic head to discharge by gravity (or accepting that pumping of the discharge will be required).

With the orientation of the Annacis diffuser parallel to the shoreline, the greatest dilution will result if the effluent discharges in only one direction; in the parlance of outfall design, this type/orientation of diffuser is known as a unidirectional or tee diffuser in a crossflow. This way, the diffuser is pulling water from behind and from the sides of the diffuser and entraining it into the discharging plume to create dilution. The logical way to orient the ports is toward the centre of the channel. This achieves two benefits: the discharge can access the greater depths of the main channel to achieve additional dilution and the plume moves away from the diffuser so that the concentration of flow returning to the area of the diffuser on an incoming tide will have lower concentration than if the diffuser had ports pointing in two directions.

Typically, unidirectional diffusers have been associated with thermal discharges from power plants; unidirectional diffusers are designed to increase mixing due to momentum. Certainly wastewater discharges have less flow than power plant discharges, and for similar discharge velocity, less momentum. But for a wastewater discharge to a river, there is very little buoyancy and ultimately the dilution relies on the momentum of individual jets.

5.4.6 Number and Spacing of Ports

Two port spacings were evaluated: 10 m spacing, which is approximately the water depth at the project site (diffuser design guidelines suggest spacing should not exceed water depth) and 5 m spacing, to test whether tighter spacing would increase dilution. The method selected for predicting dilution under unstratified conditions (the Shrivastova-Adams equation (**Section 6.2.2**) does not have port spacing as a variable; thus, dilution predicted for unstratified conditions would be the same regardless of port spacing (assuming exit velocity was maintained). Therefore, simulations of stratified conditions using the selected model Visual Plumes UM3 provided results showing the effect of port spacing on dilution. The results of four cases, using the combined stratified and unstratified runs, were evaluated, and the minimum dilution and percent of time dilution is less than 20:1 dilution are presented in **Table 5-2**.

Table 5-2. Estimated Dilution Parameters for Different Port Spacing

Alternative	Minimum Dilution	Percent of Time Dilution is less than 20:1
240-m long diffuser, 10 m port spacing, fixed orifice	12.4:1	8.3%
240-m long diffuser, 10 m port spacing, variable orifice	16.3:1	2.8%
240-m long diffuser, 5 m port spacing, fixed orifice	15.6:1	8.2%
240-m long diffuser, 5 m port spacing, variable orifice	17.7:1	2.4%

The higher minimum dilution and lower percent of time that dilution was predicted to be less than 20:1 resulted in the selection of 5 m port spacing for the preliminary diffuser design. This selection may be re-visited based on physical modeling of the preliminary Annacis diffuser.

5.4.7 Diffuser Cross Section

Figure 5-2 shows a cross-section schematic of the diffuser manifold at a discharge riser. The top of the armor rock protecting the diffuser manifold is set at the dredging grade since placing it any lower than the river bed would result in sedimentation quickly covering the exposed portions of the risers and ports.

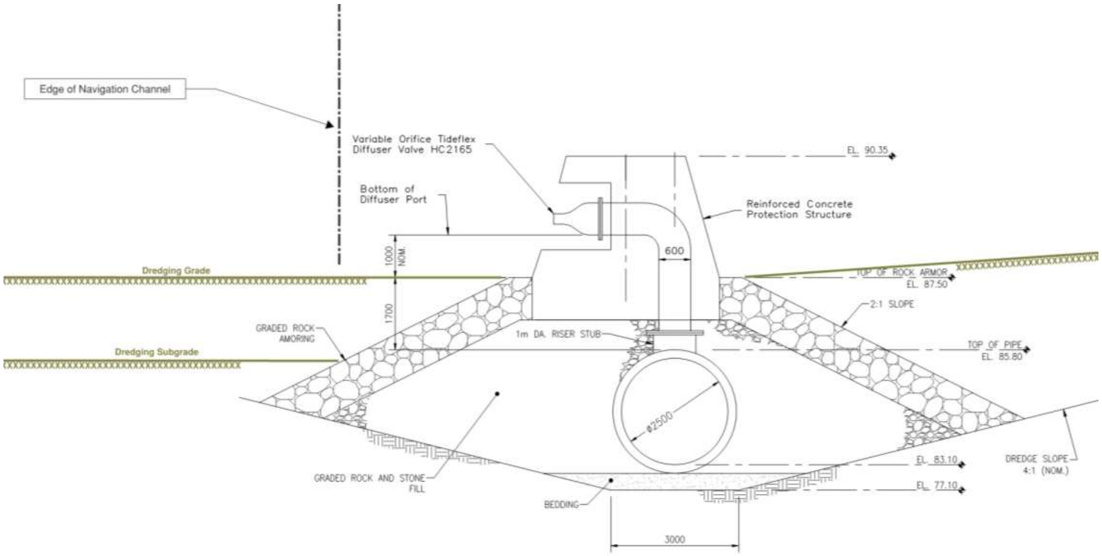

Figure 5-2. Schematic of Cross-Section of Diffuser Manifold, Riser, Port and Protective Cap

The water depth for the top of the diffuser infrastructure, which would be the top of the protection provided for the riser would be the sum of:

- 1 m above the native riverbed to allow the bottom of the diffuser port to reside above the height of predicted bed waves at the edge of the navigation channel,
- The diameter of the diffuser port, and
- An additional ~ 1 m allowance for the protective cap over the diffuser port.

Anticipated diffuser port diameters for this project range from 0.36 to 0.60 m, which means that top of the diffuser port would be about 1.4 to 1.6 m above the dredge grade. This corresponds to a depth below Chart Datum of 9.5 to 9.3 m, respectively. This configuration will require a variance of the MWR diffuser depth requirement; however, the diameter of the ports could be refined in final design and the actual depth variance will be determined.

The protective cap will be between about 2.4 and 2.8 m above the armor rock. This corresponds to a depth of 8.5 to 8.1 m below Chart Datum, respectively. The Port of Vancouver indicated that the depth of the diffuser in the area between the navigation channel and its safety boundary should be at least 6 m; therefore, there is no variance required for Port of Vancouver criteria.

The cross section shows a Tideflex-style valve over the port opening, which allows for a variable orifice to increase port discharge velocities at low effluent flow. A horizontal orientation of the valve allows for the port to be closer to the river bottom, maximizing the water depth available for dilution. The elliptically shaped valve can further improve dilution by allowing for ambient river water to reach the jet centreline faster than with an equivalent round jet. In addition, the horizontal valve provides more bottom clearance whereas a vertical valve could be partially buried if sediment deposition occurs.

There is the potential for the navigation channel to be dredged or widened in the future to accommodate larger draft vessels. The outfall infrastructure (risers, manifold, headers, protective covering) related to the AIWWTP upgrade are designed to remain outside of the current navigation channel. Assuming the channel is deepened less than about 2 metres, the outfall diffuser could remain at its design location presuming modifications are made to the rock protection armor configuration. Conversely, widening of the navigation channel would have significant impacts on the diffuser design.

5.5 Hydraulic Design

5.5.1 Hydraulic Design Analysis Summary

Hydraulic design analysis began with evaluation of hydraulic grade line and head loss in the conveyance system from the CTTs to the outfall diffuser manifold to determine the available head to drive flow through the manifold, risers and diffuser ports. Further analysis was performed iteratively in conjunction with the dilution modeling to determine optimum diffuser port sizes and resulting flow velocities to optimize dilution while working within available hydraulic head.

As will be described in the remainder of this section, the analysis culminated in three alternative configurations considered during initial dilution modeling for the outfall diffuser system:

- **Alternative 1**: A 240-m long diffuser with fixed diameter ports.
- **Alternative 2**: A 240-m long diffuser with variable orifice ports.
- **Alternative 3**: A 300-m long diffuser with variable orifice ports.

Hydraulic analysis was conducted using Visual Hydraulics software to determine the hydraulic grade line and head losses. The software calculates head loss based on user input and the pipe system design. Memoranda with details on the modeled components and model inputs and results are available in **Appendix C** and **Appendix D** for **Alternative 1** and **2**, respectively. Visual Hydraulics was also used to determine the manifold/diffuser flows, head loss, and velocities. Modeled assumptions included a Tideflex diffuser valve which would allow for a variable orifice size under different flow conditions to increase diffuser port exit velocities. The head requirement for the manifold, riser and diffuser system of 1.41 m is within 0.04 m of the available 1.45 m of head. During the early years of operation when the outfall system is new with smooth (not aged) concrete and when only a portion of the chlorine contact basin settlement allowance has occurred, there will be sufficient head to operate as configured without exceeding the maximum allowable water surface elevation at the Chlorine Contact Tanks. For Stage VIII flows, the calculated available head was only 0.69 m, which was insufficient as the head requirement for the system was 1.45 m; therefore, a net increase of head (pumping) of 0.83 m is required. **Alternative 3** has similar head availability requirements.

5.5.2 Hydraulic Design Criteria

The hydraulic design of a multiport diffuser needs to meet design criteria that affect the internal hydraulics of the diffuser pipe. These criteria ensure a uniform distribution of effluent discharge along the diffuser, set minimum scour velocities (this is not needed for the AIWWTP effluent because of its high quality), account for diffuser head losses, and set the number, spacing and diameter of discharge ports.

The main hydraulic criterion for successful diffuser operation is the achievement of an even effluent discharge from each port. Meeting this criterion ensures that the plume is discharged over the specified length of the diffuser and will achieve the initial dilutions computed by near-field models. Even port discharges were evaluated using the two criteria below and checked with the detailed hydraulic calculations of the proposed design.

- ***Uniform Discharge and Port Area Criterion*** – If the total port area of a diffuser is greater than the area of the diffuser pipe, uneven flow distribution may occur as some ports may not flow full and others may not discharge any effluent. To avoid this, French (1972) suggests that the total port area never exceed the diffuser pipe area.

- ***Densimetric Froude Number*** – When the effluent discharges to saline water, this dimensionless parameter describes the combination of density-driven buoyancy and viscosity forces at the diffuser ports. The effective densimetric Froude number at the discharge port should be greater than 1 to ensure the port is flowing full and at sufficient pressure to prevent saltwater intrusion.

In a typical outfall system, the head required to drive a diffuser forms a large proportion of the overall system head. In such cases and particularly for the AIWWTP where there is only a small amount of available head for the outfall/diffuser system, minimizing overall head losses is an important consideration in outfall design to allow much of the available head to be expended at the diffuser ports.

To make full use of the diffuser length for initial dilution, it is necessary to distribute the discharge among many ports, rather than only a few. The number and spacing of ports must be configured to provide proper plume development to achieve maximum dilution.

5.5.3 Hydraulic Grade and Head Loss

The chlorine contact tank within AIWWTP is the starting water surface elevation. The original design maximum water surface elevation in the tank of 106.01 m was lowered by 0.31 m to El. 105.70 which accounts for historic and predicted settlement through 2067. The ending water surface elevation is based on the Fraser River 200-year flood level of 103.18 m (GD+100) plus 0.11 m to allow for hydrostatic head when a salt wedge is present at the site.

In a typical diffuser design, discharge exit velocities are maximized while maintaining head losses within limits determined by available hydraulic head to support gravity flow. The available head for the diffuser design is defined by the following key assumptions:

- The design water surface elevation in the Fraser River is the 200-year recurrence interval peak winter flood level of 103.18 m.
- The design water surface elevation was increased by 0.11m to account for the hydrostatic head differential required to discharge when a salt wedge is present.
- An effluent pump station and piping will be located at the 16-m diameter launch shaft for the effluent tunnel.
- The inside diameter of the tunnel is 4.2 m, and a main vertical riser from the tunnel to the diffuser manifold will have an internal diameter of 3.8 m.
- The 3.5-m diameter diffuser manifold is joined to the vertical riser at its centre.
- All components are assumed to be made of an aged concrete for the purpose of evaluating friction head loss.

The hydraulics analysis accounts for head loss encountered through a conduit at the chlorine contact tank, through an effluent shaft and tunnel to the location of a future effluent pump station, through the pump station, through a tunnel and riser to the diffuser manifold, and through the diffuser manifold, risers, and ports. After accounting for conveyance head losses prior to the manifold, the calculated head available for the manifold, risers and diffuser ports is 1.41 m for Stage V flows. Initial dilution modeling indicated that optimizing outfall/diffuser design to take full advantage of the available gravity head for Stage V flows would be sufficient to achieve the target dilution. For Stage VIII flows, the calculated available head is only 0.69 m, which is not likely to be sufficient to achieve the target dilution. Therefore, a decision was made to optimize the outfall and diffuser design for the available gravity head for Stage V flows and include provisions in the design for a future effluent pump station to provide additional head as required to address future plant capacity expansion.

5.5.4 Hydraulic Design Alternative Evaluation

All alternatives are based on a spacing slightly less than half of the water depth - a typical convention regarding spacing to minimize the effect of merging jets – and supported by the evaluation in **Section 5.4.5** that indicated a higher minimum dilution and lower percent of time that dilution was predicted to be less than 20:1 for a 5 m port spacing. Note that the method used to calculate initial dilution (as described in **Section 6** and **7**) is insensitive to port diameter and spacing when the exit velocity is held constant and sensitivity analysis indicated that port spacing less than the water depth allows for greater dilution compared to port spacing approximately equal to the water depth with stratified conditions.

Modeling and calculations for **Alternative 1** (**Section 7.2**) predicted dilution less than 20:1 for several of the modeling scenarios. These low dilution scenarios tend to occur at lower river current because (1) the port discharge velocity is too low to entrain sufficient flow to create higher dilutions, and (2) the current speed is insufficient to move the plume downstream. The result is a plume not much wider than the length of the diffuser that relatively slowly moves toward the centre of the river until it reaches the IDZ boundary parallel to the river's flow direction.

This led to **Alternative 2** considering use of a variable orifice to increase the low port discharge velocity by adding a valve (e.g., a Tideflex diffuser valve).

Alternative 3 was considered using a longer diffuser of 300 m, using a similar port spacing and resulting in similar port velocities as **Alternative 2**, to evaluate the potential improvement in dilution with a longer diffuser section. **Alternative 3** also uses a variable orifice to increase low port discharge velocities.

Equivalent port diameters and exit velocities for each alternative at a range of flow velocities up to the predicted Stage VIII PWWF in **Table 5-3**. About ¼ of the total ports are considered to be left closed until flows exceed the planned Stave V PWWF. The variable orifice equivalent port diameters are estimated from the characteristic curves provided by the Tideflex manufacturer. Predicted dilutions from these alternatives are presented in **Section 7**.

Table 5-3. Characteristics of Diffuser Design Alternatives

Alternative/Flow	Description	Equivalent Port Diameter	Port Exit Velocity
Alternative 1	**Length**: 240 m length **Port type**: Fixed **# Ports**: 36 open at Stage V; 48 open at Stage VIII	360 mm	
7.9 m³/s			2.13 m/s
9.7 m³/s			2.62 m/s
13.7 m³/s			3.70 m/s
18.9 m³/s			5.10 m/s
25.3 m³/s			5.12 m/s
Alternative 2	**Length**: 240 m length **Port type**: Variable Tideflex valve hydraulic code 2165 **# Ports**: 36 open at Stage V; 48 open at Stage VIII		
7.9 m³/s		290 mm	3.23 m/s
9.7 m³/s		310 mm	3.57 m/s
13.7 m³/s		330 mm	4.52 m/s
18.9 m³/s		360 mm	5.14 m/s
25.3 m³/s		360 mm	5.17 m/s
Alternative 3	**Length**: 300 m length **Port type**: Variable **# Ports**: 44 open at Stage V; 60 open at Stage VIII		
7.9 m³/s		270 mm	3.15 m/s
9.7 m³/s		280 mm	3.52 m/s
13.7 m³/s		300 mm	4.02 m/s
18.9 m³/s		325 mm	5.15 m/s
25.3 m³/s		325 mm	5.11 m/s

5.6 Preliminary Diffuser Design Summary

The goal of these iterations was to determine a diffuser length, port spacing, and port diameter that provided significant dilution with a fixed port diameter so that the Stage V design flow could be discharged by gravity while maintaining other hydraulic design criteria (e.g., having ports that flow full with an even distribution of flows across the ports and port spacing no greater than the water depth). These iterations also demonstrate that pumping will be required to discharge flows greater than 18.9 m^3/s.

Based on the criteria, constraints, and analysis presented in this section and the results of initial dilution modeling presented in **Sections 6** and **7**, a preliminary design for the diffuser system was selected with the following features:

- A 240-m long diffuser manifold located just outside the edge of the navigation channel just downstream of the existing outfall. The manifold would connect to the main vertical riser from the outfall tunnel at its centre.
- The manifold would have 48, 600-mm diameter risers leading to 360 mm diameter ports discharging horizontally toward the centre of the river. For Stage V flows, 12 of the ports would be blocked off to aid in increasing dilution leaving 36 active ports. All 48 ports would be open at Stage VIII when peak wet weather flow was 25.3 m^3/s.
- The ports would be fitted with variable orifices (e.g., Tideflex diffuser valves) to increase exit velocities at low effluent flows. These valves will also reduce sediment entering the diffuser system.
- The diffuser risers would be covered with a conical sleeve or cap to protect them from anchors, ship strikes and submerged debris. The sleeve needs to accommodate access to the port terminus to permit maintenance of the variable orifices.
- The ends of the manifold would be fitted with bulkheads to facilitate internal access and/or cleaning.

Figure 5-3 shows a schematic of the diffuser along the edge of the navigation channel.

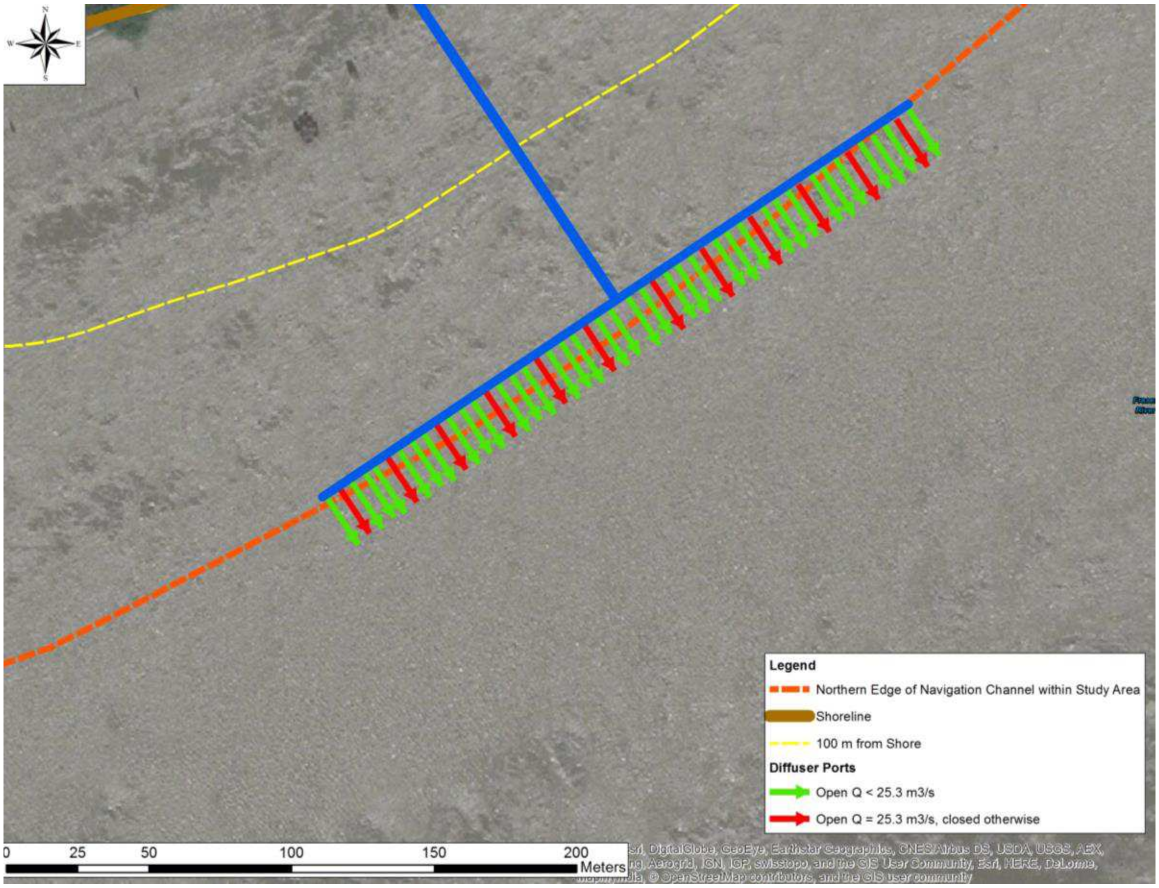

Figure 5-3. Schematic Diffuser Design along the Edge of the Navigation Channel

Section 6

Initial Dilution Modeling Approach

The objectives of the initial dilution model are to:

- Understand the factors affecting the fluid dynamics of the initial dilution process,
- Model the initial dilution process under a wide range of ambient river and effluent flow conditions, and
- Provide modeled results of initial dilution so they can be used to predict the extent to which the WQOs and WQGs are met at the IDZ boundary.

6.1 Determining Concentrations at the Edge of the IDZ

The Municipal Wastewater Regulations allow for consideration of mixing with ambient waters in determining compliance with many of the WQGs. The regulations define an initial dilution zone (IDZ) and require that WQGs be met at the edge of the IDZ. More information on the specifics of the IDZ is presented in **Section 2**.

Determining the extent to which each chemical parameter in the treated effluent (C_o) meets its WQG requires predicting the concentration of that parameter at the edge of the IDZ. The edge of the IDZ concentration (C_{IDZ}) has up to four components as follows:

- The "instantaneous" contribution from the effluent plume that has just undergone initial dilution (C_N);
- Ambient (background) concentration (C_a);
- Contributions from other significant discharges into the Fraser River that are not adequately captured by the background concentration (C_{other}), and
- Long-term background buildup as the concentration in the river due to the discharge of the treatment plant itself (C_b).

A series of equations were developed to account for the different nearfield and far-field concentrations in order to develop a total concentration at the edge of the IDZ. Neglecting other sources (**Section 6.5**), the far-field dilution (S_f) and near-field dilution (S_n) are defined as:

$$S_f = (C_o - C_a)/(C_b - C_a) \text{ and}$$

$$S_n = (C_o - C_b)/(C_N - C_b)$$

where dilution (St) total is defined as:

$$S_t = (C_o - C_a)/(C_N - C_a)$$

and is approximately the harmonic sum of the near-field and far-field dilution.

$$1/S_t = \sim 1/S_f + 1/S_n$$

To determine the concentration at the edge of the IDZ, using the definition of the far-field, near-field, and total dilution, the equation yields:

$$C_{IDZ} = C_a + (C_o - C_a)/S_f + (C_o - C_b)/S_n$$

If the frequencies of occurrence, or probability distributions, for each of the four components of the IDZ concentration can be determined, then the IDZ concentration can be predicted through a statistical analysis. The basic approach depends on the WQGs being used in a compliance determination.

- For parameters with short-term maximum WQGs, the available data is used to model input parameters statistically, such as cumulative frequencies distributions for effluent flow and ambient current. Representative values from the distribution are selected and interval of occurrence is assigned to each value. Individual model runs representing each combination of representative values are run (128 runs for the AIWWTP discharge), and the joint probability of the predicted dilution is calculated. The minimum predicted dilution for each Fraser River flow classification is applied to the maximum effluent concentration, added to the ambient background concentration (as mean or median values; see the Stage 1 EIS) and far-field concentration (when bi-directional river conditions exist), and compared to determine if the short-term maximum WQG is met.

- For parameters with long-term average (30-day) WQGs, the available data is used to develop monthly average values for each model input parameter to permit calculation of dilution on a monthly basis. For months when salinity can be present, two simulations (stratified and unstratified) are made and then are combined based on the probability of salinity being present. Then, the monthly predicted dilution is applied to the average effluent concentration, added to the monthly average ambient background concentration and monthly average far-field concentration, and compared to determine if the long-term average WQG is met.

6.2 Selection of Initial Dilution Model

6.2.1 Original Selection of Initial Dilution Model

Three primary initial dilution models exist that have the ability to predict dilution for outfall system alternatives with a multi-port diffuser: CORMIX, Visual Plumes, and VisJet.

6.2.1.1 Initial Dilution Model Comparison and Original CORMIX Selection

Previous studies of the AIWWTP discharge have used a variety of initial dilution models for the existing outfall and proposed new outfalls. A comparison of the models is shown in **Table 6-1** for factors of importance to the mixing region of Annacis Island.

Table 6-1. Comparison of Initial Dilution Models for Annacis Island

Metric	CORMIX2	UM3 in Visual Plumes	VisJet
Water Body Type	Allows for bounded waterbodies	Infinite	Infinite
Where Initial Dilution Runs End	Both near-field and far-field regions	Ends when effluent plume reaches the water surface or its maximum rise, but includes ability to simulate far-field with Brooks (Gaussian diffusion) equation	Ends when effluent plume reaches the water surface or its maximum rise
Types of Diffuser Configurations Simulated	Can simulate either unidirectional, staged or alternating diffusers. 2 or 4 ports per riser depending on type.	Simulates unidirectional diffusers and can approximate alternating diffusers. Up to 2 ports per riser.	Has the flexibility to customize the diameter of risers and ports, and number of ports for each riser
How Individual Jets are Simulated	For an unstratified ambient, uses an equivalent slot diffuser; for stratified ambient uses CorJet module which treats each port individually before merging them.	Treated as individual jets until they merge	Treated as individual jets, merging accounted for
How Dilution is Accounted	Outputs flux-averaged or centreline dilution depending on module	Default is flux-averaged dilution; centreline dilution can be reported	Ability to determine dilution at a specified plane, but may not include all individual jets if the simulation has been stopped based on reaching water surface or maximum rise

Based on this comparison, CORMIX2 was initially selected as the most appropriate model for the AIWWTP application[7] because:

1. It allows for specification of width of the bounded water body as in the case of the Fraser River.
2. It continues to calculate mixing after the plume hits the surface. In several scenarios, the plume reaches the surface within the IDZ; CORMIX2 allows for the additional dilution at the IDZ to be included.

6.2.1.2 Description of CORMIX

The USEPA program, Cornell Mixing Zone Expert System (CORMIX), is a software system used for the analysis, prediction, and design of discharges into diverse water bodies. Use of the program

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[7] The *Annacis Island Wastewater Treatment Plant Pre-Discharge Monitoring Dilution/Dispersion Study* (LWMP Environmental Monitoring and Assessments Technical Committee, 1997) also selected CORMIX for initial dilution at the existing outfall over the PLUMES (now Visual Plumes) model because it compared better to dye study results especially at low current speeds, had a bounded water body option, and agreed with fundamental dilution principles at the highest current speed.

helps to determine what dilution can be expected from given outfall configurations, discharge concentrations, and receiving water characteristics. CORMIX2[8] is the multi-port diffuser module.

Bounding the water body is important in estimating the dilution from a tee diffuser. As discussed in Adams *et al*. (1982) the separation distance between the shoreline and the diffuser is observed to reduce the effective dilution by limiting the ambient diluting water reaching the discharge ports from behind the diffuser. As seen in **Figure 6-1**, the tee diffuser system acts as a pump in pulling ambient water from behind the diffuser (as indicated by the arrows) into the discharging effluent and creating the dilution plume. The research indicated that separation distance needed to be greater than 35% of the diffuser length in order to achieve 70% of the dilution predicted for infinite water.

CORMIX2 calculates concentrations in the near-field region and in the far-field region. The near-field region includes a small area of jet mixing where no influence is felt from the ambient conditions; initial characteristics of the effluent alone dictate flow. For complex hydrodynamic cases, CORMIX simplifies the design specifications into an “equivalent slot diffuser” and thus, embraces the merging of plumes and neglects the details of individual jets. In the remainder of the near-field region, the initial characteristics of the effluent, momentum flux, buoyancy flux and outfall geometry, dominate flow patterns, but ambient conditions have some effect. The near field gives way to the far field, which is the region of the receiving water where buoyant spreading motions and passive diffusion control the trajectory and dilution of the effluent discharge plume. The far-field region is characterized by flows that are dominated by ambient conditions such as stratification and river current. (Jirka *et al*., 1996).

6.2.1.3 Centreline vs. Flux-averaged Dilution

CORMIX provides either the centreline dilution or bulk average (flux-averaged) dilution, and the output varies by the module of the model being used. For the Annacis application, the dilution at the edge of the IDZ is likely to be found in a module that outputs flux-averaged dilution.

If dilution were to be derived from a module using centreline dilution, a factor would need to be applied to the CORMIX results to bring the results to equal footing with the other models. We used the literature to select a factor that was the ratio between the flux-averaged and centreline dilution. The average dilution is what would expect to be captured in the analysis of an IDZ grab sample. A literature search comprising of a series of peer-reviewed papers was performed to determine a value to convert minimum dilution to a flux-average dilution. This literature search was initially performed after reviewing the Lai *et al.* (2011) paper on dilution of a rosette group in a crossflow. This paper summarized the flux-average to minimum dilution ratio using data from different studies, along with the ratio adopted in some commonly used line plume models. The ratio obtained from these studies differed depending on the diffuser configuration and the concentration measurement threshold, and varied from 1.1-2.6, with an average of approximately 1.4. For this purpose, Lai et al. decided to adopt the value of 1.4 to convert the average dilution from the minimum dilution. The Lai *et al.* paper was used as a starting point to evaluate the various studies and published data. The other papers reviewed included: Isaacson (1983); Baumgartner *et al*. (1992); Roberts and Snyder (1993); Doneker and Jirka (2001); Roberts *et al*. (2001); Tian *et al*. (2004, and Lai (2011).

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[8] http://www.cormix.info/CORMIX2.php

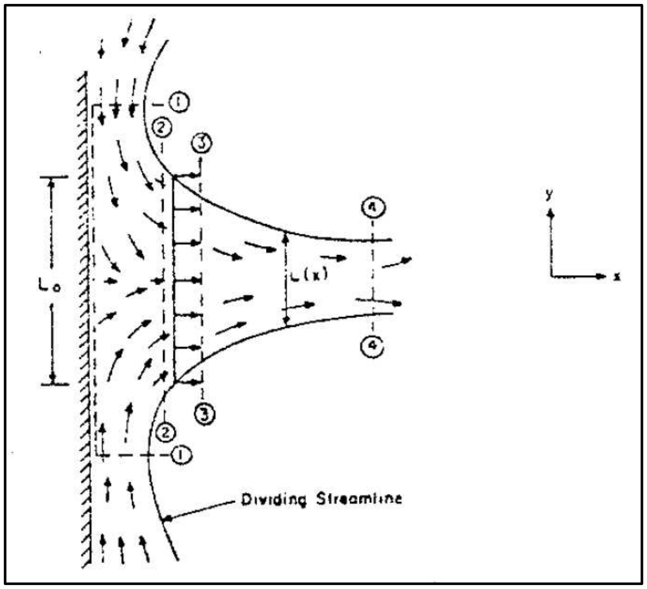

Figure 6-1. Depiction of a Tee Diffuser near a Shoreline (from Adams *et al.,* 1982)

Isaacson *et al*. (1983) examined plume dilution for diffusers with multiport risers. The authors published data on the diffuser geometry type, number of ports, port diameter, riser spacing, discharge depth, stratification, as well as measured minimum dilution. The Annacis outfall geometry and uniform stratification is similar to two of the "DW" cases. Comparison of average to minimum surface dilutions yielded an average ratio of 1.18.

Baumgartner (1992) is found in the PLUMES manual and summarizes the Roberts, Snyder, Baumgartner (RSB) linear plume model. Based on hydraulic model tests performed by Roberts in 1989, the average to minimum dilution ratio is 1.15 as similarly reported by Lai. The ratio as reported was likely a combination of all available test cases from the Roberts' 1989 experiments.

The PLUMES manual also describes theory for the UM model, which were originally the OUTPLM, UOUTPLM, and UMERGE models. The 3/2 power profile is used to determine the centreline concentration as a function of the average concentration. The UM model theory discussion states that the peak-to-mean ratio for a fully merged line plume is 2.22. However, the ratios are considerable smaller than these limiting values depending on the uniformity of the source.

Roberts and Snyder (1993) examined the Boston Harbor outfall diffuser. The flux-average dilution was estimated from the movement of dye streaks to be only 1.1-1.2 times higher than the minimum dilution, a much smaller ratio than usually assumed. The average ratio of 1.15 was used to convert minimum to average dilution.

Doneker and Jirka, in the CORMIX manual, state that to determine the flux-average dilution in a submerged jet or plume region, the ratio of flux-average to minimum centreline dilution is 1.7 for a single-port round discharge and 1.3 for a multiport plane discharge. A statement regarding the flux-average to minimum centreline dilution is also found in their 1991 paper, "Expert Systems for Mixing-Zone Analysis and Design of Pollutant Discharges."

Roberts *et al.* (2001) looked at experiments with horizontal discharges into a linearly-stratified stationary environment, basing the average dilution on entrained volume flux by photographing movements of dye streaks. The authors state that the average to minimum dilution is about 1.6 near the location of the discharge-induced turbulence collapse under the influence of buoyancy forces.

Tian *et al*. (2004) studied near-field mixing of buoyant plumes from multiport diffusers into unstratified stationary water. For a line plume, the ratio of near-field dilution to centreline dilution is 1.2.

Each paper was reviewed and individual experimental or theoretical data points were screened to create a subsample of experimental results to best match the proposed conditions for the AIWWTP outfall pipe; parameters focused on multiport diffusers, with similar length scale characteristics, and utilizing either uniform or nonlinear stratification. Applying those characteristics to the dataset reduced the range of ratios further to a range of 1.3 to 2.45. The higher end of the ratios occurs on tests that are associated with ocean outfalls where there is much stronger buoyancy mixing, which is not a common occurrence at AIWWTP; therefore, those values can be excluded. A value of 1.4 was chosen to convert centreline to flux-averaged dilution as it is consistent with the proposed diffuser design.

6.2.1.4 CORMIX Results Are Questionable

While CORMIX was selected as the model that accounts for the bounding of the river and the ability to predict dilution beyond where the plume surfaces, review of the model results indicate a concern with reasonableness of the some of the model outputs. Several of the model outcomes do not converge with expectations of fundamental principles. For example, during runs that account for salinity, the output files indicate a nearly instantaneous orientation of the plume with a total width of 240 m across the channel, which is not fundamentally possible as the main plume axis should still be along the channel as it is leaving the diffuser. This model step results in much higher dilution for cases with stratification compare to unstratified conditions, despite that prediction of a trapped plume under stratified conditions.

Additionally, the theoretical dilution equation for a tee diffuser into a quiescent water body and unbounded waters is:

$$So = \sqrt{\frac{HLU_o}{2Q_o}}$$

where S_o is the dilution at a distance of about L/2 from the diffuser, H is the water depth, L is the diffuser length, U_o is the port exit velocity, and Q_o is the effluent discharge rate. And based on a typical early diffuser design located in 10 m of water depth, a design length of 240 m, and an effluent discharge at 18.9 m^3/s (Stage V) through the fixed orifice of 0.36 m, the expected dilution would be 15.9. Model simulations at low ambient currents indicate dilution values <10:1 are common; the discount on dilutionfor using a bounded river scenario for this diffuser design is between 10 and 15%. Thus, the ability of CORMIX to accurately represent the complex estuary of the Fraser River and account for dilution at slack or low river velocities is questioned.

6.2.2 Approach Used to Estimate Dilution for the AIWWTP Outfall

6.2.2.1 Results from the Initial Dilution Models

The results of the early simulations using CORMIX2 produced some counterintuitive results, such as little variation in dilution with changing effluent and ambient conditions, and dilution for a stratified ambient with a trapped plume that were much larger than for an unstratified ambient. Consequently, we used the other two additional models (UM3 and VisJet) to determine if they provided similar results. UM3 provided reasonable results for a stratified ambient but provided very large dilutions, which were judged to be too optimistic, for unstratified conditions. The VisJet results were not usable because of the model limitation of ceasing to simulate individual plumes when they reached the surface or maximum rise, which meant that predicted dilutions at the edge of the IDZ did not include all of the jet plumes and thus over predicted dilution. The results from the models also had a wide variation in results regarding whether dilution increased or decreased with increasing ambient current. The results of the models are shown in **Figure 6-2**, where the predicted dilution either at the IDZ boundary or where a consistent dilution result could be pulled for an individual model (as labelled in the legend) is plotted against m_r, a non-dimensional measure of momentum of the ambient to discharge momentum expressed as:

$$m_r = \frac{u_a^2 * H * L}{Q_o * u_o}$$

where u_a = ambient current; H = depth of the ambient water; L = length of the diffuser; Q_o = effluent discharge; and u_o = port exit velocity of the effluent. When m_r is less than 1, the Fraser River currents are low and m_r greater than 1 represents higher current speeds.

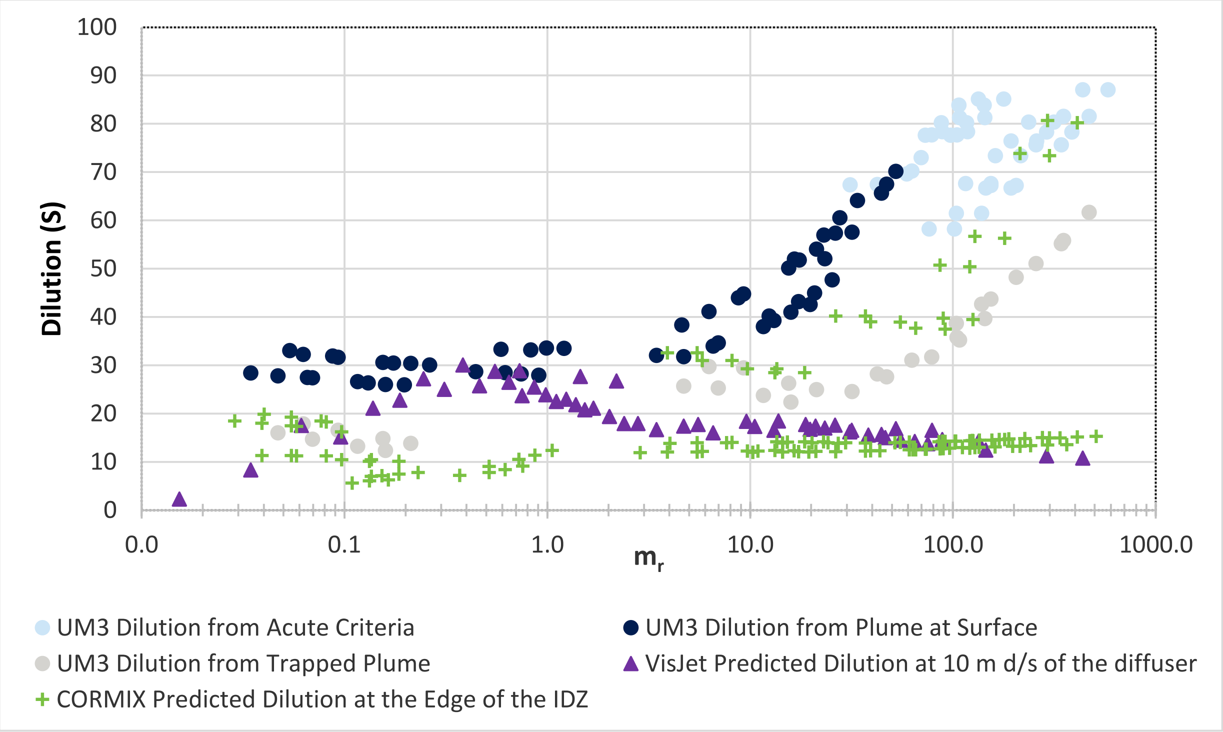

Figure 6-2. Predicted Dilution from Three Models vs. Momentum Ratio

The results show that predicted dilutions vary widely, do not follow consistent patterns among the model results, and lead to uncertainty in using the initial dilution models to predict dilution from a unidirectional diffuser. For instance, the CORMIX2 results show little change in dilution as m_r increases from 1 to 500, while the VisJet results show decreasing dilution with increasing m_r, and the UM3 results show increasing dilution with increasing m_r.

While some variability in model results is expected, the degree of variability in application to the proposed Annacis diffuser lead us to look for alternative approaches. A professor at Seoul National University, Il Won Seo, directed a set of experiments for a unidirectional diffuser partly because "dilution equations for tee diffusers lead to inaccurate predictions, particularly in strong ambient momentum conditions (Seo et al., 2001)." The goal of their research was to look at near-field dilution across a broader range of momentum ratios than previous research had resolved. By conducting experiments at larger momentum ratios, Seo's experiments, which were targeted on thermal plume discharges in the near-shore environment (i.e., discharge of heated discharges from power plants in Korea where strong tidal currents (40-80 cm/s) and relatively deeper water (10-20 m) occur replicated reasonably well the conditions found in the Fraser River at Annacis Island).

6.2.2.2 Comparison of Initial Dilution Model Results to Seo's Experimental Data

We then looked to the results of laboratory experiments using unidirectional diffusers to provide data against which to understand the computer model results. Seo *et al.* (2001) performed laboratory experiments of a tee (unidirectional) diffuser in shallow water with a crossflow; the paper is included as **Appendix G**. The experiments were for a thermal plume (the effluent is warmer than the receiving water, which is also the case for Annacis) and were done for a range of water depths, ambient currents, and port velocities. Seo used the results from the experiments to develop an equation to match the experimental results.

We believe Seo's experiments provide a firm basis from which to understand expected dilution from the proposed unidirectional diffuser for the AIWWTP. The experimental design is not a direct match to either the physical setting or proposed diffuser design, but there is sufficient closeness or overlap in the variables important to dilution, particularly when expressed non-dimensionally, to rely on the experimental results to inform dilution for Stage 1 of this project. Similarities and differences between Seo's experimental design and the proposed diffuser for Annacis are:

- Both are for a unidirectional diffuser in a crossflow.
- Ambient current – both Seo's experiments and the Fraser River have a broad range of ambient currents.
- Effect of river boundary – In Seo's experiments the ratio of the diffuser length to the distance from the near shore is 1.8; for Annacis this ratio will be around 1.4-1.5 depending on the final location of the diffuser. These values are reasonably similar.
- Thermal discharge – Seo's paper does not describe the temperatures used for ambient and effluent conditions in his experiments, though the case study he presents has a ΔT = 10°C. Thus it is reasonable to assume that this temperature differential would be within the range of his experimental design. Temperature differentials between the Annacis effluent

and Fraser River are discussed in **Section 6.3.5** and range from 6 to 9°C as averages for the three flow conditions considered.

- Ambient density – Seo's experiment was performed assuming an unstratified ambient. The Fraser River is typically unstratified, but a salt wedge is estimated to be found at the site less than 10% of the time.

- Vertical port angle – Seo's experiments use an upward angle from the horizontal of 22.5°. The proposed Annacis design is for a horizontal discharge. The upward angle discharge in Seo's data are believed to result in lower dilution than a horizontal discharge because Seo's plume will reach the surface faster.

- Ratio of ambient momentum to discharge momentum (m_r) – This parameter accounts for the momentum loss caused by stagnation of the ambient current due to an increase in pressure on the downstream side of the diffuser plume. This increase in pressure restricts the ambient water to entrain into the effluent plume (Seo *et al*., 2001). For Seo's experiments, m_r ranged from 0.03 to 103.1. For the combinations of input parameters, the range is from 0.02 to 407.91.

- Length to depth – Another non-dimensional parameter compares the length of the diffuser to the depth of water. Seo's experiments had L/H ranging from 4.6 to 13.3, while the proposed Annacis design is slightly higher at 16.7 to 22. Note for both Seo and Annacis the diffuser length was held constant and the depth varied, resulting in greater water depths for Annacis compared to the experiment.

Figure 6-3 is the comparison of the results from UM3, CORMIX, and VisJet from **Figure 6-2** plotted differently on the y-axis, to Seo's experimental data, along with the empirical equation developed from available experimental data on unidirectional diffusers (see Figure 7 of Seo *et al*. (2001) in **Appendix G**), and an earlier equation developed by Adams *et al*. (1982) for which experiments were only calculated at low momentum ratios. The x-axis is again m_r – a non-dimensional parameter of the ambient current to the effluent discharge. While the y-axis is the ratio of theoretical dilution with no current (S_o) over the predicted dilution for the models and the minimum surface dilution for the experiment/equation. S_o is given in Adams *et al*. 1982 as:

$$S_o = \sqrt{\frac{H*L*u_o}{2*Q_o}}$$

In **Figure 6-3**, a S_o/S_t ratio less than one indicates a higher dilution with current than the dilution at no current; and conversely S_o/S_t greater than one indicates lower dilution with current than with no current.

The comparison of the two equations plotted in **Figure 6-3** demonstrate the importance of the momentum ratio on predicted near-field dilution, where, as the momentum ratio gets large (due to higher ambient current) the ratio of S_o/S_t approaches unity rather than continue to rapidly increase.

Thus a decision was made to develop a method from Seo's experimental data to predict dilution at the edge of the IDZ for the Annacis outfall, when the Fraser River was unstratified.

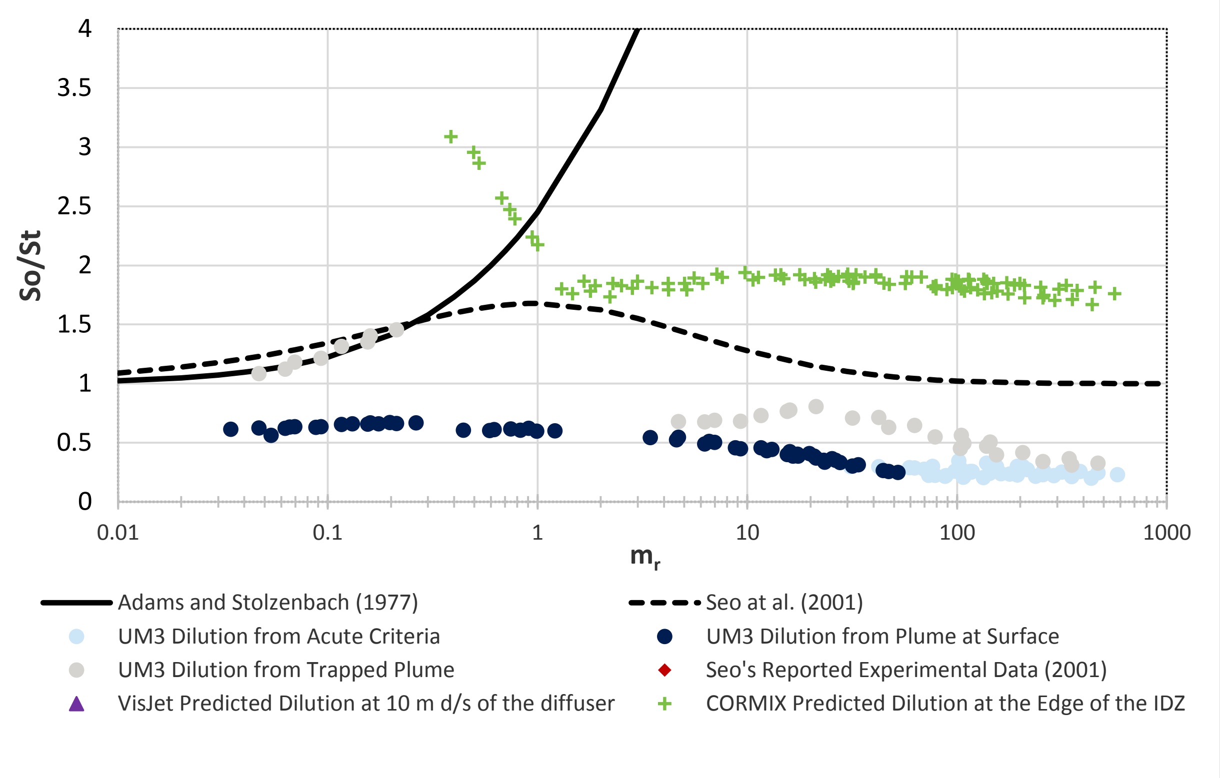

Figure 6-3. Comparison of Predicted Dilutions from Various Initial Dilution Models and Seo's Empirical Equation

6.2.2.3 Developing a Method to Predict Dilution from Seo's Data

Developing a method to predict from Seo's data is a three-step process:

1. First, an equation was developed using available experimental data for unidirectional diffusers, which combined information from Seo (2001), Adams *et al*. (1982), and others to be able to predict the minimum dilution measurable in the experimental results.

2. Then, this minimum dilution is converted to a dilution at the edge of the IDZ along the plume's centreline.

3. Finally, a factor of 1.4 is used to convert the centreline dilution measured at the edge of the IDZ to a flux-averaged dilution. The selection of the factor is described in **Section 6.2.1**.

The result is used for predicting dilution when the Fraser River is not stratified.

Table 1 (from Seo; **Appendix G**) summarizes S_t which is defined as the minimum surface dilution (i.e., based on the maximum observed temperature) that can be resolved by their measurements. There also appears to be a minor discrepancy between the S_t reported in Table 1 (a value of 10.5) and the S_t observed in Figure 5a in the equitemperature contours (a value of 9.5) based on their plotting routine. Because Seo's discharge is heated, the ambient environment is not stratified and the discharge ports have a positive inclination, the maximum surface temperature would be expected to be the maximum temperature throughout the water column. From Seo's Figure 5, it is seen that S_t occurs in a region near the diffuser and hence one could also expect significant additional dilution between this region and the edge of the IDZ.

Dr. Eric Adams of MIT and his graduate student, Ms. Ishita Shrivastava, used the data from Seo, along with that from Adams and Stolzenbach (1977) and other experimental results for thermal unidirectional diffusers to develop an equation that can be used to predict dilution for the Annacis diffuser (Shrivastava and Adams, draft manuscript). The equation extends the work of Seo, whose equation (shown in **Figure 6-3**) was only a function of m_r, to have two additional terms: f_2, which is function of L/H, and f_3, which is a function of theta (Θ_o), epsilon (ε), m_r, where theta is the angle of diffuser port from horizontal, and epsilon is approximately 0.099 and is the rate of spread of the jet half-width.

$$\frac{S_0}{S_t} = 1 + \max\{f_1(m_r)f_2(L/H), f_3(\theta_0, m_r)\}$$

where

$$f_1(m_r) = 0.45\mathrm{sech}\{0.87log_{10}(m_r)\}$$

$$f_2(L/H) = \max\left\{1, 0.18(L/H)^{3/4}\right\}$$

$$f_3(\theta_0, m_r) = \begin{cases} \max\left[\left(\dfrac{1}{\sqrt{2\varepsilon\, cot\, \theta_0}} - 1\right), 0\right] & \text{for } m_r < 1 \\ 0 & \text{for } m_r \geq 1 \end{cases}$$

The second measure of dilution could be called S_{IDZmin}. This value represents the dilution along the centreline of the plume at the boundary of the IDZ. Figure 5 from Seo's paper illustrates the non-dimensional isothermal contours at the water surface for four of the modeled cases. **Figure 6-4** displays Seo's results for a case where m_r = 11.1. The x-axis is the ratio of the distance from the centre of the diffuser to the length of the diffuser. For the proposed Annacis diffuser design, the x/L ratio at the downstream IDZ boundary is 220m/240 m or 0.92, shown as a green line in **Figure 6-4**. The value of the isotherm at x/L = 0.92 can then be compared to minimum dilution to determine a factor (a dilution ratio) to convert minimum dilution (S_t) to $S_{IDZmin.}$

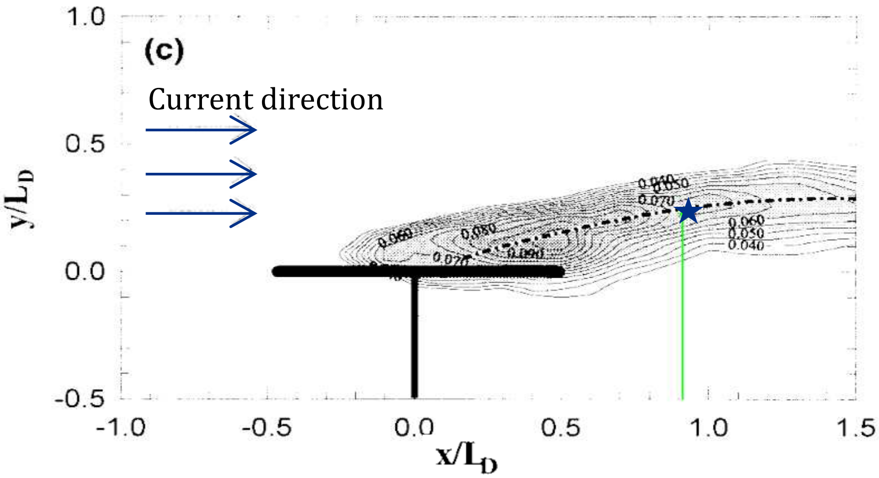

Figure 6-4. Isothermal Contours from an Experimental Result from Seo showing the Dilution at the Edge of the IDZ Boundary for the Proposed Annacis Diffuser Design

A similar procedure can be performed if the plume reaches the offshore edge of the IDZ, which occurs when the ambient velocity is very low. The dilution ratio was determined for the four cases presented by Seo in Figure 5, and the values are presented in **Table 6-2**. This procedure is performed for both the 240 and 300 m length diffusers, resulting in two slightly different equations for each diffuser length.

Table 6-2. Development of a Dilution Ratio to Determine Centreline Dilution at the Edge of the IDZ using data from Seo *et al*. (2001)

Length of Diffuser = 240 m						
Case Number from Seo	S_0 (Calculated)	S_t (Table 1, Seo)	$SIDZ_{min}$ (Figure 5, Seo)	x/L or y/L	$SIDZ_{min}/S_t$	m_r
TS316	14.9	9.5[a]	10.5[b]	0.4y	1.1	0.28
TS312	13.6	10.0	11.1	0.4y	1.1	0.96
TS607	13.1	10.5	13.7	0.9x	1.3	11.1
TS632	10.5	8.7	12.5	0.9x	1.4	103.1

Length of Diffuser = 300 m						
Case Number from Seo	S_0 (Calculated)	S_t (Table 1, Seo)	$SIDZ_{min}$ (Figure 5, Seo)	x/L or y/L	$SIDZ_{min}/S_t$	m_r
TS316	14.9	9.5[a]	10.5[b]	0.3y	1.1	0.28
TS312	13.6	10.0	10.1	0.3y	1.0	0.96
TS607	13.1	10.5	12.9	0.8x	1.2	11.1
TS632	10.5	8.7	11.8	0.8x	1.4	103.1

[a] Table 1 reports this value as 10.5 for this experimental case, but in Figure 5a, an equitemperature contour of 0.105 is distinguished near the diffuser resulting in a S_t of 9.5.

[b] Figure 5a appears to show a bolus, a small rounded region of slightly higher temperature, in front of the diffuser, which is an unlikely result but is reported as the dilution at the edge of the IDZ. It is a possible that the graphing resolution near the bolus is slightly better, or that the maximum temperature at S_t is slightly below the surface.

In Figure 5a, the case with the lowest ambient velocity, what appears to be a temperature bolus, or a bulge of closed temperature contours, occurs at approximately 0.5y/L, and near the region of interest. We would expect that concentration decreases and dilution increase as one moves away from the diffuser, but this does not appear to be the case for the 300 m long diffuser as the concentrations appear to be in a trough between the two high points of temperature. The bolus may be a result of plotting inconsistencies, or an unknown factor that caused high surface concentrations to appear in two locations. Regardless, the minimum concentrations for both diffuser lengths are pulled at their respective scaled IDZ locations and the values for the concentration at those locations are estimated based on the contours.

The data from Table 6-2 were plotted for both lengths and a well-fitted relationship resulted for the 240 m long diffuser ($r^2 = 0.97$) and a decently-fit relationship for the 300 m long diffuser ($r^2 = 0.81$) for the reason mentioned above. **Figure 6-5** depicts the relationship, which was used to calculate S_{IDZ} for each of the sets of input parameters (**Section 7**).

$$S_{IDZ}/S_t = 0.0603 * \ln(m_r) + 1.1531 \text{ for a 240 m long diffuser}$$

$$S_{IDZ}/S_t = 0.0508 * \ln(m_r) + 1.1013 \text{ for a 300 m long diffuser}$$

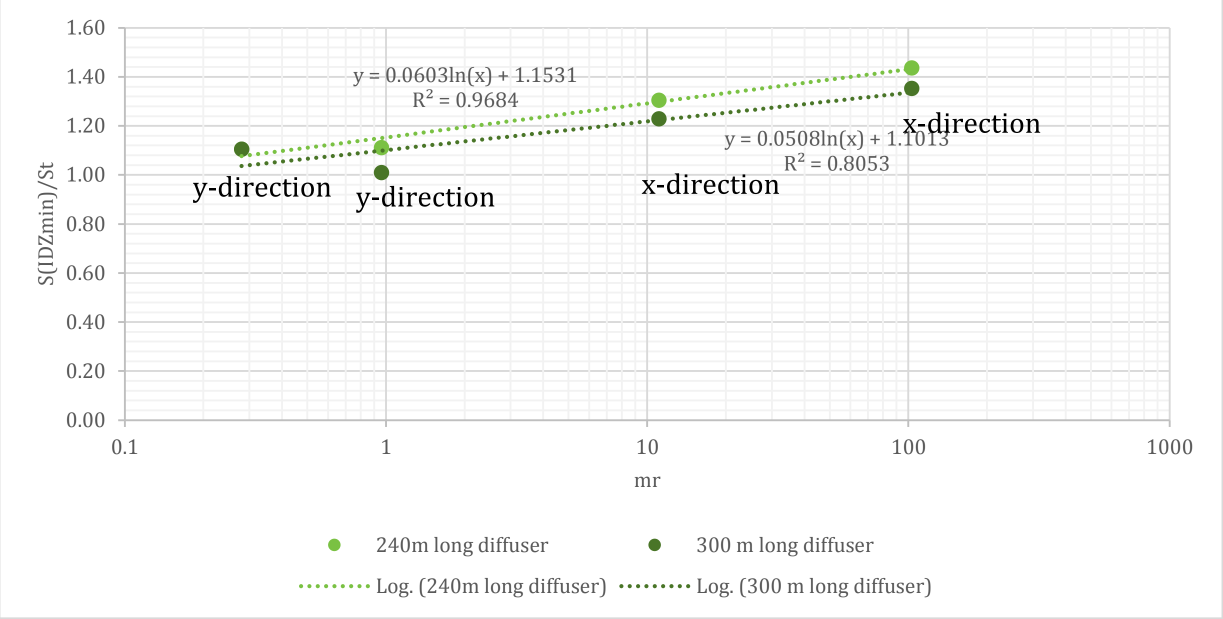

Figure 6-5. Relationship of m_r to S_{IDZ}/S_t using Four Isothermal Experimental Results from Seo *et al*. (2001) for two diffuser lengths

6.3 Instantaneous Dilution

The instantaneous dilution is taken from the results of the initial dilution predictions as the value at the time when the plume's centreline intersects one of the boundaries of the IDZ. For the proposed Annacis outfall, instantaneous dilution was predicted as follows:

- When the Fraser River is unstratified the Shrivastava-Adams equation developed in **Section 6.2.2** is used.
- When the Fraser River is stratified, the UM3 model is used; of the three initial dilution models available, UM3 provided results that were reasonable and internally consistent.

Determination of instantaneous dilution using initial dilution (or near-field) models requires the following parameters:

- Diffuser characteristics (configuration, number of ports, port size, port spacing, depth of discharge), as described in **Section 5**,
- Ambient river characteristics (width, depth, density profile, current speed), and
- Effluent characteristics (flow, density).

The data requirements for the equation to predict initial dilution are similar to those needed for an initial dilution model.

Due to the complexity of the Fraser River estuary, the ambient river and effluent characteristics are described for three flow "classifications" of the river, representing flows:

- Greater than 6,000 m^3/s –a period of freshwater and unidirectional currents when background buildup does not occur; this is the period of the higher flows during the freshet,
- Between 1,000 and 6,000 m^3/s –a period of bidirectional current and fresh water, and
- Less than 1,000 m^3/s – a period of bidirectional current when low river flows could result in salinity being present at project site

Table 6-3 provides a conceptual overview of how ambient river and effluent properties are characterized as input into the initial dilution equation.

Table 6-3. Conceptual Overview of Treatment of Initial Dilution Input Parameter Based on Flow Classifications

Initial Dilution Input Parameter	Fraser River Flow Classification		
	<1,000 m3/s	1,000 to 6,000 m3/s	>6,000 m3/s
Effluent Flow	Individual CFD	Individual CFD	Individual CFD
Effluent Temperature	Average value	Average value	Average value
Fraser River Current	One CFD represents both flow classes		Individual CFD
Fraser River Salinity	Two profiles: unstratified and stratified	Unstratified	Unstratified
Fraser River Temperature	Average value	Average value	Average value
Fraser River Depth	Low and high tide values	Low and high tide values	Low and high tide values

The following sections present the data used to develop the input parameters and how they were assigned a probability of occurrence. The probabilities of occurrence for each individual parameter is then combined to assign an overall probability of occurrence for the calculated dilution.

6.3.1 Fraser River Flow Classifications

Fraser River flows recorded at Hope are used to assign the percent of time when the flows fall within the three flow classifications defined in **Section 6.1**. **Table 6-4** summarizes the data by flow classification, where Q_a is the ambient flow**.** Flow is greater than 6,000 m^3/s only 13% of the time, between 6,000 and 1,000 m^3/s the majority of the time (64%), and is less than 1,000 m^3/s for 23% of the time.

Table 6-4. Fraser River Flow Classification

Flow Classification	Percent of Time Fraser River Flow Dataset (2008-2014)
$Q_a >= 6,000\ m^3/s$	13.2 %
$6,000\ m^3/s > Q_a >= 1,000\ m^3/s$	63.5 %
$Q_a < 1,000\ m^3/s$	23.3 %

6.3.2 Fraser River Current

Initial dilution predictions require as input the ambient current speed and current direction with respect to the diffuser alignment. Representative current speeds were used as input. As discussed in **Section 3.2.4**, current velocities are measured at a buoy located downstream of the project site. Current direction was not used in initial dilution modeling as a background buildup term will be used to capture the previously discharged flow that is incorporated into water currently being entrained into the plume.

Initially, the current speed data were divided based on the three flow classifications, but two of the flow classifications (the Q_a < 1,000 m^3/s and 6,000 m^3/s >Q_a >=1,000 m^3/s) were combined into one dataset (Q_a < 6,000 m^3/s) based on the similarity of their probability distributions.

Figure 6-6 and **Figure 6-7** show the cumulative frequency distribution of current speed for river flows greater than and less than 6,000 m^3/s, respectively. To represent the probability density function of Fraser River current speed, four values of current speed were selected as points of inflection along the curve and the percent of time of occurrence was assigned midway between the points of inflection (**Table 6-5**).

To represent conditions for parameters with long-term average WQGs, the average current speed is calculated for every month and is presented in **Section 6.3.8**.

Table 6-5. Representative Fraser River Current

Q_a >= 6,000 m^3/s			Q_a < 6,000 m^3/s		
Current Speed (m/s)	Cumulative Probability	Percent of Time	Current Speed (m/s)	Cumulative Probability	Percent of Time
0.07	0.8%	1.5%	0.03	2.5%	5.0%
0.39	13.3%	23.5%	0.38	32.5%	55.0%
0.76	56.5%	63.0%	0.78	77.5%	35.0%
1.13	94.0%	12.0%	1.41	97.5%	5.0%

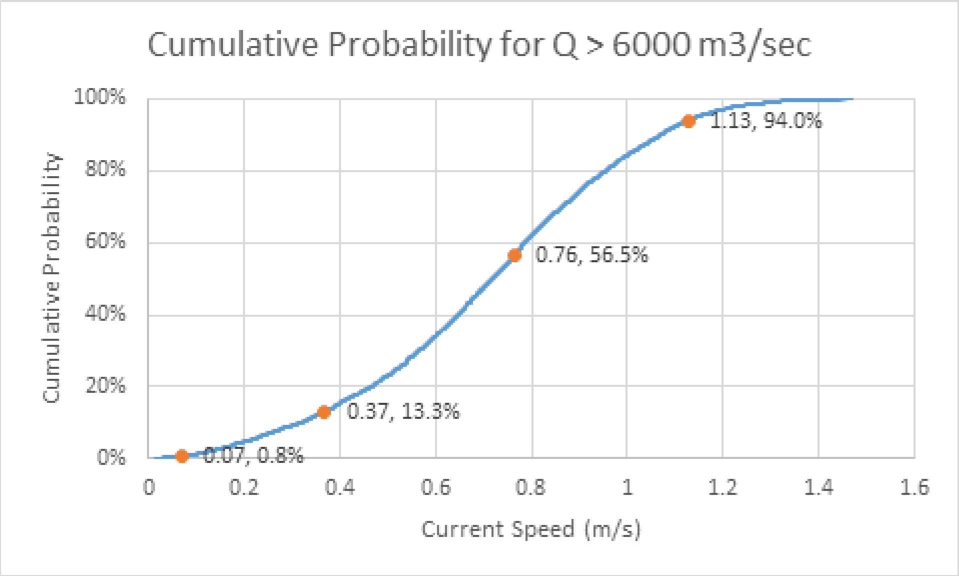

Figure 6-6. Cumulative Probability of Fraser River Current Speed for Q_a >6,000 m^3/s

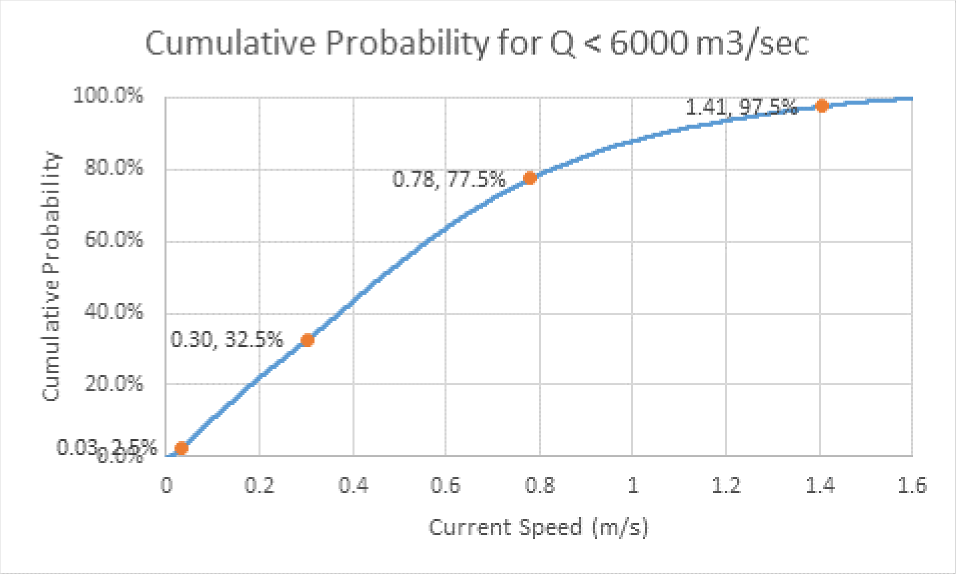

Figure 6-7. Cumulative Probability of Fraser River Current Speed for Q_a <6,000 m^3/s

6.3.4 AIWWTP Effluent Flow

Because the initial dilution process occurs on the order of minutes, initial dilution calculations are typically performed with hourly effluent flow rates (not daily flow rates). Hourly flow rates capture the greater variability of effluent flow conditions. For AIWWTP, peak instantaneous flows from 2011 through 2014 are used as the basis to develop the cumulative frequency curves as they represent recent effluent flow patterns.

The cumulative frequency curve for current flows then had to be extended for Stage V flows. This is done using the ratio of dry weather flow and peak wet weather flows for the current and Stage V periods.

The EDO report (*Potential Effluent Discharge Objectives for the Annacis Island Wastewater Treatment Plant* report (Tri-star Environmental Consulting, 2015)) states that the dry-weather flow would increase from 5.5 m^3/s to 7.4 m^3/s at Stage V. The ratio of these flows (1.34) was used as the starting point to scale the distribution of future hourly flows. The change in peak wet weather flow (12.5 to 18.9 m^3/s) is a factor of 1.51. Assuming the effluent flow pattern would not change, the current effluent flow record was converted to the Stage V flows by incrementally scaling individual data points by a ratio of 1.34 (to scale up the current minimum flow of 5.5 m^3/s to the future minimum flow of 7.37 m^3/s) to 1.52 (to scale up current recorded maximum flow from 12.4 m^3/s to the projected Stage V flow of 18.9 m^3/s).

Figure 6-8 displays the cumulative frequency curve for both the current and Stage V flows.

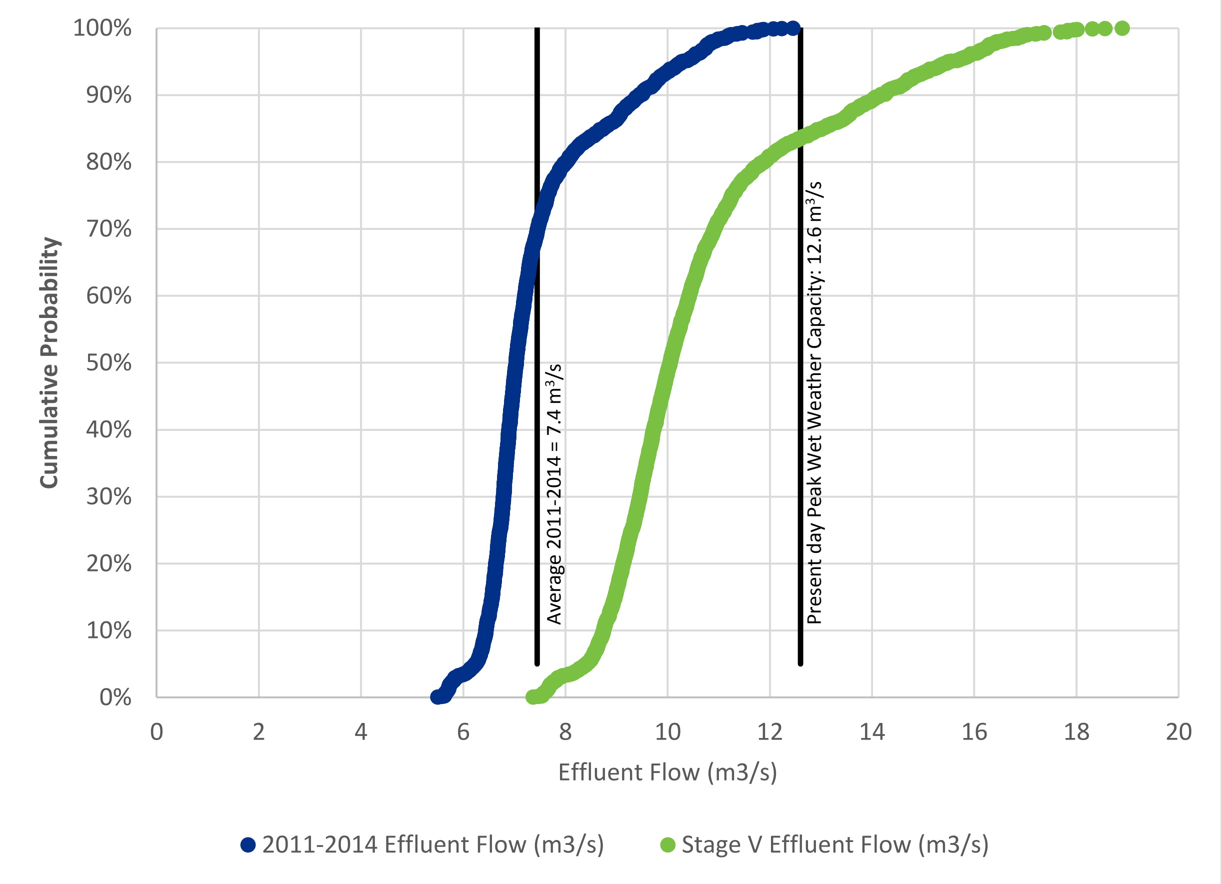

Figure 6-8. Cumulative Probability of AIWWTP Instantaneous Effluent Flow under Current (2011-2014) Conditions and at Stage V

To represent the probability of future effluent flows, four flow values were modeled. The probabilities are assigned based on inspection of **Figure 6-9** to **Figure 6-11**, which represent Stage V flows, and are summarized in **Table 6-6**. To represent conditions for parameters with long-term average WQGs, the average effluent flow is calculated for every month, and is presented in **Section 6.3.8**.

Table 6-6. Representative AIWWTP Effluent Flows

Q_a >= 6,000 m³/s			6,000 m³/s > Q_a >= 1,000 m³/s			Q_a < 1,000 m³/s		
Future Flow (m³/s)	Cumulative Probability	Percent of Time	Future Flow (m³/s)	Cumulative Probability	Percent of Time	Future Flow (m³/s)	Cumulative Probability	Percent of Time
8.6	7.5%	15%	7.9	5.0%	10%	8.8	2.0%	4%
9.5	42.5%	55%	9.7	42.5%	65%	10.2	34.5%	61%
10.4	83.0%	26%	13.7	87.0%	24%	13.2	77.5%	25%
12.3	98.0%	4%	18.9	99.0%	1%	16.2	95.0%	10%

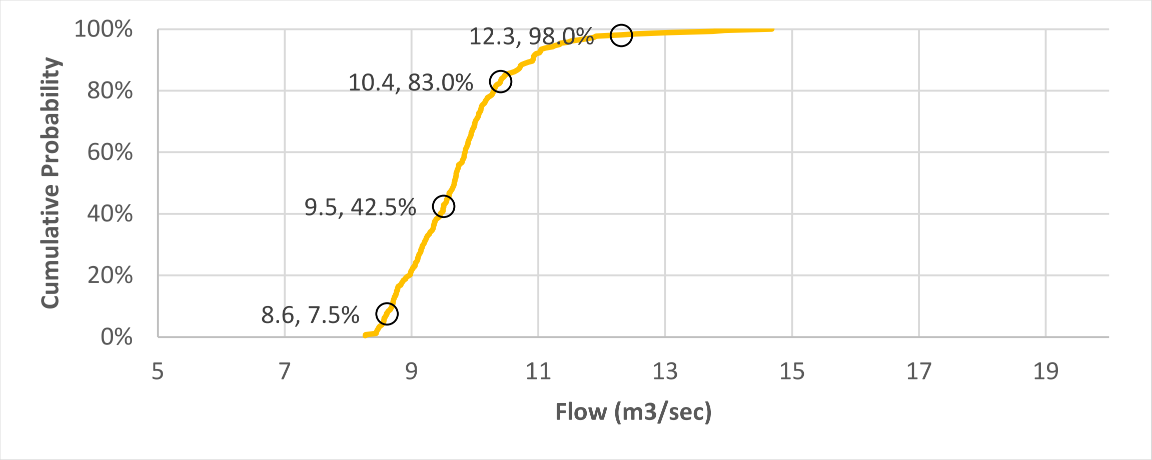

Figure 6-9. Cumulative Probability of AIWWTP Instantaneous Effluent Flow for Q_a >6,000 m^3/s

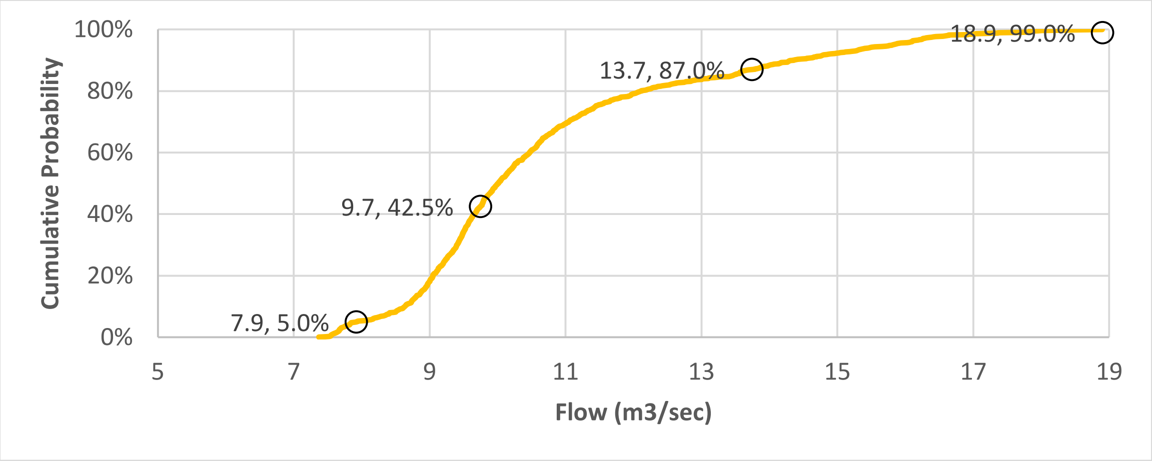

Figure 6-10. Cumulative Probability of AIWWTP Instantaneous Effluent Flow for 6,000 m^3/s>Q_a>1,000 m^3/s

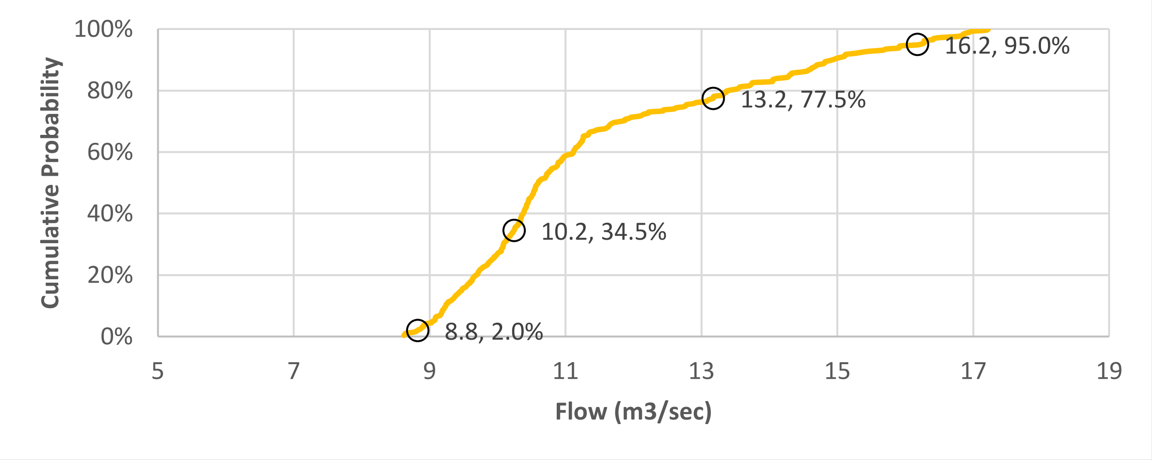

Figure 6-11. Cumulative Probability of AIWWTP Instantaneous Effluent Flow for Q_a <1,000 m^3/s

6.3.5 Seasonal Differences in Temperature

Initial dilution predictions require inputs of effluent density and the vertical profile of ambient density. Because most of the discharge scenarios are freshwater effluent discharging to a freshwater ambient, temperature data is used to define density (the addition of salinity to the ambient density input term is presented in **Section 6.3.7**).

Figure 6-12 shows the contemporaneous dataset between 2011 and 2014 for effluent and ambient temperatures measured at the Gravesend Reach buoy, which indicates that effluent temperature fluctuates less than ambient temperature. The annual average effluent temperature is 16.8°C. Average effluent temperature under the three flow classifications ranges 13.1 to 18.9°C. Ambient temperature averages 9.9°C, and averages for the three flow classifications ranged from 3.9 to 12.8°C.

Table 6-7 presents average effluent temperature, average ambient temperature for each flow classification, and their difference. To represent conditions for parameters with long-term average WQGs, the average effluent temperature and the average ambient temperature are calculated for every month and are presented in **Section 6.3.8**.

Table 6-7. Seasonal Differences in Temperature

Flow Classification	Effluent Temperature (°C)	Ambient Temperature (°C)	Temperature Difference (ΔT, °C)	Percent of Time
$Q_a >= 6{,}000\ m^3/s$	18.9	12.8	6.1	13.2 %
$6{,}000\ m^3/s > Q_a >= 1{,}000\ m^3/s$	17.4	10.6	6.8	63.5 %
$Q_a < 1{,}000\ m^3/s$	13.1	3.9	9.2	23.3 %

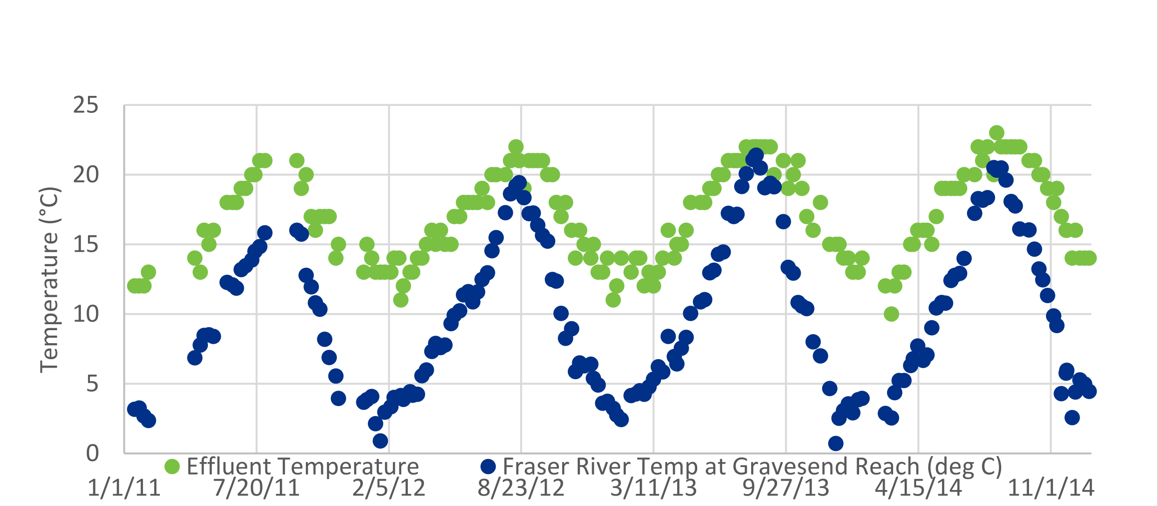

Figure 6-12. Contemporaneous Temperature Data at AIWWTP and the Fraser River at Gravesend Reach

6.3.6 Water Depth

Initial dilution predictions require as input the ambient water depth and depth at which the discharging effluent occurs. As described in **Section 2.1.4**, the Municipal Wastewater Regulations require that the diffuser be located in at least 10 m of water depth. As was discussed in **Section 5**, the project study area does not include a region of sufficient depth to accommodate the diffuser and meet the minimum depth requirements in the Municipal Wastewater Regulations. Therefore, a variance will be sought. For the initial dilution predictions, three depths were used: 10.9 m, which represents the low water depth at the elevation of the dredging grade when the flow in the Fraser River is less than 6,000 m^3/s; 12.2 m as the low water depth when the flow in the Fraser River is greater than 6,000 m^3/s; and 14.4 m, which represents a typical high water level at that location. Each water depth was assigned a 50% probability of occurrence.

To represent parameters for long-term average WQGs, the monthly average depth above the diffuser in the Fraser River was calculated assuming the discharge occurs 10 m below Chart Datum; the values are presented in **Section 6.3.8**.

6.3.7 Salinity

The majority of the model runs assume that the discharging effluent is “fresh” (0 ppt of salinity) to a freshwater body; hence, a uniform, unstratified density profile. As described in **Section 3.2.3** and **Section 3.6**, there is the potential to encounter salinity at the project site given low Fraser River flow and occurrence of a bidirectional current. As demonstrated in the IDZ monitoring data and the data measured at the Gravesend Reach buoy, salinity can be present, but is not always present, at the site when the ambient flow is less than 1,000 m^3/s. The percent of time that the joint occurrence of an ambient flow of less than 1,000 m^3/s and when salinity is greater than 1 ppt is approximately 35% of the time.

To represent conditions for parameters long-term average WQGs, the percent of time the ambient flow is greater than and less than 1,000 m^3/s is calculated. When the flow is less than 1,000 m^3/s, the percent of time that the potential for salinity is then multiplied by the 35% of the time that salinity is predicted to be present, as described in the paragraph above. This is presented in **Section 6.3.8**.

The stratified density profile is based on the measurements presented in LWMP (1997), which are currently the best available data of salinity profiles at or near the project site. **Figure 6-13** shows the pycnocline, the depth where the density gradient is greatest, at 6 m; salinity then increases linearly and reaches a salinity of 6 ppt is reached at the river bottom.

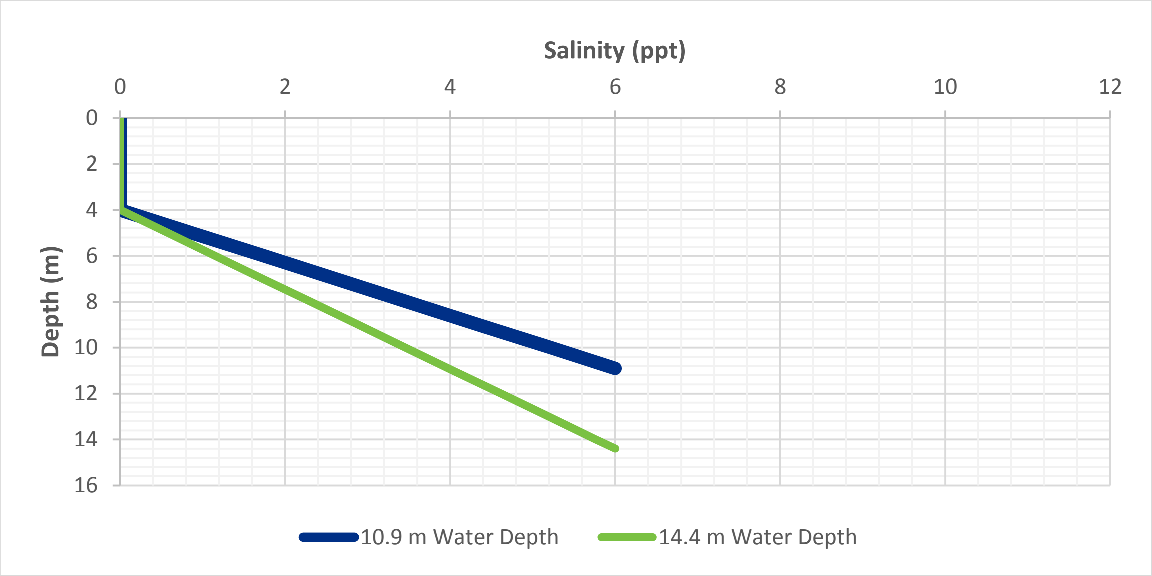

Figure 6-13. Profiles of Salinity at Low- and High-tide Water Depths Based on the Measurements Performed by Seaconsult (1995)

6.3.8 Model Input Summary

This section summarizes the input parameters for the initial dilution predictions simulations. **Table 6-8** presents the input parameters that are common to all UM3 runs.

Table 6-8. Input Parameters for Fixed Variables

Variable	Input Value
Channel width, m	590
Channel winding and non-uniformity	Slight Meander/Medium
River current, m/s	Varies
Wind velocity, m/s	2.4
Manning's friction factor	0.02
Distance from first port to right bank, m	170
Effluent water type	Fresh
Contraction ratio	1

Table 6-9 summarizes the 128 calculations of initial dilution that represent the range of model input parameters to create the cumulative frequency graph of predicted dilution that is used to determine the percentage of time that parameters with short-term maximum endpoints meet WQGs. **Figure 6-14** provides a schematic view of each of the 128 runs and their input values and probabilities.

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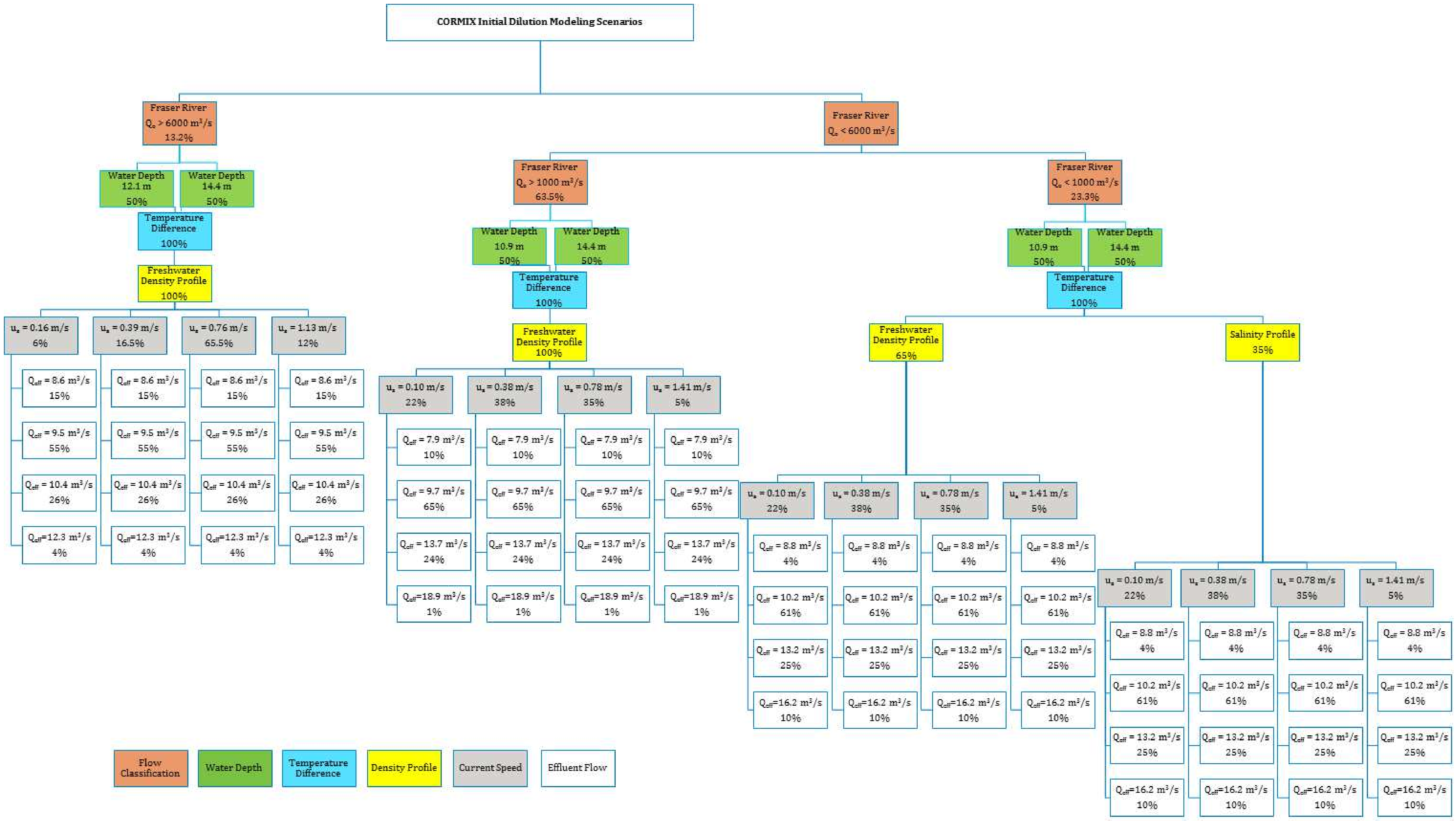

Figure 6-14. Schematic View of Initial Dilution Modeling Scenarios

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Table 6-9. Number of Alternative Input Parameters for Instantaneous Predictions

Flow Classification	Water Depths	Effluent Flows	Current Speed	Temperature Difference	Density Profile
Q_a >= 6,000 m^3/s	2	4	4	1	1
6,000 m^3/s > Q_a >= 1,000 m^3/s	2	4	4	1	1
Q_a < 1,000 m^3/s	2	4	4	1	2

Table 6-10 summarizes the model input parameters for average (monthly) prediction model runs. Eighteen 'runs' represent the average monthly conditions (12 runs with an unstratified density profile and 6 runs with a stratified density profile). The probability of occurrence of salinity on a monthly basis was determined by calculating the monthly percent of time when the Fraser River was less than 1,000 m^3/s. If there were times in the month when the Fraser River flow had occurrences of both above and below 1,000 m^3/s, then calculations were executed with both an unstratified and stratified density profiles. A monthly probability weighted flux-averaged initial dilution included accounting for the presence of salinity and hence the application of the stratified density profile as well as the remaining dilution coming from times when freshwater is present.

Table 6-10. Effluent and Ambient Model Input Parameters for Average (30-day) Predictions

Month	Monthly Average Effluent Temp. (°C)	Monthly Average Future Effluent Flow (m^3/s)	Monthly Average Ambient Depth (m)	Monthly Average Ambient Velocity Magnitude (m/s)	Monthly Average Ambient Temp. (°C)	% of time Q_a > 1,000 m^3/s (Unstratified Density Profile Possible [Fresh])	% of time Q_a < 1,000 m^3/s (Potential for Stratified Density Profile [Saline])
January	13	12.0	12.1	0.43	3.0	44%	56%
February	13	11.2	12.1	0.37	3.5	12%	88%
March	13	11.8	12.0	0.37	4.9	17%	83%
April	15	11.0	12.0	0.40	7.1	84%	16%
May	17	10.2	12.4	0.49	10.0	100%	0%
June	19	9.9	12.8	0.63	12.9	100%	0%
July	21	9.3	12.6	0.51	16.6	100%	0%
August	21	9.0	12.2	0.37	19.1	100%	0%
September	21	9.5	12.1	0.38	16.6	100%	0%
October	19	10.6	12.1	0.41	11.6	100%	0%
November	16	12.2	12.2	0.42	6.9	95%	5%
December	14	11.7	12.1	0.44	3.9	65%	35%

6.4 Ambient Background Concentrations

Ambient background concentrations are water quality data measured at a distance sufficiently upstream from the discharge to not be influenced by the discharge. Data representative of ambient background concentrations were compiled from available data and evaluated for relevance and data quality. The closest upstream station that describes ambient background conditions is the upstream reference area for Annacis' REM program (**Section 3.6**). Additional sources of ambient background data are the "upstream of Sapperton Bar" location of the Ambient Environmental Monitoring Program for the Fraser River (**Section 3.4**), and available federal-provincial monitoring data collected at Gravesend Reach (**Section 3.2**).

Because of its independence of any outfall characteristics, the ambient background concentration for a parameter would typically be characterized with a long-term average concentration at the boundary of the IDZ. In the Fraser River, however, sediment load varies significantly with season, and the increased sediment load results in increased concentrations for some parameters. For example, comparison of Fraser River flow to concentrations of both aluminum and iron at Hope shows a strong correlation between flow and metal concentration. Interestingly, the metal concentration rises with the beginning of the seasonal flow increase and peaks prior to the peak freshet flow. Therefore, the incorporation of ambient background concentration will need to account for this seasonal difference.

Figures 6-15 and **Figure 6-16** show the relationship between copper concentration and aluminum concentration, respectively, and flow at Hope. The strong correlation between copper and turbidity measured at Hope is evident in **Figure 6-17**.

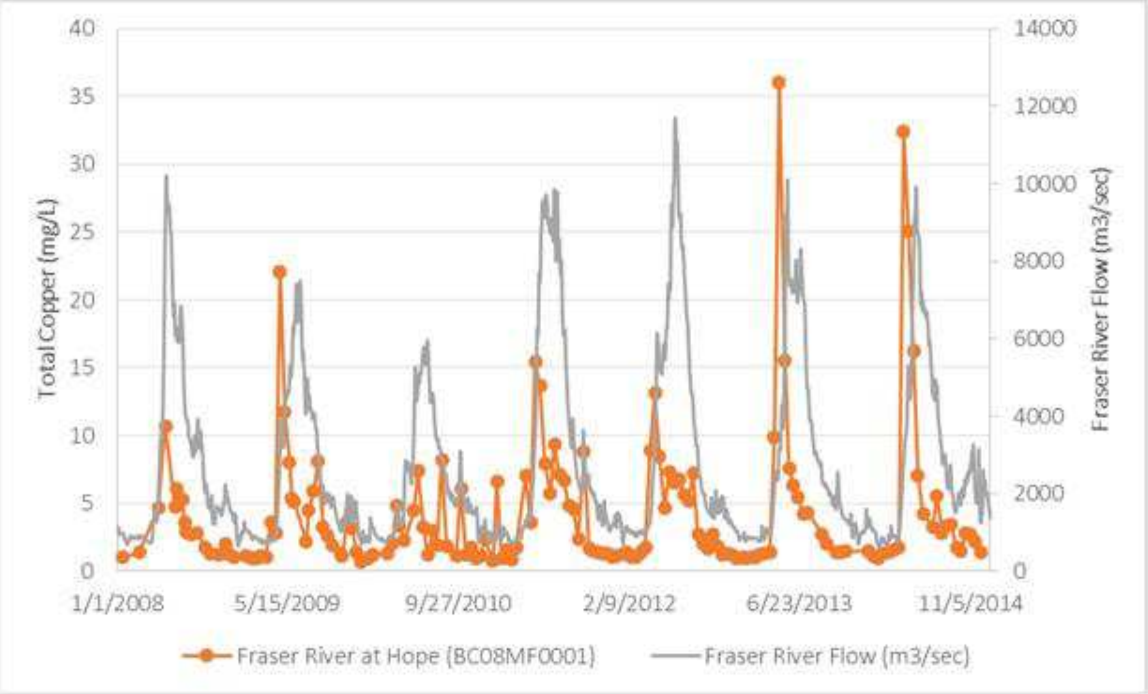


Figure 6-15. Time Series of Copper Concentration and Flow at Hope

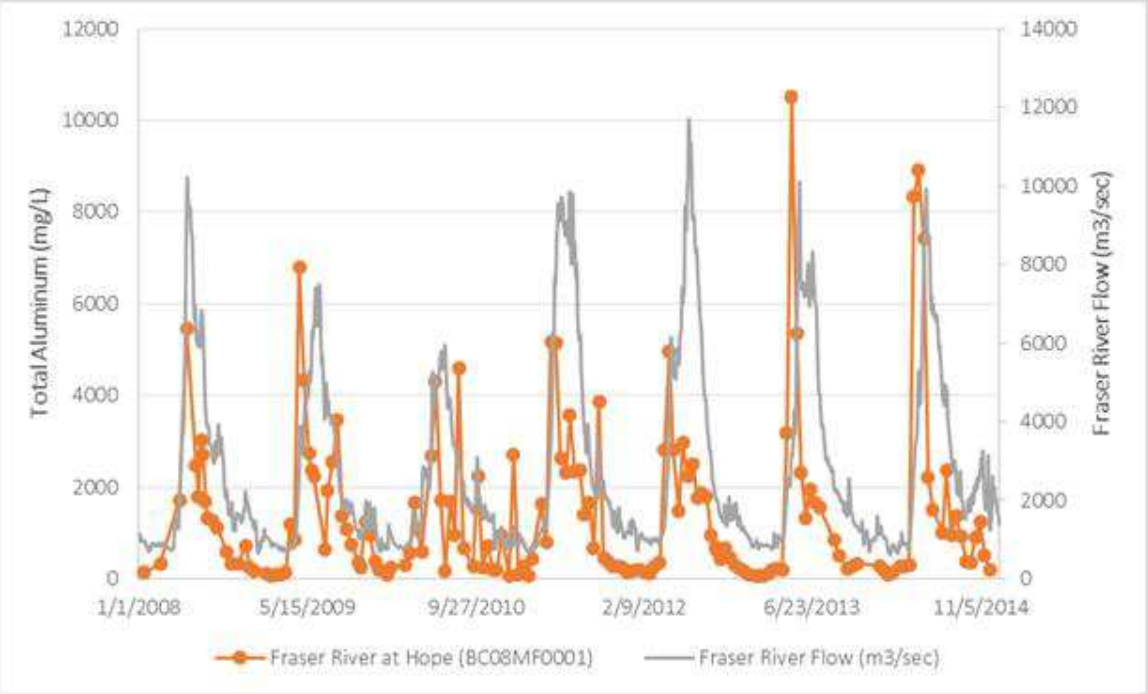


Figure 6-16. Time Series of Aluminum Concentration and Flow at Hope

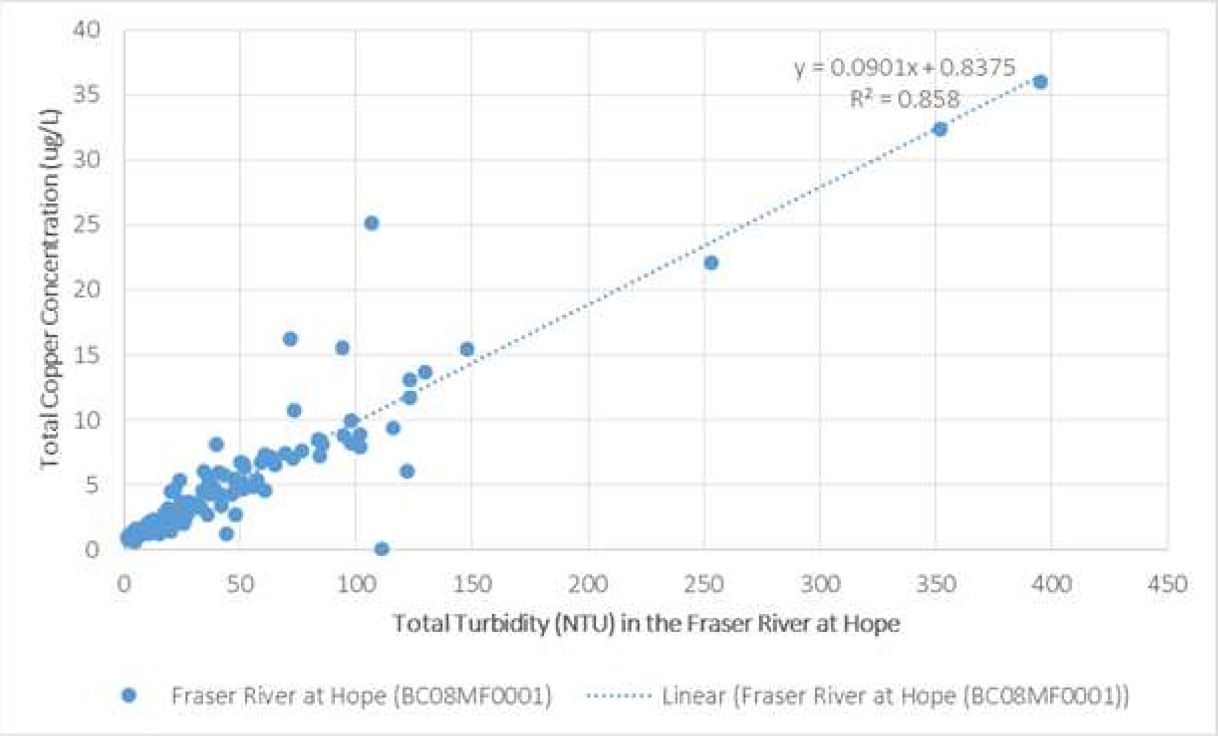


Figure 6-17. Correlation between Copper Concentration and Turbidity at Hope (2008-2014)

Golder Associates evaluated the ambient water quality data and performed the analysis to develop values of ambient background to be used in the predictions at the edge of the IDZ. The general approach used is presented below; the detailed approach is provided by in the Stage 1 EIS describes the data and assumptions used to develop ambient background concentrations for the calculation of the predicted concentration at the edge of the IDZ. Individual ambient background concentration for each parameter are found in the Stage 1 EIS.

- The primary data set is the data from REM program's reference area stations. The REM data have been collected in February-March and September-October; data from 2011-2014 are used to coincide with the data period used for effluent characterization.
- As the REM program data are only collected when the Fraser River is at seasonal low flow, additional data is included to improve the year-round characterization of ambient background levels. Water quality data from Gravesend Reach fill this gap for nutrients, major ions and metals. Samples at Gravesend Reach collected from 2011-2014 will be used to augment the REM program data. (N.B.: Sapperton Bar data are not used because they also are collected at low flows, which are adequately characterized by the REM reference area).
- For each of the conditions described below, mean values were calculated if a water quality parameters had 10 or more samples. If ambient average concentration was not calculated, median concentration is used as a means to define central tendency. Parameters that were not detected were taken at the full value of their detection limit.
  - For parameters with short-term maximum endpoints, average values are calculated for each Fraser River flow classification (>6,000 m^3/s, 6,000>Q>1,000 m^3/s, <1,000 m^3/s) (**Section 6.1.5**) and added with 100% probability of occurring with that flow classification.
  - For parameters with long-term average endpoints, a high flow average is computed and used for April, May, June, July, and August; a low flow average is computed and used for the remaining months.
- If a water quality criterion exists, but not ambient data is available, a concentration of zero is used.
- Data are screened to determine appropriateness to compare to WQG or WQO depending on any determined relationship with river flow/sediment load, availability of detectable data, or parameters that require special other inputs, such as ammonia, to compare to WQGs.

6.5 Contributions from Other Sources

Research was conducted to determine if there were other discharges (CSO, municipal or industrial) between the upstream reference area used as part of Annacis' REM program and Annacis Island. Discharges in this reach of the Fraser River could be the source of contamination that is not otherwise captured in the ambient background station.

No discharges were found, therefore, the analysis of the concentration at the edge of the IDZ does not need to include this term.

6.6 Background Buildup

The background buildup concentration is associated with the presence of previously diluted effluent within the Fraser River as a result of the tidal processes in the Fraser River. The background buildup concentration can be considered as a steady-state average process wherein re-entrainment of previously discharge effluent occurs after tidally reversing currents over many cycles.

For the AIWWTP discharge, background buildup only needs to be considered when the currents at the site are bidirectional.

The *Annacis Island Wastewater Treatment Plant Pre-Discharge Monitoring Dilution/Dispersion Study* (LWMP Environmental Monitoring and Assessments Technical Committee, 1997) provides a description of the mixing processes at the existing outfall based on analysis of a dye study conducted in the mid-1990s; the mixing processes were found to vary with river velocity. When currents were moderate to high (e.g., flood/ebb periods of tidal cycle), the effluent rapidly dispersed due to jet velocity and (temperature-driven only) buoyancy. Then vertical diffusivity mixed the effluent field over the entire vertical section. When there was little current (e.g., slack tide periods), the effluent field rose rapidly to the surface, where it spread slowly incorporating additional dilution through gravitational spreading. Residual current (the net downstream flow when tides are removed) carried the effluent field away from the discharge point. At the lower current velocities, the study concludes “there is little or no opportunity for previously discharged, diluted effluent to be re-entrained in the forming effluent field. The effect of multiple dosing thus is not significant.” The study does not provide a conclusion about the effect of multiple dosings during moderate and high currents.

Previous initial dilution studies of the AIWWTP discharge accounted for background buildup either through using CORMIX’s tidal reversal conditions to account for transient recirculation and re-entrainment of the discharge plume remaining from the previous tidal cycle (Seaconsult, 1995) or through the use of a far-field model (RMA) to obtain a 14-day average of the background buildup (Black and Veatch, 2015). In the latter case, the goal of the modeling was to demonstrate whether the effluent plumes discharging from two nearby diffusers would have overlapping plumes at a 20:1 dilution (they did not overlap). Subsequent analysis by AECOM (2015), however, demonstrates the strong potential for plume overlap and discounting of dilution. Furthermore, initial dilution modeling by Black and Veatch of the preliminary conceptual design of the outfall upgrade using VISJET did not apply background buildup into the initial jet plume modeling efforts, hence previous estimates of dilution at the IDZ may be too high.

The present study includes consideration of background buildup for the following reasons.

- Dye study data confirm that the effluent field can be found throughout the water column, which will be located upriver of the outfall during flooding tides; thus, the return flow during ebbing tide has the potential to return a portion of the effluent field in the entrainment water used for dilution during ebbing tides.

- The diffuser design being evaluated discharges horizontally and not vertically, and this will result in altered mixing dynamics versus that observed in the dye study; horizontally

> discharging ports improve instantaneous dilution over vertical ports, and should minimize, if not avoid, the expression of the rising plume as boils on the river's surface. Further, the singular direction of the ports will push the plume to the middle of the river and the river flow being entrained into newly discharging effluent will come from behind the diffuser.

The presence of background buildup in the Fraser River will reduce the available potential dilution at the edge of the IDZ. For the Stage 1 EIS, a background buildup concentration is calculated as the potential background buildup dilution (S_{BB}) multiplied by the mean effluent concentration. S_{BB} is the ambient flow divided by the projected future effluent flow as developed and reported in **Section 6.3.4**:

$$S_{BB} = \frac{u_a HW}{Q_{eff}}$$

where the ambient flow can be represented by the product of the ambient velocity as measured at Gravesend Reach (**Section 3.2.4**), u_a; the water depth as determined to be the distance between a depth at discharge of 88.4 m (GD+100) and the water surface elevation measured at New Westminster (**Section 3.4**), H; and the river width, W; and the effluent flow (**Section 6.3.4**), Q_{eff}.

Two estimates of background buildup were derived representing different time-scale processes in the river. A more conservative estimate looked for a critical 12-hour period (a tidal cycle) representing a period of low residual current (when flow at Hope is less than 1,000 m^3/s) testing the ability of the river to flush over the course of a tidal cycle. A CFD of the 12-hour averages was developed, and the 5% exceedance value was selected to represent the risk of background buildup for parameters with short-term maximum WQGs (**Figure 6-18**). The 5% exceedance 12-hour average background buildup dilution is 250:1. Background buildup concentrations are only considered when bidirectional flow in the Fraser River flow exists (i.e., when $Q < 6,000\ m^3/s$).

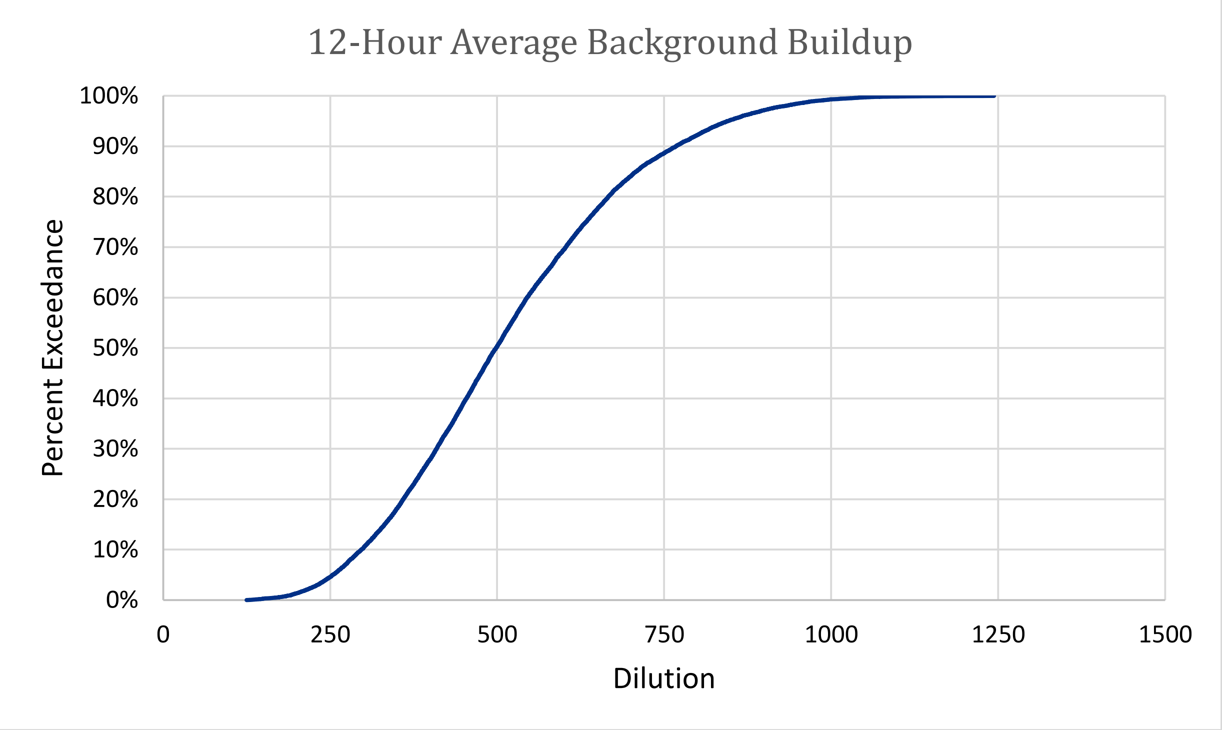


Figure 6-18. Cumulative Frequency Distribution of 12-hour Average Background Buildup Dilution.

For average predictions, a CFD was developed for each of the monthly instantaneous background buildup dilutions, and the 50% exceedance value was used to develop estimates of background buildup and listed in **Table 6-11**. This background buildup dilution will be used for long-term average WQGs.

Table 6-11. Monthly Background Buildup Dilution for Use in Average Predictions

Month	Monthly Average Background Buildup Dilution
January	494
February	480
March	412
April	425
May	544
June	660
July	598
August	534
September	588
October	533
November	405
December	462

Because the Stage 1 EIS makes conservative assumptions to result in an assessment that is more likely to over-predict adverse effects than to under-predict them, all parameters will be assumed to be chemically conservative. This assumption and the approach for estimating the background buildup dilution will be refined during the Stage 2 EIS using results from numerical modeling.

Section 7

Initial Dilution Prediction Results

This section presents the results of initial dilution predictions for three diffuser designs:

- Alternative 1 is a 240-m long diffuser with a fixed port diameter,
- Alternative 2 is a 240-m long diffuser with the variable diameter orifice, and
- Alternative 3 – a 300-m long diffuser with a variable diameter orifice.

Results are presented in terms of cumulative frequencies of dilution and monthly average dilution (for Alternative 2 only, which is the recommended alternative). These results are then used with effluent and ambient background data to make predictions of concentrations at the edge of the IDZ.

7.1 Approach to Determining the Initial Dilution Ratio

The conceptual diffusers, as described in **Section 5**, are the physical configuration used to predict dilution using the Shrivastava-Adams equations for unstratified conditions and the initial dilution in UM3 for stratified conditions. To assess the potential critical combinations of all of these input variables, a probabilistic approach was used.

Each combination of input parameters results in a probability of occurrence of initial dilution that is the product of the probabilities of each of the input parameters (percent of time Q_a occurs, percent of time current speed occurs, percent of time depth occurs, etc.). Predictions are used to define the initial dilution at the edge of the IDZ, which are assigned the joint probability of the model input parameters.

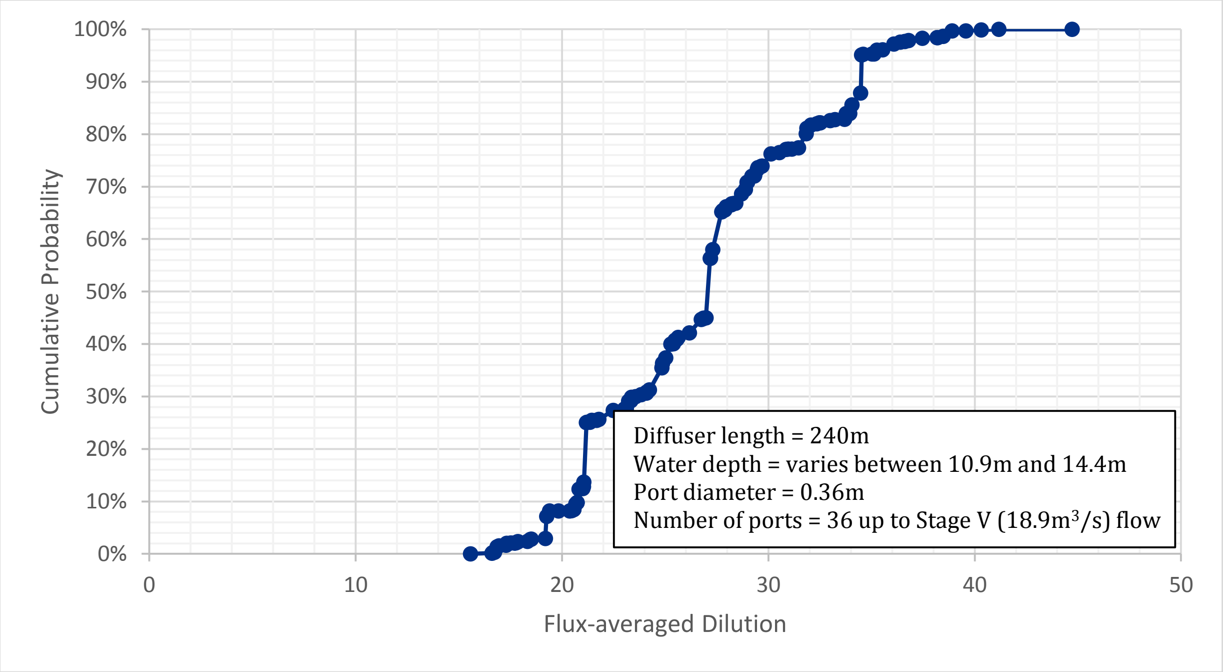
The results of dilution predictions for Alternatives 1 and 2 are listed in tables in **Appendix E** and **Appendix F**, respectively. These tables provide the dilution for each combination of ambient Fraser River flow rate, ambient Fraser River current, depth at discharge, predicted future effluent flow rate, and density profile. Note that each combination of parameters is assumed to occur independently of the others, resulting in a probability of occurrence of each prediction that is the product of the probabilities of each of the input parameters. For example, there is a 23.3% chance of the Fraser River flow being less than 1,000 m^3/s, and there is an 11.0% chance that Fraser River velocities are 0.1 m/s, there is a 50% chance that the depth at discharge is 10.9 m, and there is a 4% chance that the future effluent flow is 8.8 m^3/s, and a 35% chance that salinity is present in the water column. Therefore, the probability of occurrence of the resulting dilution is 0.018% (0.233 * 0.11 * 0.50 * 0.04 * 0.35 = 0.00018). In this manner, the probabilities of each of prediction was calculated. This method was applied to provide predicted dilution for assessing potential impacts for short-term maximum WQGs. A different approach was made when determining the probability of occurrence for parameters with long-term average endpoints as explained in **Section 7.3**.

7.2 Fixed Orifice, Multiport Diffuser and Stage V Flows (Alternative 1)

Figure 7-1 shows the cumulative frequency distribution of flux-averaged initial dilutions as a result of the predictions (Alternative 1). **Appendix E** is a summary table of the primary model inputs, assigned probabilities, and initial dilution results. The cumulative frequency distribution indicates that predicted instantaneous dilution at the IDZ boundary ranges from 15.6:1 to 44.7:1.

Predicted dilution is always greater than 10:1, but is less than 20:1 about 8% of the time, which represents a fraction of the 128 cases simulated. The lowest values occur when low river current is combined with the presence of a salt wedge, which traps the plume in the bottom layer of the river. Most of the cases with dilution less than 20:1 occur at lower river current speeds, recognizing the impact of the square of the current speed in the momentum ratio. A few cases occur when the effluent flow and port velocity are high and the momentum from the diffuser (denominator of m_r) is about equal to the momentum in the river (numerator of m_r); in these instances, the Shirvastava-Adams equation notes the largest negative impact on dilution compared to dilution for the same input parameters at no current (the ratio of S_t/S_o).

Since the characteristics of the ambient waters are not changeable, improvement in initial dilution can only occur by changing the diffuser design. Previously it was noted that dilution from a unidirectional diffuser in a cross flow is relatively insensitive as length varies. This leaves exit port velocity as the remaining term to use to improve dilution – in this case, through the application of variable orifice ports, to increase dilution at lower effluent flow rates.



Diffuser length = 240m
Water depth = varies between 10.9m and 14.4m
Port diameter = 0.36m
Number of ports = 36 up to Stage V (18.9m^3/s) flow

Figure 7-1. Cumulative Frequency Distribution of Predicted Instantaneous Dilution at the IDZ for a Multiport Diffuser with a Fixed Orifice (Alternative 1)

7.3 Variable Orifice, Multiport Diffuser and Stage V Flows (Alternative 2)

7.3.1 Cumulative Frequency Dilution Results

The port discharge velocity drives the momentum flux of a jet discharging into a river. When effluent and ambient currents flows are low, the port discharge velocity is too low at a fixed orifice diameter of 360 mm to entrain sufficient flow to create higher dilutions. The low port discharge velocity can be increased by adding a valve (e.g., a Tideflex diffuser valve) to a port to create a variable orifice.

This larger port discharge velocity will improve the momentum flux and can increase initial dilution. Based on a manufacturer's flow vs. velocity curve for a 600 mm Tideflex diffuser valve (Hydraulic Code 2165), the effective port discharge velocity can be ascertained. The effective port area and the corresponding diameter of the variable orifice is then back-calculated from the effluent flow per port and port discharge velocity. The port diameter is then used as an input into predictive tools with all other input characteristics remaining the same. **Appendix F** is a summary table of the model inputs, assigned probabilities, and predicted initial dilution results for a variable orifice.

Figure 7-2 is the cumulative frequency distribution for Alternative 2 of predicted initial dilution for a variable orifice compared against the distribution for a fixed orifice (same as **Figure 7-1**). Predicted dilutions range from about 17.8:1 to 47.8:1, demonstrating the increase in initial dilution using a variable orifice. While the percentage of time the predictions are less than 20:1 are even more reduced, this is predicted to occur less than 3% of the time. These lowest dilutions occur under stratified and unstratified conditions when the ambient current are low.

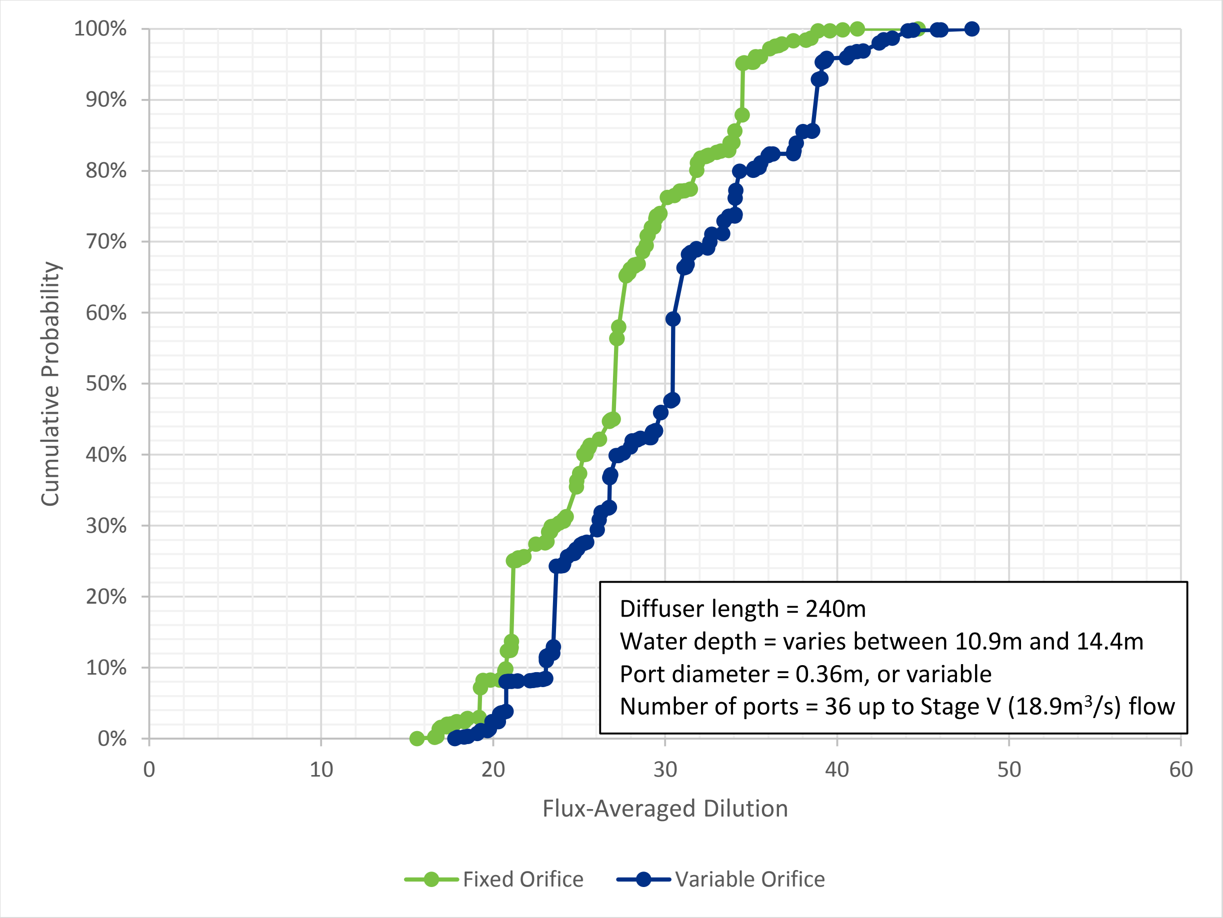


Figure 7-2. Cumulative Frequency Distribution of Initial Dilution at the IDZ for a Variable Orifice vs. Fixed Orifice (Alternatives 1 and 2)

7.3.2 Predicted Monthly Average Model Dilution

Table 7-1 summarizes the average monthly, flux-averaged initial dilutions for Alternative 2 as a result of the Shrivastava-Adams equation for unstratified conditions and UM3 results for stratified conditions was applied to develop the monthly probability weighted flux averaged initial dilution.

The results in **Table 7-1** indicate that across the months, there is limited variability in dilution as a result of unstratified flow and that the major difference in the probability weighted flux-averaged dilution is as a result of the seasonal presence of salinity.

Figure 7-3 shows the predicted average monthly, flux-averaged initial dilution results.

Table 7-1. Predicted Monthly Average Flux-Averaged Dilutions for Alternative 2

Month	Flux- Averaged Initial Dilution for an Unstratified Density Profile (Fresh)	Flux- Averaged Initial Dilution for a Stratified Density Profile (Saline)	Percent of Time Salinity is Present and Q_a <1000 m^3/s (Saline)	Percent of Time Salinity is not Present and Q_a <1000 m^3/s (Fresh)	Predicted Monthly Flux-Averaged Initial Dilution
January	26.3	30.2	35%	65%	27.7
February	25.9	30.1	35%	65%	27.4
March	25.2	29.5	35%	65%	26.7
April	26.7	30.8	35%	65%	28.1
May	29.9	N/A	0%	100%	29.9
June	33.3	N/A	0%	100%	33.3
July	31.8	N/A	0%	100%	31.8
August	28.9	N/A	0%	100%	28.9
September	28.0	N/A	0%	100%	28.0
October	27.3	N/A	0%	100%	27.3
November	26.1	30.8	35%	65%	27.7
December	26.9	29.6	35%	65%	27.8

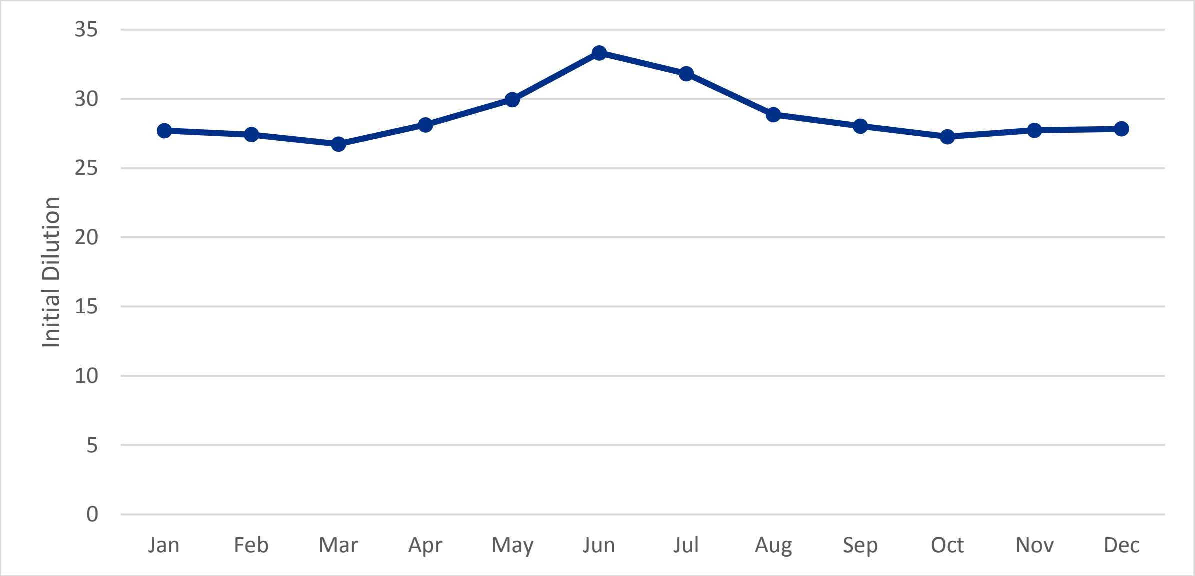


Figure 7-3. Monthly Flux-Averaged Initial Dilution at the Edge of the IDZ for Alternative 2

7.4 Results for Increased Length (Alternative 3)

Alternative 3 explores increasing the length and number of ports (and maintaining the discharge velocity and port spacing), while holding the head loss constant. An equivalent diffuser to Alternative 2 (variable ports) would have 60 ports of 0.325 m diameter at 5 m spacing for Stage VIII flows, but only 40 ports would be open for Stage V flows.

The Shirvastava-Adams equation does not capture the difference in port spacing. Although exit velocity is being held constant, length changes. The length of the diffuser is present in the equation for momentum ratio, fundamental dilution, and within the Shirvastava-Adams equation. The result of a slight change in length, while holding other major factors constant, results in minor improvements compared to Alternatives 1 and 2. This minor improvement may be verified by using a scaled physical model.

The results are presented in **Figure 7-4**, and show a minor increase in predicted dilutions which range from about 18.1:1 to 52.9:1.

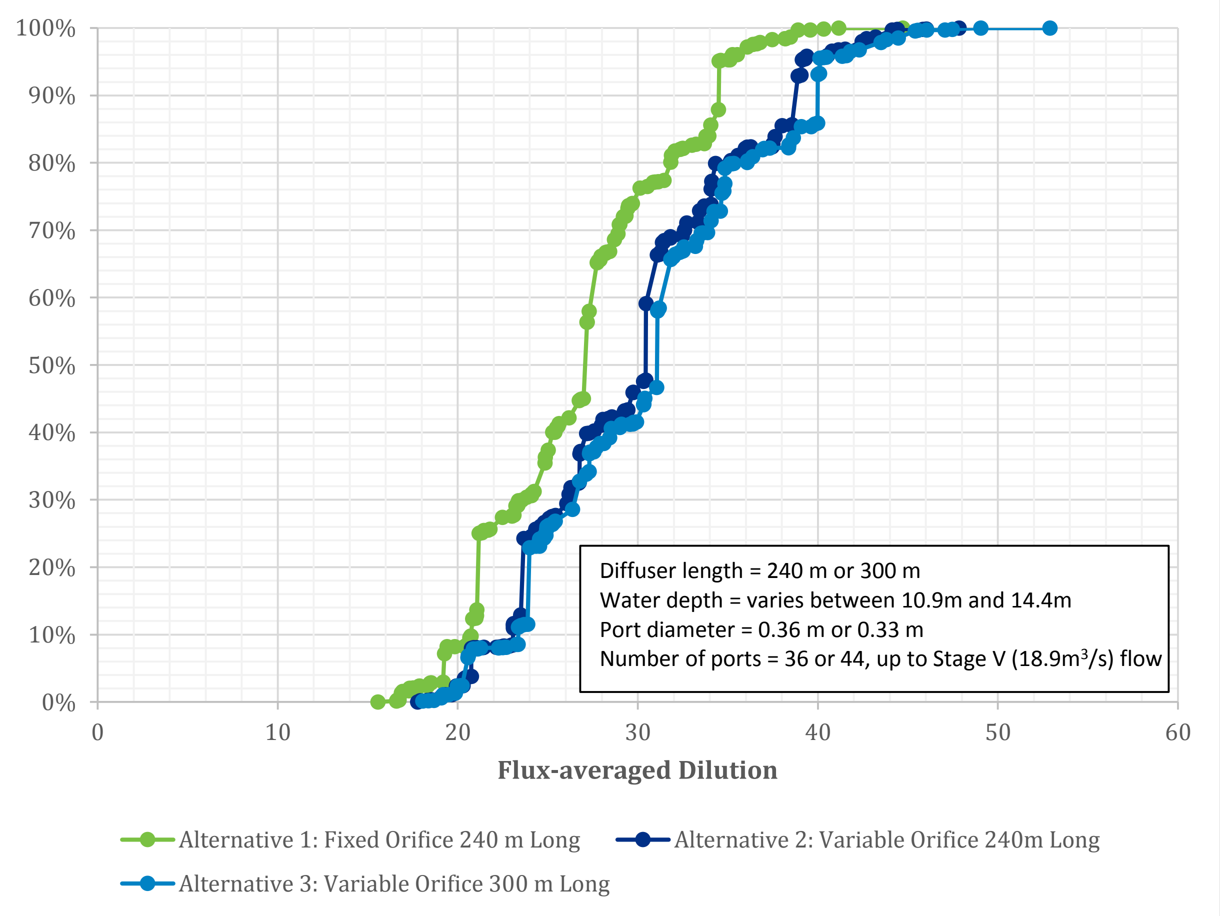


Figure 7-4. Comparison of UM3 Predictions of Initial Dilution for a 240-m long Diffuser with 18 vs. 40 Ports under Stratified Conditions (Alternative 1 and 3)

7.5 Results for Stage VIII Flows

As described in **Section 5.5**, the proposed diffuser is to be constructed with 48 ports. Thirty-six ports are open for the Stage V flows of 18.9 m^3/s and twelve additional ports are opened during the increase to Stage VIII flows of 25.3 m^3/s. The results in this section are applicable to Alternative 2 and 3 as the equivalent port diameter is the same (**Table 5-2**).

Initial dilution predictions were executed using the model input conditions (range of ambient current speeds, ambient depths, temperature difference, and density profiles) that described the Fraser River flow classification of 6000 m^3/s > Q >1000 m^3/s. The effluent flow was held at 25.3 m^3/s as these model runs were not included to determine probabilistic-weighted initial dilution, but rather to ensure that the diffuser could function as designed for the Stage V to Stage VIII increase and still be operational without a negative impact to initial dilution. **Figure 7-5** show the initial dilution for these calculations compared to the Stage V flows. The port diameter for each stage in this comparison is 0.36 m, but the difference is the number of ports that are open. The diffuser, when operating at Stage VIII flows shows decreased initial dilution due to the variable orifice being optimized to having the fixed orifice at Stage VIII flows. The variable orifice is functioning with increased port exit velocity with Stage V flows and hence the slightly improved initial dilution.

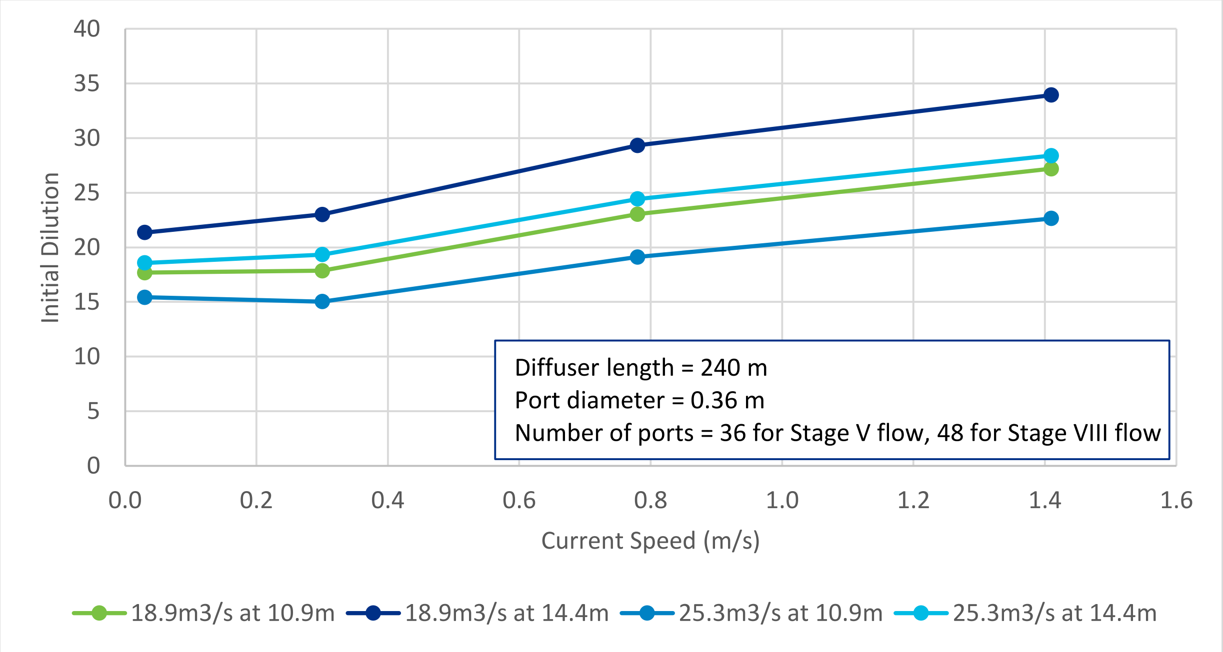


Figure 7-5. Comparison of the Stage V Effluent Flow (18.9 m^3/s) to a Stage VIII Effluent Flow (25.3 m3/s) with a Fixed Orifice Diameter of 360 mm

7.6 Predictions at the Edge of the IDZ

This section provides predictions of effluent concentrations at the edge of the IDZ for:

- The interim guideline for temperature in estuaries where the comparison to the criterion is calculated directly using matched pairs of river and effluent temperature data from 2011-2014, and
- The remaining effluent parameters where the comparison to criteria follows the methodology described in **Section 7.1**.

7.6.1 Comparison of the Effect of Effluent Temperature on Ambient Water Temperature

The interim water quality temperature guideline to protect aquatic life limits the temperature changes to a +/- 1°C temperature variation at any time, location or depth in marine and estuarine waters. A conservative analysis was undertaken to evaluate this guideline using the minimum dilutions associated with effluent flow class. The simplification is justified if the guideline is met in all circumstances, otherwise an assessment of predicted daily dilution would be used.

The conservative comparison of effluent and river temperatures at the edge of the IDZ was performed as follows:

- Contemporaneous temperature data between 2011-2014 from the AIWWTP daily operational dataset and ambient river temperature measured at the Gravesend Reach buoy are compared, and the difference in temperature calculated for each date.
- The data are then correlated by date to the Fraser River flow at Hope to determine the flow classification and the respective value of minimum dilution associated with each flow class.
- The effluent temperatures are divided by the minimum dilution and then compared the corresponding river temperatures.

The differences between effluent and ambient temperature range between 0.03°C to 14.3°C. The maximum difference occurred during the winter months when flow was less than 1,000 m^3/s. Based on the minimum predicted dilution for the less than 1,000 m^3/s flow classification, the predicted impact in temperature is 0.8°C and is less than the allowable change in the interim guideline.

7.6.2 Predictions of Concentrations at the Edge of the IDZ

The goal of this Stage 1 dilution analysis was to provide the best estimate of dilution for a multiport diffuser design, while making conservative assumptions as stipulated for Stage 1 EIS analysis. The best estimate of dilution at the edge of the IDZ has three components: ambient background concentrations, background buildup concentrations, and initial dilution predictions. Initial dilution was calculated for a 240-m long diffuser with 36 ports fitted with a variable orifice under Stage V effluent flows (Alternative 2). A probability distribution of initial dilution was determined for a wide range of effluent and river conditions, and various components of the predicted initial dilutions are used in determining the edge of IDZ concentrations for comparison to WQGs.

The details of the prediction methodology are described in **Section 6.1**, and summarized below.

Calculations for comparison to short-term maximum WQGs are based on the maximum concentration of each parameter as detected (or if all analyses had not detected results, the maximum detection limit) in the effluent data base (**Appendix A**). Calculations for comparison to long-term average WQGs are based on the average effluent concentration of each parameter. Ambient data, summarized by Golder Associates in the Stage 1 EIS, are categorized by the three river flow classification for instantaneous calculations and by high flow months (April, May, June, July, and August) or low flow months (January, February, March, September, October, November, December) for average calculations.

Background buildup concentrations are only included in the assessment for instantaneous predictions when bi-directional flow is present (when $Q < 6{,}000$ m^3/s) as described in **Section 6.6.**

Near-field concentrations are calculated based on the minimum predicted dilution for each flow classification, which ranges from 17.8:1 to 19.7:1, or the monthly average predicted dilution, which ranges from 26.7:1 to 33.3:1, as described in **Section 7.2.2**. Concentrations at the edge of the IDZ are based on the methodology described in **Section 6.1**.

Predictions are presented for only parameters that have water quality guidelines, objectives, or other screening criteria. If effluent data are not available, predictions are not determined. For instances when ambient data are not available, an ambient concentration of zero is assumed. For instances when mean concentrations for ambient data are not available, median concentrations, as a substitute of central tendency, are used. Some parameters that do not have ambient or effluent data, but may have water quality guidelines are also included to demonstrate a gap and potential need for future monitoring.

A summary of the predicted concentrations at the edge of the IDZ calculations for use in comparison to WQGs is presented in **Table 7-2,** along with the data on effluent and ambient concentrations. Golder Associates uses these predictions to assess compliance with the WQGs, WQOs and other screening criteria in the Stage 1 EIS.

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Table 7-2. Predicted Concentrations at the Edge of the IDZ for a 240-m Long Diffuser with 36 Variable Orifice Ports for Stage V Flows

		EFFLUENT INFORMATION		AMBIENT INFORMATION					FINAL CONCENTRATIONS (EDGE OF THE IDZ)														
		INSTANTANEOUS	LONG-TERM AVERAGE	INSTANTANEOUS			LONG-TERM AVERAGE		INSTANTANEOUS			LONG-TERM AVERAGE											
PARAMETER	UNITS	MAX CONC	AVG CONC	HIGH FLOW AVG CONC	MOD FLOW AVG CONC	LOW FLOW AVG CONC	APR-AUG (APR-OCT for biota) AVG CONC	JAN FEB MAR SEP OCT NOV DEC AVG CONC	HIGH FLOW CONC	MOD FLOW CONC	LOW FLOW CONC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Conventional Parameters																							
pH	-	7.2	7.0	7.8	7.4	7.7	7.70	7.52															
Salinity	ppt	0.78	0.35	0.04	0.06	0.21	0.06	0.12	0.08	0.11	0.25	0.14	0.14	0.14	0.07	0.07	0.07	0.07	0.07	0.14	0.14	0.14	0.14
Conductivity	µS/cm	1486	619	-	61	67	69	64		150	153	87	87	88	93	91	89	90	92	87	87	87	87
Specific conductivity	µS/cm			96	96	111	119	102															
Temperature	°C	22.8	17.0	13.5	12.5	3.6	13.5	8.6	14.6	13.8	4.9	9.2	9.2	9.3	14.1	14.1	14.0	14.0	14.1	9.2	9.2	9.2	9.2
Dissolved oxygen	mg/L	5.6	4.6	12	11	13	11	12															
Carbonaceous Biochemical Oxygen Demand (CBOD5)	mg/L	28	6.9						1.4	1.7	1.6	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3
Dissolved organic carbon	mg/L	15	10.9	4	3	2	4	2	4.8	3.5	3.1	2.5	2.5	2.5	2.5	2.5	2.4	2.5	2.5	2.5	2.5	2.5	2.5
Hardness, as $CaCO_3$	mg/L	61	45	44	49	71	49	57	47	52	74	59	59	59	51	50	50	50	50	59	59	59	59
Total Residual Chlorine	mg/L	<0.1	<0.06						<0.005	<0.006	<0.006	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Total alkalinity, as $CaCO_3$	mg/L			42	43	50	45	40															
Total dissolved solids	mg/L			-	86	304	-	249															
Total organic carbon	mg/L	17	13	-	2.1	2.5	-	2		3.1	3.5	2.7	2.7	2.8						2.7	2.7	2.7	2.7
Total suspended solids	mg/L	24	8.6	112	26	12	81	15	113	28	14	16	16	16	81	81	81	81	81	16	16	16	16

		EFFLUENT INFORMATION		AMBIENT INFORMATION					FINAL CONCENTRATIONS (EDGE OF THE IDZ)														
		INSTANTANEOUS	LONG-TERM AVERAGE	INSTANTANEOUS			LONG-TERM AVERAGE		INSTANTANEOUS			LONG-TERM AVERAGE											
PARAMETER	UNITS	MAX CONC	AVG CONC	HIGH FLOW AVG CONC	MOD FLOW AVG CONC	LOW FLOW AVG CONC	APR-AUG (APR-OCT for biota) AVG CONC	JAN FEB MAR SEP OCT NOV DEC AVG CONC	HIGH FLOW CONC	MOD FLOW CONC	LOW FLOW CONC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Turbidity	NTU			68	22	6	55	8															
Major Ions																							
Bicarbonate	mg/L																						
Carbonate	mg/L																						
Chloride	mg/L			1	9	71	5	35															
Fluoride	mg/L	0.14	0.07	0.04	0.03	0.04	0.04	0.03	0.04	0.04	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Sulphate	mg/L	21.8	17.0	5	9	15	7	10	7	10	17	10	10	10	7	7	7	7	7	10	10	10	10
Calcium	mg/L	18.2	12.9	13	14	16	14	14	14	15	17	15	15	15	14	14	14	14	14	15	15	15	15
Magnesium	mg/L	5.6	3.1	3	4	8	3	5	2.9	3.8	8.2	5.3	5.3	5.3	3.6	3.6	3.6	3.6	3.6	5.3	5.3	5.3	5.3
Potassium	mg/L			0.7	0.9	2.3	0.8	1.5															
Nutrients																							
Ammonia (un-ionized)	mg-N/L	0.93	0.54	4.69E-04	2.76E-04	3.97E-04	5.27E-04	3.14E-04	0.048	0.056	0.055	0.021	0.021	0.022	0.021	0.019	0.017	0.018	0.020	0.020	0.021	0.021	0.021
Total ammonia	mg-N/L	37.2	29.8	0.03	0.05	0.07	0.04	0.06	1.92	2.28	2.24	1.19	1.20	1.24	1.17	1.09	0.98	1.03	1.13	1.17	1.20	1.20	1.19
Total phosphorus	mg-P/L	4.3	2.5	0.19	0.06	0.03	0.13	0.03	0.40	0.31	0.28	0.13	0.13	0.13	0.23	0.22	0.21	0.21	0.22	0.12	0.13	0.13	0.13
Dissolved phosphorus	mg-P/L	4.0	2.2	0.01	0.02	0.02	0.01	0.02	0.21	0.26	0.25	0.10	0.11	0.11	0.10	0.09	0.08	0.09	0.09	0.10	0.11	0.11	0.10
Nitrate	mg-N/L	0.32	0.03	0.02	0.07	0.19	0.04	0.12	0.03	0.09	0.21	0.12	0.12	0.12	0.04	0.04	0.04	0.04	0.04	0.12	0.12	0.12	0.12
Nitrate + nitrite	mg-N/L			0.09	0.19	0.20	0.20	0.16															
Nitrite	mg-N/L	0.39	0.05	9.61E-03	4.24E-03	2.83E-03	9.15E-03	2.72E-03	2.94E-02	2.76E-02	2.56E-02	4.73E-03	4.76E-03	4.82E-03	1.11E-02	1.10E-02	1.08E-02	1.09E-02	1.11E-02	4.70E-03	4.76E-03	4.75E-03	4.73E-03
Total nitrogen (calculated)	mg-N/L			0.30	0.33	0.38	0.44	0.30															
Total Phosphate - as P	mg-P/L			-	0.03	0.03	0.06	0.03															
Total Metals																							
Aluminum	µg/L	140	48	2464	579	173	1814	252	2471	585	181	254	254	254	1811	1812	1812	1812	1812	254	254	254	254
Antimony	µg/L			0.09	0.05	0.07	0.08	0.05															
Arsenic	µg/L	1.7	0.7	1.1	0.5	0.5	0.9	0.5	1.1	0.6	0.6	0.5	0.5	0.5	0.9	0.9	0.9	0.9	0.9	0.5	0.5	0.5	0.5
Barium	µg/L	16	5	40	20	16	34	16	41	21	17	16	16	16	34	34	34	34	34	16	16	16	16

		EFFLUENT INFORMATION		AMBIENT INFORMATION					FINAL CONCENTRATIONS (EDGE OF THE IDZ)														
		INSTANTANEOUS	LONG-TERM AVERAGE	INSTANTANEOUS			LONG-TERM AVERAGE		INSTANTANEOUS			LONG-TERM AVERAGE											
PARAMETER	UNITS	MAX CONC	AVG CONC	HIGH FLOW AVG CONC	MOD FLOW AVG CONC	LOW FLOW AVG CONC	APR-AUG (APR-OCT for biota) AVG CONC	JAN FEB MAR SEP OCT NOV DEC AVG CONC	HIGH FLOW CONC	MOD FLOW CONC	LOW FLOW CONC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Beryllium	µg/L			0.07	0.02	<0.01	0.05	<0.01															
Bismuth	µg/L			0.02	0.01	<0.005	0.02	<0.005															
Boron	µg/L	303	158	3	12	31	6	<10	19	30	48	16	16	16	12	12	11	11	12	16	16	16	16
Cadmium	µg/L	3.7	0.3	0.06	0.03	0.02	0.06	0.02	0.249	0.250	0.234	0.027	0.027	0.027	0.066	0.065	0.064	0.065	0.066	0.027	0.027	0.027	0.027
Chromium	µg/L	5	1.0	4.4	1.1	0.4	3.4	0.5	4.6	1.4	0.7	0.51	0.51	0.51	3.46	3.46	3.45	3.46	3.46	0.51	0.51	0.51	0.51
Cobalt	µg/L	1.1	0.6	2.2	0.5	0.2	1.6	0.2	2.2	0.6	0.2	0.26	0.26	0.26	1.65	1.65	1.65	1.65	1.65	0.26	0.26	0.26	0.26
Copper	µg/L	43	20	6.5	2.3	1.4	5.2	1.5	8.7	4.9	3.9	2.2	2.2	2.3	5.9	5.9	5.8	5.8	5.9	2.2	2.2	2.2	2.2
Iron	µg/L	1650	510	3644	868	298	2725	381	3728	963	393	400	400	400	2738	2738	2737	2737	2739	399	400	400	400
Lead	µg/L	2.0	0.7	1.5	0.4	0.2	1.1	0.2	1.6	0.5	0.3	0.24	0.25	0.25	1.17	1.17	1.17	1.17	1.17	0.24	0.25	0.25	0.24
Lithium	µg/L			2.4	1.3	1.7	2.1	1.3															
Manganese	µg/L	94	62	113	33	18	87	19	117	39	23	22	22	22	89	89	89	89	89	22	22	22	22
Mercury	µg/L	<0.05	<0.05		<0.01	<0.01	<0.01	<0.01	<0.003	<0.013	<0.013	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012	<0.012
Molybdenum	µg/L	15	1.4	0.5	0.7	0.8	0.6	0.7	1.3	1.6	1.7	0.79	0.79	0.79	0.62	0.62	0.61	0.62	0.62	0.79	0.79	0.79	0.79
Nickel	µg/L	22	2.9	7.7	2.4	1.1	6.6	1.1	8.8	3.8	2.4	1.2	1.3	1.3	6.6	6.6	6.6	6.6	6.6	1.2	1.3	1.3	1.2
Platinum	µg/L			<0.001	<0.001	<0.001	<0.001	<0.001															
Selenium	µg/L	<10	<0.65	0.1	0.1	0.1	0.1	0.1	0.6	0.7	0.7	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Silver	µg/L	<1	<0.55	0.02	0.01	<0.005	0.02	<0.005	0.07	0.07	<0.063	<0.026	<0.026	<0.027	0.04	0.03	0.03	0.03	0.04	<0.025	<0.026	<0.026	<0.026
Strontium	µg/L			82	77	103	83	86															
Thallium	µg/L			0.02	0.01	0.01	0.02	0.01															
Tin	µg/L			0.01	0.03	0.03	0.02	<0.01															
Titanium	µg/L			-	6.40	4.18	-	4.8															
Tungsten	µg/L			0.01	0.01	0.01	0.01	0.01															
Uranium	µg/L			0.29	0.21	0.22	0.26	0.20															
Vanadium	µg/L			5.9	1.6	1.0	4.5	0.9															
Zinc	µg/L	67	25	10.3	3.0	2.2	7.9	2.0	13.7	7.1	6.1	3.0	3.0	3.0	8.9	8.8	8.7	8.7	8.8	2.9	3.0	3.0	3.0
Dissolved Metals																							
Aluminum	µg/L	47	14	138	45	15	116	22	140	48	18	23	23	23	116	116	116	116	116	23	23	23	23
Antimony	µg/L			0.04	0.04	0.06	0.04	0.05															
Arsenic	µg/L	<10	2	0.37	0.34	0.39	0.37	0.35	0.87	0.94	0.97	0.42	0.42	0.42	0.44	0.43	0.43	0.43	0.43	0.42	0.42	0.42	0.42
Barium	µg/L	6.8	3.3	13.1	13.1	13.8	14.0	13.0	13.4	13.4	14.2	13.1	13.1	13.1	14.1	14.1	14.1	14.1	14.1	13.1	13.1	13.1	13.1
Beryllium	µg/L			0.01	0.01	<0.01	0.01	<0.01															
Bismuth	µg/L			1.44E-03	3.00E-03	<0.005	2.12E-03	<0.005															
Boron	µg/L	286	151	3.2	12.1	<32	5.7	<11	17.7	29.2	48.6	16.7	16.8	17.0	11.5	11.1	10.5	10.7	11.3	16.6	16.8	16.8	16.7
Cadmium	µg/L	2.0	0.24	0.01	0.01	0.01	0.02	0.01	0.12	0.13	0.13	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02

		EFFLUENT INFORMATION		AMBIENT INFORMATION					FINAL CONCENTRATIONS (EDGE OF THE IDZ)														
		INSTANTANEOUS	LONG-TERM AVERAGE	INSTANTANEOUS			LONG-TERM AVERAGE		INSTANTANEOUS			LONG-TERM AVERAGE											
PARAMETER	UNITS	MAX CONC	AVG CONC	HIGH FLOW AVG CONC	MOD FLOW AVG CONC	LOW FLOW AVG CONC	APR-AUG (APR-OCT for biota) AVG CONC	JAN FEB MAR SEP OCT NOV DEC AVG CONC	HIGH FLOW CONC	MOD FLOW CONC	LOW FLOW CONC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Chromium	µg/L	3.8	0.7	0.3	0.1	0.1	0.2	0.1	0.45	0.37	0.37	0.16	0.16	0.16	0.27	0.27	0.27	0.27	0.27	0.16	0.16	0.16	0.16
Cobalt	µg/L	<1	0.6	0.1	0.1	0.04	0.1	0.04	0.16	0.11	0.10	0.06	0.06	0.06	0.12	0.12	0.12	0.12	0.12	0.06	0.06	0.06	0.06
Copper	µg/L	29.1	10.3	1.1	0.8	0.8	1.1	0.8	2.6	2.6	2.5	1.2	1.2	1.2	1.5	1.5	1.4	1.4	1.5	1.2	1.2	1.2	1.2
Iron	µg/L	285	125	146	55	43	130	37	160	72	59	42	42	42	135	134	134	134	135	42	42	42	42
Lead	µg/L	<1	0.55	0.09	0.03	0.02	0.08	0.02	0.14	0.09	0.08	0.04	0.04	0.04	0.10	0.10	0.09	0.09	0.10	0.04	0.04	0.04	0.04
Lithium	µg/L			0.7	0.9	1.6	0.9	1.1															
Manganese	µg/L	75	50	9	6	9	10	6	13	11	13	8	8	8	12	12	12	12	12	8	8	8	8
Mercury	µg/L			-	<0.01	<0.01	<0.01	<0.01															
Molybdenum	µg/L	13.5	1.3	0.7	0.7	0.8	0.7	0.8	1.4	1.5	1.6	0.8	0.8	0.8	0.8	0.8	0.7	0.8	0.8	0.8	0.8	0.8	0.8
Nickel	µg/L	21.4	2.7	0.8	0.7	0.5	1.2	0.5	1.9	2.0	1.8	0.6	0.6	0.6	1.3	1.2	1.2	1.2	1.2	0.6	0.6	0.6	0.6
Platinum	µg/L			<0.001	<0.001	<0.001	<0.001	0.001															
Selenium	µg/L	<1	<0.56	0.08	0.08	0.12	0.09	0.09	0.13	0.14	0.18	0.12	0.12	0.12	0.11	0.11	0.11	0.11	0.11	0.12	0.12	0.12	0.12
Silver	µg/L	<10	<0.65	0.0017	0.004	<0.005	0.002	<0.005	0.5	0.6	<0.063	<0.026	<0.026	<0.027	0.027	0.025	0.023	0.024	0.026	<0.025	<0.026	<0.026	<0.026
Strontium	µg/L			70	74	103	74	85															
Thallium	µg/L			4.38E-03	4.64E-03	<0.002	4.87E-03	4.86E-03															
Tin	µg/L			<0.005	8.00E-03	<0.011	<0.005	<0.01															
Titanium	µg/L			-	<0.5	<0.5	-	<0.5															
Tungsten	µg/L			6.31E-03	8.33E-03	6.00E-03	7.28E-03	8.29E-03															
Uranium	µg/L			0.2	0.2	0.2	0.2	0.2															
Vanadium	µg/L			0.7	0.4	0.6	0.6	0.4															
Zinc	µg/L	51	18	0.5	0.5	0.8	0.4	0.7	3.0	3.6	3.8	1.4	1.4	1.4	1.1	1.1	1.0	1.0	1.1	1.4	1.4	1.4	1.4
Biota																							
Coliforms Fecal (April)	MPN/100mL		19				35								36								
Coliforms Fecal (May)	MPN/100mL		77				35									38							
Coliforms Fecal (June)	MPN/100mL		39				35										36						
Coliforms Fecal (July)	MPN/100mL		27				35											36					
Coliforms Fecal (August)	MPN/100mL		24				35												36				
Coliforms Fecal (September)	MPN/100mL		38				35													36			
Coliforms Fecal (October)	MPN/100mL		27				35														36		
Enterococcus	MPN/100mL		27				15								16	16	16	16	16	16	16		
Escherichia, Coli	MPN/100mL		38				27								28	28	28	28	28	28	28		
Herbicide																							

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		INSTANTANEOUS	LONG-TERM AVERAGE	INSTANTANEOUS			LONG-TERM AVERAGE		INSTANTANEOUS			LONG-TERM AVERAGE											
PARAMETER	UNITS	MAX CONC	AVG CONC	HIGH FLOW AVG CONC	MOD FLOW AVG CONC	LOW FLOW AVG CONC	APR-AUG (APR-OCT for biota) AVG CONC	JAN FEB MAR SEP OCT NOV DEC AVG CONC	HIGH FLOW CONC	MOD FLOW CONC	LOW FLOW CONC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2,4-D (2,4-dichlorophenoxyaceticacid)	ng/L																						
4-chloro-2-methylphenoxyaceticacid (MCPA)	ng/L																						
Atrazine	ng/L																						
Bromocil	ng/L																						
Bromoxynl	ng/L																						
Cyanazine	ng/L																						
Dicamba	ng/L																						
Dinoseb	ng/L																						
Glyphosate	ng/L																						
Linuron	ng/L	<1.47	<1.22						<0.075	<0.088	<0.086	<0.046	<0.047	<0.049	<0.046	<0.043	<0.038	<0.04	<0.044	<0.046	<0.047	<0.047	<0.046
Metolachlor	ng/L	0.53	0.49						0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Metribuzin	ng/L																						
Picloram	ng/L																						
Simazene	ng/L																						
Tebuthiuron1-(5-tert-butyl-1,3,4-thiadiazol-2-yl)-1,3-dimethylurea	ng/L																						
Triallate	ng/L	<0.0832	<0.08						<0.004	<0.005	<0.005	<0.003	<0.003	<0.003	<0.003	<0.003	<0.002	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
Trifluralin	ng/L	0.12	0.11						0.006	0.007	0.007	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
Insecticide																							
Aldicarb	ng/L	<0.498	<0.496						<0.025	<0.03	<0.029	<0.019	<0.019	<0.02	<0.019	<0.017	<0.016	<0.016	<0.018	<0.019	<0.019	<0.019	<0.019
Carbaryl	ng/L	3.99	3.75						0.20	0.24	0.23	0.14	0.14	0.15	0.14	0.13	0.12	0.12	0.14	0.14	0.14	0.14	0.14
Carbofuran	ng/L	<0.498	<0.496						<0.025	<0.03	<0.029	<0.019	<0.019	<0.02	<0.019	<0.017	<0.016	<0.016	<0.018	<0.019	<0.019	<0.019	<0.019
Chlorpyrifos	ng/L	<1.01	<1						<0.051	<0.061	<0.059	<0.038	<0.039	<0.04	<0.038	<0.035	<0.032	<0.033	<0.037	<0.037	<0.039	<0.039	<0.038
Deltamethrin	ng/L	<2.88	<1.41						<0.146	<0.173	<0.168	<0.054	<0.054	<0.056	<0.053	<0.049	<0.044	<0.046	<0.051	<0.053	<0.054	<0.054	<0.053
Diazinon	ng/L	1.40	1.21						0.07	0.08	0.08	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.05
Dimethoate	ng/L																						
Endosulfan	ng/L																						
Imidacloprid	ng/L	26	23						1.30	1.53	1.49	0.88	0.89	0.91	0.87	0.81	0.72	0.76	0.84	0.86	0.89	0.88	0.87
Lindane (hexachlorocyclohexane)	ng/L	<0.831	0.44						<0.042	<0.05	<0.049	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.02	0.02	0.02	0.02	0.02
Malathion	ng/L																						
Methoprene	ng/L	<62	<60.03						<3.151	<3.723	<3.621	<2.285	<2.31	<2.387	<2.271	<2.112	<1.89	<1.985	<2.189	<2.241	<2.311	<2.309	<2.283
Permethrin	ng/L	19.9	14.5						1.01	1.20	1.16	0.55	0.56	0.58	0.55	0.51	0.46	0.48	0.53	0.54	0.56	0.56	0.55
Fungicide																							
Captan	ng/L	<2.65	<2.01						<0.135	<0.159	<0.155	<0.076	<0.077	<0.08	<0.076	<0.071	<0.063	<0.066	<0.073	<0.075	<0.077	<0.077	<0.076
Chlorothalonil	ng/L	0.1	0.1						0.005	0.006	0.006	0.003	0.003	0.003	0.003	0.002	0.002	0.002	0.003	0.003	0.003	0.003	0.003

		EFFLUENT INFORMATION		AMBIENT INFORMATION					FINAL CONCENTRATIONS (EDGE OF THE IDZ)														
		INSTANTANEOUS	LONG-TERM AVERAGE	INSTANTANEOUS			LONG-TERM AVERAGE		INSTANTANEOUS			LONG-TERM AVERAGE											
PARAMETER	UNITS	MAX CONC	AVG CONC	HIGH FLOW AVG CONC	MOD FLOW AVG CONC	LOW FLOW AVG CONC	APR-AUG (APR-OCT for biota) AVG CONC	JAN FEB MAR SEP OCT NOV DEC AVG CONC	HIGH FLOW CONC	MOD FLOW CONC	LOW FLOW CONC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Polycyclic Aromatic Hydrocarbons																							
Acenaphthene	µg/L	<0.1	0.046	<0.01	<0.01	<0.01	<0.01	<0.01	<0.015	<0.016	<0.016	0.0117	0.0118	0.0118	0.0117	0.0116	0.0114	0.0115	0.0117	0.0117	0.0118	0.0117	0.0117
Acenaphthylene	µg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Acridine	µg/L	<0.05	0.032	<0.01	<0.01	<0.01	<0.01	<0.01	<0.013	<0.013	<0.013	0.0112	0.0112	0.0112	0.0112	0.0111	0.0110	0.0110	0.0111	0.0112	0.0112	0.0112	0.0112
Anthracene	µg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Benz(a)anthracene	µg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Benzo(a)pyrene	µg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Benzo(b)fluoranthene	µg/L	<0.1	<0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.015	<0.016	<0.016	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011
Benzo(g,h,i)perylene	µg/L	0.022	0.012	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Benzo(k)fluoranthene	µg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chrysene	µg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Dibenz(a,h)anthracene	µg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fluoranthene	µg/L	0.044	0.017	<0.01	<0.01	<0.01	<0.01	<0.01	0.012	0.013	0.013	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
Fluorene	µg/L	<0.1	0.036	<0.01	<0.01	<0.01	<0.01	<0.01	<0.015	<0.016	<0.016	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
Indeno(1,2,3-c,d)pyrene	µg/L	<0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.011	<0.011	<0.011	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
1-Methylnaphthalene	µg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
2-Methylnaphthalene	µg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Naphthalene	µg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Phenanthrene	µg/L	<0.03	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.022	<0.022	<0.022	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Pyrene	µg/L	0.028	0.017	<0.01	<0.01	<0.01	<0.01	<0.01	0.011	0.012	0.012	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
Quinoline	µg/L	1.31	0.28	<0.01	<0.01	<0.01	<0.01	<0.01	0.08	0.09	0.09	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Alkylphenols																							
4-Nonylphenols	ng/L	2630	1127	8	8	8	8	8	142	166	162	51	52	53	51	48	44	46	50	51	52	52	51
4-Nonylphenol monoethoxylates	ng/L	1430	907	<8.4	<8.4	<8.4	<8.4	<8.4	81	94	92	43	43	44	43	40	37	38	41	42	43	43	43
4-Nonylphenol diethoxylates	ng/L	3580	1553	<12.1	<12.1	<12.1	<12.1	<12.1	194	227	221	71	72	74	71	67	61	63	69	70	72	72	71
Octylphenol	ng/L	<38.6	<8.49	<2.545	<2.545	<2.545	<2.545	<2.545	<4.51	<4.85	<4.79	<2.86	<2.87	<2.88	<2.86	<2.84	<2.81	<2.82	<2.85	<2.86	<2.87	<2.87	<2.86
Nonylphenol TEQ	ng/L			<22.25	<22.25	<22.25	<22.25	<22.25															
Sterols and Hormones																							
17 α-Ethinyl-Estradiol	ng/L	<49.2	7.8	0.8	0.8	0.8	0.8	0.8	3.3	3.7	3.6	1.1	1.1	1.1	1.1	1.0	1.0	1.0	1.0	1.0	1.1	1.1	1.1
Campesterol	ng/L	6750	4180	226	226	226	226	226	569	630	619	385	386	392	384	373	357	364	378	382	386	386	385
β-Sitosterol	ng/L	185000	22391	1282	1282	1282	1282	1282	10685	12387	12082	2132	2141	2169	2126	2067	1985	2020	2096	2116	2142	2140	2131
β-Stigmastanol	ng/L	3040	1373	378	378	378	378	378	533	559	554	429	430	432	429	426	421	423	427	429	430	430	429
Polychlorinated Biphenyls																							
PCB-77	pg/L	3.3	2.1	0.6	0.6	0.6	0.6	0.6	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7

		EFFLUENT INFORMATION		AMBIENT INFORMATION					FINAL CONCENTRATIONS (EDGE OF THE IDZ)														
		INSTANTANEOUS	LONG-TERM AVERAGE	INSTANTANEOUS			LONG-TERM AVERAGE		INSTANTANEOUS			LONG-TERM AVERAGE											
PARAMETER	UNITS	MAX CONC	AVG CONC	HIGH FLOW AVG CONC	MOD FLOW AVG CONC	LOW FLOW AVG CONC	APR-AUG (APR-OCT for biota) AVG CONC	JAN FEB MAR SEP OCT NOV DEC AVG CONC	HIGH FLOW CONC	MOD FLOW CONC	LOW FLOW CONC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
PCB-105	pg/L	16.7	13.1	2.1	2.1	2.1	2.1	2.1	2.9	3.1	3.1	2.6	2.6	2.6	2.6	2.6	2.5	2.5	2.6	2.6	2.6	2.6	2.6
PCB-126	pg/L	<2.74	<1.39	<0.672	<0.672	<0.672	<0.672	<0.672	<0.811	<0.834	<0.829	<0.724	<0.724	<0.726	<0.723	<0.72	<0.715	<0.717	<0.722	<0.723	<0.724	<0.724	<0.723
PCB-169	pg/L	<1.69	<1.06	<0.6715	<0.6715	<0.6715	<0.6715	<0.6715	<0.757	<0.77	<0.768	<0.71	<0.711	<0.712	<0.71	<0.707	<0.704	<0.705	<0.709	<0.71	<0.711	<0.71	<0.71
Total PCBs	pg/L	1320	1109	155	155	155	155	155	222	234	232	197	198	199	197	194	190	192	195	196	198	197	197
Polybrominated Diphenyl Ethers																							
Penta-BDE-99	pg/L	4150	3167	49	49	49	49	49	259	298	291	169	170	174	168	160	148	153	164	167	170	170	169
Penta-BDE-100	pg/L	832	637	11	11	11	11	11	53	60	59	35	35	36	35	33	31	32	34	34	35	35	35
Tri BDE (total)	pg/L			6	6	6	6	6															
Tetra BDE (total)	pg/L			62	62	62	62	62															
Penta BDE (total)	pg/L			65	65	65	65	65															
Hexa BDE (total)	pg/L			19	19	19	19	19															
Hepta BDE (total)	pg/L			12	12	12	12	12															
Octa-BDE-203	pg/L	96	74.17	17	17	17	17	17	22	22	22	20	20	20	20	19	19	19	19	19	20	20	20

blank	Effluent data: Effluent data were not available, and thus predictions not calculated
▨	Ambient data: Instead of the mean concentration, the median concentration is used. If median is a detection limit, then the detection limit is used.
*	Geometric means were calculated for biota effluent and ambient concentrations

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Section 8

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Appendix A

Summary Statistics for 2011-2014 AIWWTP Effluent Quality Data

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PARAMETER	Units	# of Samples	# of Samples < MDL	Percent of Samples < MDL	Minimum	Median	Mean	95th Percentile	Maximum	Group
Escherichia, Coli	MPN/100mL	68	5	7%	<18	7900	38	47950	54000	Bacteriological
Enterococus	MPN/100mL	121	24	20%	10.0	2500	27	24000	42000	Bacteriological
Coliforms Fecal	MPN/100mL	120	8	7%	<1.8	17000	NC	80550	490000	Bacteriological
Aluminum	µg/L	174	0	0%	7.0	14.0	14	20.0	47	Dissolved Metals
Arsenic	µg/L	126	18	14%	0.5	0.7	2	10.0	<10	Dissolved Metals
Barium	µg/L	174	0	0%	1.8	3.0	3	5.3	6.8	Dissolved Metals
Boron	µg/L	174	0	0%	90.0	148.0	151	226.1	286	Dissolved Metals
Cadmium	µg/L	174	173	99%	<0.2	<0.2	0	NC	2	Dissolved Metals
Calcium	µg/L	126	0	0%	8670	12400	12237	16850	17900	Dissolved Metals
Chromium	µg/L	174	48	28%	0.50	0.60	1	1.00	3.8	Dissolved Metals
Cobalt	µg/L	174	139	80%	0.5	<0.5	1	1.0	<1	Dissolved Metals
Copper	µg/L	174	1	1%	2.0	9.2	10.3	21.7	29.1	Dissolved Metals
Iron	µg/L	174	0	0%	81.0	120.0	125	170.4	285	Dissolved Metals
Lead	µg/L	174	173	99%	<0.5	<0.5	1	NC	<1	Dissolved Metals
Magnesium	µg/L	126	0	0%	2200	2850	2909	3673	4420	Dissolved Metals
Manganese	µg/L	174	0	0%	4.4	49.9	50	68.3	74.9	Dissolved Metals
Molybdenum	µg/L	174	16	9%	0.7	1.00	1	2.00	13.5	Dissolved Metals
Nickel	µg/L	174	0	0%	1.6	2.20	3	4.84	21.4	Dissolved Metals
Selenium	µg/L	124	124	100%	<0.5	<0.5	<0.56	NC	<1	Dissolved Metals
Silver	µg/L	173	173	100%	<0.5	<0.5	<0.65	NC	<10	Dissolved Metals
Sodium	µg/L	126	0	0%	23100	39800	38884	51525	52800	Dissolved Metals
Zinc	µg/L	174	0	0%	10.0	16.0	18	34.1	51	Dissolved Metals
2,4'-DDD	ng/l	6	2	33%	0.115	0.134	0	NC	0.244	Herbicides
2,4'-DDE	ng/l	6	6	100%	<0.0605	<0.0837	<0.11	NC	<0.199	Herbicides
2,4'-DDT	ng/l	6	6	100%	<0.0845	<0.154	<0.16	NC	<0.237	Herbicides
3[OH] Carbofuran	ng/l	3	3	100%	<0.494	<0.495	<0.5	NC	<0.498	Herbicides
4,4'-DDD	ng/l	6	6	100%	<0.0323	<0.1081	<0.12	NC	<0.216	Herbicides
4,4'-DDE	ng/l	6	0	0%	0.3	0.46	1	NC	1.23	Herbicides
4,4'-DDT	ng/l	6	6	100%	<0.0701	<0.147	<0.15	NC	<0.247	Herbicides
Alachlor	ng/l	3	3	100%	<1.28	<1.48	<1.42	NC	<1.51	Herbicides
Dacthal	ng/l	3	0	0%	0.042	0.043	0	NC	0.044	Herbicides
Diazinon	ng/l	3	0	0%	1.0	1.20	1	NC	1.4	Herbicides
Dieldrin	ng/l	6	3	50%	0.066	0.147	0.3	NC	<0.681	Herbicides
Dimethenamid	ng/l	3	3	100%	<0.112	<0.114	<0.12	NC	<0.139	Herbicides
Dioxacarb	ng/l	3	3	100%	<0.494	<0.495	<0.5	NC	<0.498	Herbicides
EndosulphanSulphate	ng/l	6	6	100%	<0.214	<0.465	<0.46	NC	<0.677	Herbicides
Endrin	ng/l	6	6	100%	<0.0353	<0.11875	<0.27	NC	<0.717	Herbicides
EndrinAldehyde	ng/l	3	3	100%	<0.27	<0.855	<0.74	NC	<1.08	Herbicides
EndrinKetone	ng/l	6	6	100%	<0.0412	<0.1365	<0.13	NC	<0.195	Herbicides
Ethalfluralin	ng/l	3	3	100%	<0.359	<0.398	<0.39	NC	<0.424	Herbicides
Flufenacet	ng/l	3	3	100%	<15.4	<19.3	<19.37	NC	<23.4	Herbicides
Flutriafol	ng/l	3	3	100%	<0.721	<0.918	<0.91	NC	<1.1	Herbicides
Hexachlorobenzene	ng/l	6	3	50%	0.096	0.109	0.106	NC	0.113	Herbicides
Linuron	ng/l	3	3	100%	<0.891	<1.3	<1.22	NC	<1.47	Herbicides
Pendimethalin	ng/l	3	3	100%	<1.38	<1.81	<2.28	NC	<3.66	Herbicides
Quintozene	ng/l	3	3	100%	<0.0128	<0.0192	<0.02	NC	<0.0274	Herbicides

PARAMETER	Units	# of Samples	# of Samples < MDL	Percent of Samples < MDL	Minimum	Median	Mean	95th Percentile	Maximum	Group
Tebuconazol	ng/l	3	0	0%	7.0	7.24	7	NC	7.57	Herbicides
Tecnazene	ng/l	3	3	100%	<0.0101	<0.0134	<0.01	NC	<0.0151	Herbicides
Triallate	ng/l	3	3	100%	<0.0753	<0.0794	<0.08	NC	<0.0832	Herbicides
Trifluralin	ng/l	3	0	0%	0.1	0.113	0.112	NC	0.117	Herbicides
Allethrin	ng/L	7	7	100%	<31.2	<34.1	<62.37	NC	<115	Insecticides
Prallethrin	ng/L	7	7	100%	<86.3	<124	<156.14	NC	<232	Insecticides
Cinerin I	ng/L	7	7	100%	<1.7	<5.18	<8.62	NC	<34.9	Insecticides
Jasmolin I	ng/L	7	7	100%	<5.83	<17.4	<31.19	NC	<129	Insecticides
Pyrethrin I	ng/L	7	7	100%	<4.5	<11.3	<19.71	NC	<69.4	Insecticides
Cinerin II	ng/L	7	7	100%	<1.38	<2.81	<5.46	NC	<11.3	Insecticides
Jasmolin II	ng/L	7	7	100%	<5.75	<10.7	<22.48	NC	<46.8	Insecticides
Pyrethrin II	ng/L	7	7	100%	<3.91	<6.88	<15.43	NC	<32.3	Insecticides
Resmethrin	ng/L	7	7	100%	<1.6	<2.58	<7.64	NC	<17.6	Insecticides
Piperonyl butoxide	ng/L	7	0	0%	232.0	384.0	411	NC	544	Insecticides
Tetramethrin	ng/L	7	7	100%	<1.27	<2.41	<3.98	NC	<7.56	Insecticides
Bifenthrin	ng/L	7	7	100%	<0.995	<2.1	<2.25	NC	<3.32	Insecticides
Fenpropathrin	ng/L	7	7	100%	<5.04	<9.08	<9.07	NC	<13.6	Insecticides
Phenothrin	ng/L	7	7	100%	<0.659	<1.17	<1.52	NC	<2.57	Insecticides
Permethrin	ng/L	7	0	0%	12.9	13.80	15	NC	19.9	Insecticides
L-Cyhalothrin	ng/L	7	7	100%	<0.501	<0.593	<0.93	NC	<1.59	Insecticides
Cyfluthrin	ng/L	7	7	100%	<1.63	<2.59	<3.39	NC	<5.84	Insecticides
Cypermethrin	ng/L	7	7	100%	<0.603	<0.918	<1.45	NC	<2.69	Insecticides
Flucythrinate	ng/L	7	7	100%	<0.5	<0.503	<0.96	NC	<1.65	Insecticides
Fenvalerate	ng/L	7	7	100%	<0.52	<0.9	<1.06	NC	<1.67	Insecticides
Deltamethrin	ng/L	7	7	100%	<0.501	<0.729	<1.41	NC	<2.88	Insecticides
Aldicarb	ng/l	3	3	100%	<0.494	<0.495	<0.496	NC	<0.498	Insecticides
Aldicarb Sulfone	ng/l	3	3	100%	<0.998	<1	<1	NC	<1.01	Insecticides
Aldicarb Sulfoxide	ng/l	3	3	100%	<0.494	<0.495	<0.5	NC	<0.498	Insecticides
Aldrin	ng/l	6	4	67%	0.019	<0.224	0.35	NC	<0.975	Insecticides
alpha-Endosulphan	ng/l	6	2	33%	0.271	0.539	0.56	NC	0.824	Insecticides
Aminocarb	ng/l	3	3	100%	<0.494	<0.495	<0.496	NC	<0.498	Insecticides
Bendiocarb	ng/l	3	3	100%	<0.988	<0.991	<0.99	NC	<0.996	Insecticides
beta-Endosulphan	ng/l	6	6	100%	<0.19	<0.584	<0.54	NC	<0.761	Insecticides
Butralin	ng/l	3	3	100%	<1.83	<1.92	<1.97	NC	<2.15	Insecticides
Butylate	ng/l	3	3	100%	<0.239	<0.306	<0.35	NC	<0.499	Insecticides
Captan	ng/l	3	3	100%	<1.33	<2.04	<2.01	NC	<2.65	Insecticides
Carbaryl	ng/l	3	0	0%	3.6	3.69	3.75	NC	3.99	Insecticides
Carbofuran	ng/l	3	3	100%	<0.494	<0.495	<0.496	NC	<0.498	Insecticides
Chlordane, alpha (cis)	ng/l	6	5	83%	0.05	<0.1201	0.13	NC	<0.208	Insecticides
Chlordane, gamma (trans)	ng/l	6	4	67%	0.074	<0.1204	0.14	NC	0.258	Insecticides
Chlordane, oxy-	ng/l	6	6	100%	<0.0803	<0.7455	<0.94	NC	<2.59	Insecticides
Chlorothalonil	ng/l	3	0	0%	0.044	0.064	0.07	NC	0.103	Insecticides
Chlorpyrifos	ng/l	3	3	100%	<0.998	<1	<1	NC	<1.01	Insecticides
HCH, alpha	ng/l	6	3	50%	0.052	0.184	0.32	NC	<0.789	Insecticides
HCH, alpha	ng/l	3	3	100%	<0.052	<0.065	<0.06	NC	<0.077	Insecticides
HCH, beta	ng/l	6	3	50%	0.441	0.537	0.56	NC	<0.745	Insecticides
HCH, delta	ng/l	6	5	83%	<0.0416	<0.4754	0.60	NC	<1.44	Insecticides
Lindane (hexachlorocyclohexane)	ng/l	6	2	33%	0.2	0.337	0.44	NC	<0.831	Insecticides
Heptachlor	ng/l	6	3	50%	<0.0056	0.166	0.34	NC	0.954	Insecticides
Heptachlor Epoxide	ng/l	6	4	67%	<0.061	<0.4915	0.5	NC	<1.13	Insecticides
Imidacloprid	ng/l	3	0	0%	18.7	24.8	23	NC	25.5	Insecticides
Methiocarb	ng/l	3	3	100%	<0.998	<1	<1	NC	<1.01	Insecticides
Methomyl	ng/l	3	3	100%	<0.494	<0.495	<0.5	NC	<0.498	Insecticides
Methoprene	ng/l	3	3	100%	<56.1	<62	<60.03	NC	<62	Insecticides
Methoxychlor	ng/l	6	5	83%	0.0156	<0.4585	0.5	NC	<1.21	Insecticides
Metolachlor	ng/l	3	0	0%	0.5	0.483	0	NC	0.534	Insecticides
Mexacarbate	ng/l	3	3	100%	<0.487	<0.488	<0.49	NC	<0.491	Insecticides
Mirex	ng/l	6	6	100%	<0.013	<0.12415	<0.14	NC	<0.296	Insecticides
Nonachlor, cis-	ng/l	6	6	100%	<0.0512	<0.06795	<0.07	NC	<0.0892	Insecticides
Nonachlor, trans-	ng/l	6	5	83%	<0.0412	<0.0729	0.1	NC	<0.0856	Insecticides
Oxamyl	ng/l	3	3	100%	<0.678	<0.948	<1.03	NC	<1.46	Insecticides

PARAMETER	Units	# of Samples	# of Samples < MDL	Percent of Samples < MDL	Minimum	Median	Mean	95th Percentile	Maximum	Group
Perthane	ng/l	3	3	100%	<6.34	<7.12	<7.17	NC	<8.04	Insecticides
Pirimicarb	ng/l	3	3	100%	<0.494	<0.495	<0.5	NC	<0.498	Insecticides
Promecarb	ng/l	3	3	100%	<0.988	<0.991	<0.99	NC	<0.996	Insecticides
Propoxur	ng/l	3	0	0%	1.3	1.82	2	NC	1.88	Insecticides
Calcium	µg/L	174	0	0%	9070	12850	12901	17270	18200	Major Ions
Magnesium	µg/L	174	0	0%	2280	3050	3095	3867	5610	Major Ions
Sodium	µg/L	126	0	0%	23700	41250	40405	52550	55400	Major Ions
Fluoride	mg/L	24	8	33%	0.05	0.06	0	0.12	0.14	Major Ions
Sulphate	mg/L	48	0	0%	12.4	17.15	17	20.27	21.8	Major Ions
Cyanide	mg/L	48	48	100%	<0.02	<0.02	<0.02	NC	<0.02	Miscellaneous
Hexachlorobutadiene	ng/l	3	0	0%	0.2	0.35	0	NC	0.357	Miscellaneous
Octachlorostyrene	ng/l	3	3	100%	<0.0104	<0.0105	<0.01	NC	<0.0124	Miscellaneous
WHO 2005 TOTAL (TEQ ND=0)	ng/l	3	0	0%	0.0017	0.0018	0	NC	0.00199	Miscellaneous
WHO 2005 TOTAL (TEQ ND=1/2 DL)	ng/l	3	0	0%	0.1	0.11	0	NC	0.129	Miscellaneous
Dissolved Phosphorus	µg/L	174	0	0%	482	2200	2204	3354	3980	Nutrients
Total ammonia	mg/L	173	0	0%	12.9	30.3	30	36.2	37.2	Nutrients
Dissolved Organic Carbon	mg/L	89	0	0%	7.1	10.8	11	13.9	15	Nutrients
Nitrate	mg/L	174	41	24%	0.01	0.02	0	0.09	0.32	Nutrients
Nitrite	mg/L	174	13	7%	<0.01	0.04	0	0.10	0.39	Nutrients
Total Kjeldahl Nitrogen	mg/L	174	0	0%	16.0	32.5	32	39.0	44	Nutrients
Total Organic Carbon	mg/L	74	0	0%	9.2	13.1	13	16.1	17.4	Nutrients
Total Phosphorus	µg/L	174	0	0%	747	2565	2498	3564	4250	Nutrients
4-Nonylphenol diethoxylates	ng/L	27	2	7%	<22.6	1420.0	1553	2744.0	3580	Phenols
4-Nonylphenol monoethoxylates	ng/L	27	0	0%	180.0	946.0	907	1345.0	1430	Phenols
4-Nonylphenols	ng/L	27	0	0%	615.0	960.0	1127	1842.0	2630	Phenols
Octylphenol	ng/L	27	27	100%	<1.46	<2.97	<8.49	NC	<38.6	Phenols
Conductivity	µS/cm	30	0	0%	315.0	582.6	619	717.9	1486	Physical Parameters
Conductivity (lab)	µmhos/cm	126	0	0%	343.0	555.0	545	618.5	673	Physical Parameters
Dissolved Oxygen	mg/L	30	0	0%	4.0	4.55	5	5.38	5.59	Physical Parameters
Dissolved Oxygen % Sat	% Sat	30	0	0%	42.0	47.3	48	52.5	53.3	Physical Parameters
Hardness, as CaCO3	mg/L	174	0	0%	32.9	44.8	45	58.9	60.8	Physical Parameters
pH	pH units	30	0	0%	6.5	7.0	7	7.2	7.2	Physical Parameters
pH (lab)	pH units	126	0	0%	6.7	7.1	7	7.2	7.3	Physical Parameters
Salinity	ppt	30	0	0%	0.3	0.34	0	0.40	0.776	Physical Parameters
Temperature	°C	30	0	0%	10.4	17.2	17	22.6	22.8	Physical Parameters
Total Suspended Solids	mg/L	126	0	0%	4.0	8.0	9	15.0	24	Physical Parameters
Volatile Suspended Solids	mg/L	92	0	0%	3.0	7.0	7	12.5	22	Physical Parameters
Oil and Grease	mg/L	48	41	85%	<3	<3	4	7.95	19	Physical Parameters
BDE-7	pg/L	3	0	0%	0.8	1.26	1	NC	1.39	Polybrominated Diphenyl Ethers
BDE-8 + 11	pg/L	3	0	0%	1.3	1.56	2	NC	2.12	Polybrominated Diphenyl Ethers
BDE-10	pg/L	3	3	100%	<0.365	<0.368	<0.37	NC	<0.38	Polybrominated

PARAMETER	Units	# of Samples	# of Samples < MDL	Percent of Samples < MDL	Minimum	Median	Mean	95th Percentile	Maximum	Group
										Diphenyl Ethers
BDE-12 + 13	pg/L	3	0	0%	0.9	1.30	1	NC	1.31	Polybrominated Diphenyl Ethers
BDE-15	pg/L	3	0	0%	4.8	5.28	5	NC	6.35	Polybrominated Diphenyl Ethers
BDE-17 + 25	pg/L	3	0	0%	28.8	31.2	32	NC	34.6	Polybrominated Diphenyl Ethers
BDE-28 + 33	pg/L	3	0	0%	51.7	57.7	57	NC	62.6	Polybrominated Diphenyl Ethers
BDE-30	pg/L	3	3	100%	<0.368	<0.38	<0.42	NC	<0.516	Polybrominated Diphenyl Ethers
BDE-32	pg/L	3	2	67%	<0.368	<0.38	0.4	NC	0.384	Polybrominated Diphenyl Ethers
BDE-35	pg/L	3	0	0%	0.7	1.21	1	NC	1.41	Polybrominated Diphenyl Ethers
BDE-37	pg/L	3	0	0%	2.3	2.81	3	NC	2.92	Polybrominated Diphenyl Ethers
BDE-47	pg/L	3	0	0%	2610.0	2620	2890	NC	3440	Polybrominated Diphenyl Ethers
BDE-49	pg/L	3	0	0%	69.4	78.1	80	NC	92.5	Polybrominated Diphenyl Ethers
BDE-51	pg/L	3	0	0%	9.8	10.1	10	NC	11.5	Polybrominated Diphenyl Ethers
BDE-66	pg/L	3	0	0%	58.6	58.6	61	NC	66.9	Polybrominated Diphenyl Ethers
BDE-71	pg/L	3	0	0%	9.5	10.9	11	NC	11.2	Polybrominated Diphenyl Ethers
BDE-75	pg/L	3	0	0%	4.2	4.23	4	NC	4.87	Polybrominated Diphenyl Ethers
BDE-77	pg/L	3	1	33%	<0.368	0.59	1	NC	1.23	Polybrominated Diphenyl Ethers
BDE-79	pg/L	3	2	67%	<0.365	<0.368	1.1	NC	2.43	Polybrominated Diphenyl Ethers
BDE-85	pg/L	3	0	0%	87.9	89.0	111	NC	157	Polybrominated Diphenyl Ethers

PARAMETER	Units	# of Samples	# of Samples < MDL	Percent of Samples < MDL	Minimum	Median	Mean	95th Percentile	Maximum	Group
BDE-99	pg/L	3	0	0%	2310.0	2380	2763	NC	3600	Polybrominated Diphenyl Ethers
BDE-100	pg/L	3	0	0%	468.0	482	553	NC	709	Polybrominated Diphenyl Ethers
BDE-105	pg/L	3	3	100%	<2.07	<2.68	<2.79	NC	<3.61	Polybrominated Diphenyl Ethers
BDE-116	pg/L	3	1	33%	<3.23	16.2	13	NC	18.4	Polybrominated Diphenyl Ethers
BDE-119 + 120	pg/L	3	0	0%	7.4	9.1	9	NC	11.3	Polybrominated Diphenyl Ethers
BDE-126	pg/L	3	1	33%	1.81	2.33	2	NC	2.45	Polybrominated Diphenyl Ethers
BDE-128	pg/L	3	2	67%	<1.47	<1.98	13	NC	<35.8	Polybrominated Diphenyl Ethers
BDE-138 + 166	pg/L	3	0	0%	20.3	20.6	32	NC	54.8	Polybrominated Diphenyl Ethers
BDE-140	pg/L	3	0	0%	6.7	7.5	9	NC	13.5	Polybrominated Diphenyl Ethers
BDE-153	pg/L	3	0	0%	221.0	222.0	271	NC	369	Polybrominated Diphenyl Ethers
BDE-154	pg/L	3	0	0%	174.0	185.0	211	NC	275	Polybrominated Diphenyl Ethers
BDE-155	pg/L	3	0	0%	11.7	14.8	18	NC	27.2	Polybrominated Diphenyl Ethers
BDE-181	pg/L	3	3	100%	<0.932	<1.03	<1.79	NC	<3.41	Polybrominated Diphenyl Ethers
BDE-183	pg/L	3	0	0%	33.1	36.0	43	NC	59.5	Polybrominated Diphenyl Ethers
BDE-190	pg/L	3	0	0%	4.2	5.39	6	NC	9.54	Polybrominated Diphenyl Ethers
BDE-203	pg/L	3	0	0%	30.5	34.5	39	NC	51.3	Polybrominated Diphenyl Ethers
BDE-206	pg/L	3	0	0%	101	115.0	158	NC	257	Polybrominated Diphenyl Ethers
BDE-207	pg/L	3	0	0%	99.1	139.0	160	NC	241	Polybrominated

PARAMETER	Units	# of Samples	# of Samples < MDL	Percent of Samples < MDL	Minimum	Median	Mean	95th Percentile	Maximum	Group
										Diphenyl Ethers
BDE-208	pg/L	3	0	0%	67.5	101.0	128	NC	215	Polybrominated Diphenyl Ethers
BDE-209	pg/L	3	0	0%	1930	2090	3790	NC	7350	Polybrominated Diphenyl Ethers
Di-BDE-7	pg/L	3	0	0%	1.2	1.46	1	NC	1.52	Polybrominated Diphenyl Ethers
Di-BDE-8 + 11	pg/L	3	0	0%	1.3	1.54	1	NC	1.6	Polybrominated Diphenyl Ethers
Di-BDE-10	pg/L	3	3	100%	<1.01	<1.02	<1.04	NC	<1.09	Polybrominated Diphenyl Ethers
Di-BDE-12 + 13	pg/L	3	0	0%	1.5	1.85	2	NC	3.58	Polybrominated Diphenyl Ethers
Di-BDE-15	pg/L	3	0	0%	4.8	4.86	5	NC	6.77	Polybrominated Diphenyl Ethers
Tri-BDE-17 + 25	pg/L	3	0	0%	35.0	41.4	43	NC	52.7	Polybrominated Diphenyl Ethers
Tri-BDE-28 + 33	pg/L	3	0	0%	54.9	56.9	63	NC	76.2	Polybrominated Diphenyl Ethers
Tri-BDE-30	pg/L	3	3	100%	<1.01	<1.02	<1.02	NC	<1.03	Polybrominated Diphenyl Ethers
Tri-BDE-32	pg/L	3	3	100%	<1.01	<1.02	<1.02	NC	<1.03	Polybrominated Diphenyl Ethers
Tri-BDE-35	pg/L	3	1	33%	<1.01	1.03	1	NC	2.24	Polybrominated Diphenyl Ethers
Tri-BDE-37	pg/L	3	0	0%	2.7	3.6	4	NC	5.2	Polybrominated Diphenyl Ethers
Tetra-BDE-47	pg/L	3	0	0%	2800.0	2850	3290	NC	4220	Polybrominated Diphenyl Ethers
Tetra-BDE-49	pg/L	3	0	0%	70.7	77.7	91	NC	124	Polybrominated Diphenyl Ethers
Tetra-BDE-51	pg/L	3	0	0%	9.8	10.7	12	NC	14.7	Polybrominated Diphenyl Ethers
Tetra-BDE-66	pg/L	3	0	0%	61.9	65.1	77	NC	103	Polybrominated Diphenyl Ethers

PARAMETER	Units	# of Samples	# of Samples < MDL	Percent of Samples < MDL	Minimum	Median	Mean	95th Percentile	Maximum	Group
Tetra-BDE-71	pg/L	3	0	0%	11.8	12.4	13	NC	15.2	Polybrominated Diphenyl Ethers
Tetra-BDE-75	pg/L	3	0	0%	3.8	5.2	5	NC	7.02	Polybrominated Diphenyl Ethers
Tetra-BDE-77	pg/L	3	3	100%	<1.01	<1.02	<1.02	NC	<1.03	Polybrominated Diphenyl Ethers
Tetra-BDE-79	pg/L	3	0	0%	21.0	23.4	25	NC	29.5	Polybrominated Diphenyl Ethers
Penta-BDE-85	pg/L	3	0	0%	117.0	117	139	NC	183	Polybrominated Diphenyl Ethers
Penta-BDE-99	pg/L	3	0	0%	2670.0	2680.0	3167	NC	4150	Polybrominated Diphenyl Ethers
Penta-BDE-100	pg/L	3	0	0%	531.0	547.0	637	NC	832	Polybrominated Diphenyl Ethers
Penta-BDE-105	pg/L	3	3	100%	<6.06	<7.51	<7.07	NC	<7.65	Polybrominated Diphenyl Ethers
Penta-BDE-116	pg/L	3	1	33%	<10.7	32.5	37	NC	67.4	Polybrominated Diphenyl Ethers
Penta-BDE-119 + 120	pg/L	3	0	0%	10.0	11.1	11	NC	11.6	Polybrominated Diphenyl Ethers
Penta-BDE-126	pg/L	3	3	100%	<3.36	<4.13	<3.91	NC	<4.25	Polybrominated Diphenyl Ethers
Hexa-BDE-128	pg/L	3	3	100%	<2.84	<4.21	<4.7	NC	<7.04	Polybrominated Diphenyl Ethers
Hexa-BDE-138 + 166	pg/L	3	0	0%	28.4	33.1	38	NC	52	Polybrominated Diphenyl Ethers
Hexa-BDE-140	pg/L	3	0	0%	8.0	8.82	10	NC	14.3	Polybrominated Diphenyl Ethers
Hexa-BDE-153	pg/L	3	0	0%	237.0	249.00	289	NC	382	Polybrominated Diphenyl Ethers
Hexa-BDE-154	pg/L	3	0	0%	189.0	206.0	229	NC	292	Polybrominated Diphenyl Ethers
Hexa-BDE-155	pg/L	3	0	0%	14.9	15.8	17	NC	20.9	Polybrominated Diphenyl Ethers
Hepta-BDE-181	pg/L	3	0	0%	1.1	1.58	2	NC	2.09	Polybrominated

PARAMETER	Units	# of Samples	# of Samples < MDL	Percent of Samples < MDL	Minimum	Median	Mean	95th Percentile	Maximum	Group
										Diphenyl Ethers
Hepta-BDE-183	pg/L	3	0	0%	42.8	48.8	51	NC	61.5	Polybrominated Diphenyl Ethers
Hepta-BDE-190	pg/L	3	1	33%	<1.01	5.0	5	NC	8.5	Polybrominated Diphenyl Ethers
Octa-BDE-203	pg/L	3	0	0%	54.9	71.4	74	NC	96.2	Polybrominated Diphenyl Ethers
Nona-BDE-206	pg/L	3	0	0%	239.0	278.0	302	NC	388	Polybrominated Diphenyl Ethers
Nona-BDE-207	pg/L	3	0	0%	321.0	404	423	NC	544	Polybrominated Diphenyl Ethers
Nona-BDE-208	pg/L	3	0	0%	243.0	265	326	NC	470	Polybrominated Diphenyl Ethers
Deca-BDE-209	pg/L	3	0	0%	3270.0	3610	4117	NC	5470	Polybrominated Diphenyl Ethers
PCB-1	pg/L	9	0	0%	8.3	16.40	17	NC	26.8	Polychlorinated Biphenyls
PCB-2	pg/L	9	0	0%	0.8	1.99	2	NC	2.56	Polychlorinated Biphenyls
PCB-3	pg/L	9	0	0%	1.3	4.81	4	NC	6.72	Polychlorinated Biphenyls
PCB-4	pg/L	9	0	0%	99.1	124.00	126	NC	149	Polychlorinated Biphenyls
PCB-5	pg/L	9	9	100%	<0.705	<3.44	<2.97	NC	<4.81	Polychlorinated Biphenyls
PCB-6	pg/L	9	0	0%	5.0	6.87	7	NC	9.34	Polychlorinated Biphenyls
PCB-7	pg/L	9	6	67%	1.25	<3.57	3.0	NC	<4.29	Polychlorinated Biphenyls
PCB-8	pg/L	9	0	0%	17.1	26.30	25	NC	31.1	Polychlorinated Biphenyls
PCB-9	pg/L	9	3	33%	1.9	3.39	4	NC	6.47	Polychlorinated Biphenyls
PCB-10	pg/L	9	2	22%	2.9	3.85	4	NC	<4.43	Polychlorinated Biphenyls
PCB-11	pg/L	9	0	0%	54.3	66.00	68	NC	94.7	Polychlorinated Biphenyls
PCB-12 + 13	pg/L	9	3	33%	3.25	3.80	4	NC	<4.41	Polychlorinated Biphenyls
PCB-14	pg/L	9	9	100%	<0.662	<3.16	<2.73	NC	<4.34	Polychlorinated Biphenyls

PARAMETER	Units	# of Samples	# of Samples < MDL	Percent of Samples < MDL	Minimum	Median	Mean	95th Percentile	Maximum	Group
PCB-15	pg/L	9	0	0%	18.9	25.50	25	NC	33.2	Polychlorinated Biphenyls
PCB-16	pg/L	9	0	0%	9.2	12.50	13	NC	16.2	Polychlorinated Biphenyls
PCB-17	pg/L	9	0	0%	11.8	17.70	17	NC	20.1	Polychlorinated Biphenyls
PCB-18 + 30	pg/L	9	0	0%	18.4	29.60	27	NC	32.6	Polychlorinated Biphenyls
PCB-19	pg/L	9	0	0%	7.9	10.50	11	NC	14.2	Polychlorinated Biphenyls
PCB-20 + 28	pg/L	9	0	0%	24.0	37.40	36	NC	44.2	Polychlorinated Biphenyls
PCB-21 + 33	pg/L	9	0	0%	9.3	15.90	15	NC	19.1	Polychlorinated Biphenyls
PCB-22	pg/L	9	0	0%	8.6	13.90	13	NC	16.9	Polychlorinated Biphenyls
PCB-23	pg/L	9	8	89%	<0.183	<0.831	0.9	NC	2.75	Polychlorinated Biphenyls
PCB-24	pg/L	9	5	56%	0.239	<0.563	1	NC	<1.26	Polychlorinated Biphenyls
PCB-25	pg/L	9	0	0%	2.4	3.39	3	NC	4.49	Polychlorinated Biphenyls
PCB-26 + 29	pg/L	9	0	0%	4.9	7.61	7	NC	9.32	Polychlorinated Biphenyls
PCB-27	pg/L	9	0	0%	2.5	3.49	3	NC	4.71	Polychlorinated Biphenyls
PCB-31	pg/L	9	0	0%	20.3	34.20	32	NC	41	Polychlorinated Biphenyls
PCB-32	pg/L	9	0	0%	6.8	10.70	11	NC	13.7	Polychlorinated Biphenyls
PCB-34	pg/L	9	7	78%	<0.183	<0.81	0.9	NC	2.65	Polychlorinated Biphenyls
PCB-35	pg/L	9	0	0%	1.6	2.54	2	NC	3.64	Polychlorinated Biphenyls
PCB-36	pg/L	9	5	56%	0.35	<0.894	1	NC	<1.73	Polychlorinated Biphenyls
PCB-37	pg/L	9	0	0%	4.3	7.45	7	NC	9.47	Polychlorinated Biphenyls
PCB-38	pg/L	9	9	100%	<0.183	<0.766	<0.79	NC	<1.75	Polychlorinated Biphenyls
PCB-39	pg/L	9	9	100%	<0.183	<0.747	<0.79	NC	<1.77	Polychlorinated Biphenyls
PCB-40 + 41 + 71	pg/L	9	0	0%	8.9	13.00	13	NC	16.7	Polychlorinated Biphenyls
PCB-42	pg/L	9	0	0%	4.2	5.70	6	NC	6.99	Polychlorinated Biphenyls

PARAMETER	Units	# of Samples	# of Samples < MDL	Percent of Samples < MDL	Minimum	Median	Mean	95th Percentile	Maximum	Group
PCB-43	pg/L	9	4	44%	0.721	1.31	1	NC	<2.04	Polychlorinated Biphenyls
PCB-44 + 47 + 65	pg/L	9	0	0%	24.8	38.40	36	NC	46.6	Polychlorinated Biphenyls
PCB-45 + 51	pg/L	9	0	0%	4.4	7.66	7	NC	11.1	Polychlorinated Biphenyls
PCB-46	pg/L	9	1	11%	0.98	1.82	2	NC	2.68	Polychlorinated Biphenyls
PCB-48	pg/L	9	0	0%	3.5	4.76	5	NC	7.12	Polychlorinated Biphenyls
PCB-49 + 69	pg/L	9	0	0%	11.2	15.70	16	NC	20.6	Polychlorinated Biphenyls
PCB-50 + 53	pg/L	9	0	0%	3.0	4.07	5	NC	7.39	Polychlorinated Biphenyls
PCB-52	pg/L	9	0	0%	33.2	48.90	51	NC	82.1	Polychlorinated Biphenyls
PCB-54	pg/L	9	7	78%	<0.183	<0.557	0.7	NC	1.83	Polychlorinated Biphenyls
PCB-55	pg/L	9	9	100%	<0.218	<1.11	<1.07	NC	<2.4	Polychlorinated Biphenyls
PCB-56	pg/L	9	0	0%	6.1	8.86	9	NC	10.5	Polychlorinated Biphenyls
PCB-57	pg/L	9	9	100%	<0.206	<1.04	<0.99	NC	<2.15	Polychlorinated Biphenyls
PCB-58	pg/L	9	9	100%	<0.218	<1.02	<1	NC	<2.12	Polychlorinated Biphenyls
PCB-59 + 62 + 75	pg/L	9	0	0%	1.5	2.07	2	NC	2.83	Polychlorinated Biphenyls
PCB-60	pg/L	9	0	0%	3.8	5.04	5	NC	5.91	Polychlorinated Biphenyls
PCB-61 + 70 + 74 + 76	pg/L	9	0	0%	31.1	46.30	46	NC	66.6	Polychlorinated Biphenyls
PCB-63	pg/L	9	4	44%	0.53	1.00	1	NC	<2.07	Polychlorinated Biphenyls
PCB-64	pg/L	9	0	0%	7.5	10.80	11	NC	13.4	Polychlorinated Biphenyls
PCB-66	pg/L	9	0	0%	12.2	17.70	17	NC	22.2	Polychlorinated Biphenyls
PCB-67	pg/L	9	6	67%	0.375	<0.926	0.9	NC	<1.92	Polychlorinated Biphenyls
PCB-68	pg/L	9	0	0%	1.0	1.54	2	NC	3.46	Polychlorinated Biphenyls
PCB-72	pg/L	9	9	100%	<0.199	<0.976	<1.18	NC	<3.7	Polychlorinated Biphenyls
PCB-73	pg/L	9	9	100%	<0.183	<0.745	<0.71	NC	<1.47	Polychlorinated Biphenyls

PARAMETER	Units	# of Samples	# of Samples < MDL	Percent of Samples < MDL	Minimum	Median	Mean	95th Percentile	Maximum	Group
PCB-77	pg/L	9	1	11%	<1.06	2.10	2	NC	3.31	Polychlorinated Biphenyls
PCB-78	pg/L	9	8	89%	<0.216	<1.08	1.1	NC	2.52	Polychlorinated Biphenyls
PCB-79	pg/L	9	7	78%	0.431	<0.869	1.0	NC	<1.81	Polychlorinated Biphenyls
PCB-80	pg/L	9	9	100%	<0.203	<0.977	<0.9	NC	<2.04	Polychlorinated Biphenyls
PCB-81	pg/L	9	9	100%	<0.213	<1.12	<1.08	NC	<2.19	Polychlorinated Biphenyls
PCB-82	pg/L	9	1	11%	<2.05	3.63	4	NC	4.73	Polychlorinated Biphenyls
PCB-83 + 99	pg/L	9	0	0%	16.8	22.30	22	NC	26.3	Polychlorinated Biphenyls
PCB-84	pg/L	9	0	0%	7.4	11.10	11	NC	14.8	Polychlorinated Biphenyls
PCB-85 + 116 + 117	pg/L	9	0	0%	5.3	7.44	7	NC	8.01	Polychlorinated Biphenyls
PCB-86 + 87 + 97 + 108 + 119 + 125	pg/L	9	0	0%	21.9	29.00	28	NC	34.7	Polychlorinated Biphenyls
PCB-88 + 91	pg/L	9	0	0%	3.8	5.94	5	NC	7.06	Polychlorinated Biphenyls
PCB-89	pg/L	9	8	89%	<0.382	<1.27	1.3	NC	<1.92	Polychlorinated Biphenyls
PCB-90 + 101 + 113	pg/L	9	0	0%	33.0	44.80	42	NC	50.4	Polychlorinated Biphenyls
PCB-92	pg/L	9	1	11%	<0.349	7.35	7	NC	8.75	Polychlorinated Biphenyls
PCB-93 + 95 + 98 + 100 + 102	pg/L	9	0	0%	26.7	35.20	37	NC	48.7	Polychlorinated Biphenyls
PCB-94	pg/L	9	9	100%	<0.377	<1.31	<1.28	NC	<1.96	Polychlorinated Biphenyls
PCB-96	pg/L	9	9	100%	<0.205	<0.704	<0.65	NC	<1.1	Polychlorinated Biphenyls
PCB-103	pg/L	9	7	78%	0.411	<1.05	1.1	NC	<1.62	Polychlorinated Biphenyls
PCB-104	pg/L	9	8	89%	<0.183	<0.626	0.6	NC	1.54	Polychlorinated Biphenyls
PCB-105	pg/L	9	0	0%	8.9	13.90	13	NC	16.7	Polychlorinated Biphenyls
PCB-106	pg/L	9	9	100%	<0.237	<1.21	<1.13	NC	<2.38	Polychlorinated Biphenyls
PCB-107 + 124	pg/L	9	4	44%	0.904	1.82	2	NC	<2.61	Polychlorinated Biphenyls
PCB-109	pg/L	9	1	11%	1.65	2.04	2	NC	2.72	Polychlorinated Biphenyls

PARAMETER	Units	# of Samples	# of Samples < MDL	Percent of Samples < MDL	Minimum	Median	Mean	95th Percentile	Maximum	Group
PCB-110 + 115	pg/L	9	0	0%	31.8	43.40	42	NC	47.7	Polychlorinated Biphenyls
PCB-111	pg/L	9	9	100%	<0.257	<0.923	<0.9	NC	<1.39	Polychlorinated Biphenyls
PCB-112	pg/L	9	9	100%	<0.254	<0.906	<0.86	NC	<1.36	Polychlorinated Biphenyls
PCB-114	pg/L	9	3	33%	0.759	1.50	1	NC	<2.55	Polychlorinated Biphenyls
PCB-118	pg/L	9	0	0%	24.0	36.50	34	NC	41.7	Polychlorinated Biphenyls
PCB-120	pg/L	9	9	100%	<0.244	<0.854	<0.84	NC	<1.28	Polychlorinated Biphenyls
PCB-121	pg/L	9	9	100%	<0.263	<0.928	<0.91	NC	<1.4	Polychlorinated Biphenyls
PCB-122	pg/L	9	9	100%	<0.262	<1.38	<1.28	NC	<2.71	Polychlorinated Biphenyls
PCB-123	pg/L	9	5	56%	<0.499	<1.48	2	NC	<2.62	Polychlorinated Biphenyls
PCB-126	pg/L	9	9	100%	<0.274	<1.68	<1.39	NC	<2.74	Polychlorinated Biphenyls
PCB-127	pg/L	9	9	100%	<0.242	<1.25	<1.19	NC	<2.55	Polychlorinated Biphenyls
PCB-128 + 166	pg/L	9	0	0%	4.2	4.99	5	NC	5.99	Polychlorinated Biphenyls
PCB-129 + 138 + 160 + 163	pg/L	9	0	0%	29.4	36.80	37	NC	42.9	Polychlorinated Biphenyls
PCB-130	pg/L	9	2	22%	1.45	2.33	2	NC	2.64	Polychlorinated Biphenyls
PCB-131	pg/L	9	9	100%	<0.491	<1.88	<1.52	NC	<2.39	Polychlorinated Biphenyls
PCB-132	pg/L	9	0	0%	9.4	11.20	12	NC	13.7	Polychlorinated Biphenyls
PCB-133	pg/L	9	8	89%	<0.528	<1.76	1.5	NC	<2.23	Polychlorinated Biphenyls
PCB-134 + 143	pg/L	9	3	33%	1.28	2.03	2	NC	2.55	Polychlorinated Biphenyls
PCB-135 + 151 + 154	pg/L	9	0	0%	9.5	11.30	12	NC	16.2	Polychlorinated Biphenyls
PCB-136	pg/L	9	0	0%	2.8	4.25	4	NC	6.11	Polychlorinated Biphenyls
PCB-137	pg/L	9	1	11%	1.66	1.95	2	NC	2.64	Polychlorinated Biphenyls
PCB-139 + 140	pg/L	9	7	78%	<0.515	<1.72	1.5	NC	<2.19	Polychlorinated Biphenyls
PCB-141	pg/L	9	0	0%	5.0	5.77	6	NC	7.66	Polychlorinated Biphenyls

PARAMETER	Units	# of Samples	# of Samples < MDL	Percent of Samples < MDL	Minimum	Median	Mean	95th Percentile	Maximum	Group
PCB-142	pg/L	9	9	100%	<0.485	<1.89	<1.5	NC	<2.41	Polychlorinated Biphenyls
PCB-144	pg/L	9	3	33%	<0.419	1.78	2	NC	2.28	Polychlorinated Biphenyls
PCB-145	pg/L	9	9	100%	<0.287	<0.951	<0.85	NC	<1.38	Polychlorinated Biphenyls
PCB-146	pg/L	9	0	0%	4.4	5.98	6	NC	11.7	Polychlorinated Biphenyls
PCB-147 + 149	pg/L	9	0	0%	21.3	27.1	26	NC	29.9	Polychlorinated Biphenyls
PCB-148	pg/L	9	9	100%	<0.355	<1.21	<1.07	NC	<1.74	Polychlorinated Biphenyls
PCB-150	pg/L	9	9	100%	<0.269	<0.897	<0.81	NC	<1.34	Polychlorinated Biphenyls
PCB-152	pg/L	9	9	100%	<0.257	<0.842	<0.76	NC	<1.25	Polychlorinated Biphenyls
PCB-153 + 168	pg/L	9	0	0%	26.5	34.5	33	NC	38.1	Polychlorinated Biphenyls
PCB-155	pg/L	9	0	0%	1.8	2.17	2	NC	2.89	Polychlorinated Biphenyls
PCB-156 + 157	pg/L	9	0	0%	3.6	4.77	5	NC	6.13	Polychlorinated Biphenyls
PCB-158	pg/L	9	0	0%	2.3	3.72	3	NC	4.29	Polychlorinated Biphenyls
PCB-159	pg/L	9	9	100%	<0.361	<1.33	<1.06	NC	<1.72	Polychlorinated Biphenyls
PCB-161	pg/L	9	9	100%	<0.35	<1.27	<1.04	NC	<1.62	Polychlorinated Biphenyls
PCB-162	pg/L	9	9	100%	<0.375	<1.34	<1.07	NC	<1.7	Polychlorinated Biphenyls
PCB-164	pg/L	9	2	22%	<1.49	1.99	2	NC	2.6	Polychlorinated Biphenyls
PCB-165	pg/L	9	9	100%	<0.394	<1.49	<1.18	NC	<1.89	Polychlorinated Biphenyls
PCB-167	pg/L	9	2	22%	1.16	1.58	2	NC	1.87	Polychlorinated Biphenyls
PCB-169	pg/L	9	9	100%	<0.345	<1.26	<1.06	NC	<1.69	Polychlorinated Biphenyls
PCB-170	pg/L	9	0	0%	5.1	5.80	6	NC	7.54	Polychlorinated Biphenyls
PCB-171 + 173	pg/L	9	2	22%	<1.28	1.72	2	NC	2.18	Polychlorinated Biphenyls
PCB-172	pg/L	9	6	67%	0.671	<1.32	1.3	NC	<2.11	Polychlorinated Biphenyls
PCB-174	pg/L	9	0	0%	4.5	5.32	6	NC	7.85	Polychlorinated Biphenyls

PARAMETER	Units	# of Samples	# of Samples < MDL	Percent of Samples < MDL	Minimum	Median	Mean	95th Percentile	Maximum	Group
PCB-175	pg/L	9	9	100%	<0.408	<1.12	<1.05	NC	<1.88	Polychlorinated Biphenyls
PCB-176	pg/L	9	3	33%	<0.739	1.05	1	NC	1.49	Polychlorinated Biphenyls
PCB-177	pg/L	9	0	0%	2.9	3.37	4	NC	4.54	Polychlorinated Biphenyls
PCB-178	pg/L	9	1	11%	1.30	1.84	2	NC	2.14	Polychlorinated Biphenyls
PCB-179	pg/L	9	0	0%	2.6	3.34	4	NC	4.82	Polychlorinated Biphenyls
PCB-180 + 193	pg/L	9	0	0%	12.3	14.4	15	NC	19.7	Polychlorinated Biphenyls
PCB-181	pg/L	9	9	100%	<0.439	<1.22	<1.11	NC	<1.95	Polychlorinated Biphenyls
PCB-182	pg/L	9	9	100%	<0.414	<1.14	<1.06	NC	<1.91	Polychlorinated Biphenyls
PCB-183 + 185	pg/L	9	1	11%	<1.55	4.50	5	NC	6.7	Polychlorinated Biphenyls
PCB-184	pg/L	9	0	0%	4.2	5.2	5	NC	6.71	Polychlorinated Biphenyls
PCB-186	pg/L	9	9	100%	<0.341	<0.913	<0.84	NC	<1.49	Polychlorinated Biphenyls
PCB-187	pg/L	9	0	0%	7.9	10.00	10	NC	13.2	Polychlorinated Biphenyls
PCB-188	pg/L	9	9	100%	<0.254	<0.872	<0.74	NC	<1.34	Polychlorinated Biphenyls
PCB-189	pg/L	9	9	100%	<0.356	<1.19	<1.16	NC	<2.15	Polychlorinated Biphenyls
PCB-190	pg/L	9	2	22%	0.92	1.38	1	NC	2.23	Polychlorinated Biphenyls
PCB-191	pg/L	9	9	100%	<0.315	<0.938	<0.86	NC	<1.54	Polychlorinated Biphenyls
PCB-192	pg/L	9	9	100%	<0.359	<1.04	<0.96	NC	<1.73	Polychlorinated Biphenyls
PCB-194	pg/L	9	0	0%	2.3	3.20	3	NC	4.95	Polychlorinated Biphenyls
PCB-195	pg/L	9	4	44%	0.658	1.41	1	NC	<2.53	Polychlorinated Biphenyls
PCB-196	pg/L	9	4	44%	1.12	1.7	2	NC	2.2	Polychlorinated Biphenyls
PCB-197 + 200	pg/L	9	4	44%	<0.646	1.2	1	NC	2.17	Polychlorinated Biphenyls
PCB-198 + 199	pg/L	9	0	0%	3.2	4.03	4	NC	5.08	Polychlorinated Biphenyls
PCB-201	pg/L	9	8	89%	<0.361	<0.882	0.9	NC	<1.37	Polychlorinated Biphenyls

PARAMETER	Units	# of Samples	# of Samples < MDL	Percent of Samples < MDL	Minimum	Median	Mean	95th Percentile	Maximum	Group
PCB-202	pg/L	9	4	44%	0.928	1.38	1	NC	1.75	Polychlorinated Biphenyls
PCB-203	pg/L	9	0	0%	1.8	2.28	2	NC	3.76	Polychlorinated Biphenyls
PCB-204	pg/L	9	9	100%	<0.357	<0.906	<0.92	NC	<1.46	Polychlorinated Biphenyls
PCB-205	pg/L	9	9	100%	<0.355	<1.01	<1.02	NC	<1.95	Polychlorinated Biphenyls
PCB-206	pg/L	9	6	67%	1.25	<3.44	3.1	NC	<4.94	Polychlorinated Biphenyls
PCB-207	pg/L	9	9	100%	<0.543	<2.55	<2.17	NC	<3.56	Polychlorinated Biphenyls
PCB-208	pg/L	9	8	89%	<0.624	<3.12	3	NC	<4.11	Polychlorinated Biphenyls
PCB-209	pg/L	9	0	0%	1.1	2.05	2	NC	2.9	Polychlorinated Biphenyls
Total PCBs	pg/L	6	0	0%	885.4	1130.0	1109	NC	1320	Polychlorinated Biphenyls
Total Monochloro Biphenyls	pg/L	6	0	0%	16.0	23.2	23	NC	29.1	Polychlorinated Biphenyls
Total Dichloro Biphenyls	pg/L	6	0	0%	249.0	273.5	270	NC	287	Polychlorinated Biphenyls
Total Trichloro Biphenyls	pg/L	6	0	0%	187.0	213.0	211	NC	240	Polychlorinated Biphenyls
Total Tetrachloro Biphenyls	pg/L	6	0	0%	208.0	260.5	255	NC	301	Polychlorinated Biphenyls
Total Pentachloro Biphenyls	pg/L	6	0	0%	213	268	256	NC	294	Polychlorinated Biphenyls
Total Hexachloro Biphenyls	pg/L	6	0	0%	127.0	156.0	154	NC	175	Polychlorinated Biphenyls
Total Heptachloro Biphenyls	pg/L	6	0	0%	34.4	43.8	43	NC	51.3	Polychlorinated Biphenyls
Total Octachloro Biphenyls	pg/L	6	0	0%	3.2	8.41	9	NC	13.1	Polychlorinated Biphenyls
Total Nonachloro Biphenyls	pg/L	2	0	0%	11.8	11.8	12	NC	11.8	Polychlorinated Biphenyls
Decachloro Biphenyl	pg/L	2	0	0%	2.05	4.97	5	NC	7.89	Polychlorinated Biphenyls
Acenaphthene	µg/L	8	7	88%	<0.01	<0.04	0.05	NC	<0.1	Polycyclic Aromatic Hydrocarbons
Acenaphthylene	µg/L	8	8	100%	<0.01	<0.01	<0.01	NC	<0.01	Polycyclic Aromatic Hydrocarbons
Acridine	µg/L	8	4	50%	<0.02	0.03	0.03	NC	<0.05	Polycyclic Aromatic Hydrocarbons

PARAMETER	Units	# of Samples	# of Samples < MDL	Percent of Samples < MDL	Minimum	Median	Mean	95th Percentile	Maximum	Group
Anthracene	µg/L	8	8	100%	<0.01	<0.01	<0.01	NC	<0.01	Polycyclic Aromatic Hydrocarbons
Benz(a)anthracene	µg/L	8	8	100%	<0.01	<0.01	<0.01	NC	<0.01	Polycyclic Aromatic Hydrocarbons
Benzo(a)pyrene	µg/L	8	8	100%	<0.01	<0.01	<0.01	NC	<0.01	Polycyclic Aromatic Hydrocarbons
Benzo(b)fluoranthene	µg/L	8	8	100%	<0.01	<0.01	<0.02	NC	<0.1	Polycyclic Aromatic Hydrocarbons
Benzo(g,h,i)perylene	µg/L	8	7	88%	<0.01	<0.01	0.01	NC	0.022	Polycyclic Aromatic Hydrocarbons
Benzo(k)fluoranthene	µg/L	8	8	100%	<0.01	<0.01	<0.01	NC	<0.01	Polycyclic Aromatic Hydrocarbons
Chrysene	µg/L	8	8	100%	<0.01	<0.01	<0.01	NC	<0.01	Polycyclic Aromatic Hydrocarbons
Dibenz(a,h)anthracene	µg/L	8	8	100%	<0.01	<0.01	<0.01	NC	<0.01	Polycyclic Aromatic Hydrocarbons
Fluoranthene	µg/L	8	4	50%	<0.01	0.012	0.02	NC	0.044	Polycyclic Aromatic Hydrocarbons
Fluorene	µg/L	8	7	88%	<0.02	<0.03	0.04	NC	<0.1	Polycyclic Aromatic Hydrocarbons
Indeno(1,2,3-c,d)pyrene	µg/L	8	8	100%	<0.01	<0.01	<0.01	NC	<0.02	Polycyclic Aromatic Hydrocarbons
1-Methylnaphthalene	µg/L	8	8	100%	<0.01	<0.05	<0.05	NC	<0.05	Polycyclic Aromatic Hydrocarbons
2-Methylnaphthalene	µg/L	8	8	100%	<0.01	<0.05	<0.05	NC	<0.05	Polycyclic Aromatic Hydrocarbons
Naphthalene	µg/L	8	8	100%	<0.05	<0.05	<0.05	NC	<0.05	Polycyclic Aromatic Hydrocarbons
Phenanthrene	µg/L	8	8	100%	<0.02	<0.02	<0.02	NC	<0.03	Polycyclic Aromatic Hydrocarbons
Pyrene	µg/L	8	4	50%	0.01	0.02	0.02	NC	0.028	Polycyclic Aromatic Hydrocarbons
Quinoline	µg/L	8	4	50%	0.03	0.06	0.28	NC	1.31	Polycyclic Aromatic Hydrocarbons
Androsterone	ng/L	21	16	76%	<2.59	<11	11	19.1	<22.6	Sterols and Hormones

PARAMETER	Units	# of Samples	# of Samples < MDL	Percent of Samples < MDL	Minimum	Median	Mean	95th Percentile	Maximum	Group
Desogestrel	ng/L	21	21	100%	<22	<44.5	<51.23	NC	<149	Sterols and Hormones
17 α-Estradiol	ng/L	21	21	100%	<1.43	<5.44	<6.28	NC	<23.2	Sterols and Hormones
Estrone	ng/L	21	1	5%	<11.2	101.0	102	195.0	289	Sterols and Hormones
Equilin	ng/L	21	21	100%	<14.4	<37.7	<41.8	NC	<160	Sterols and Hormones
Androstenedione	ng/L	21	21	100%	<40	<89.9	<116.9	NC	<388	Sterols and Hormones
17 α-Dihydroequilin	ng/L	21	19	90%	6.97	<22.8	30	45.0	<190	Sterols and Hormones
17 β-Estradiol	ng/L	21	10	48%	<4.21	6.9	10	17.4	28.4	Sterols and Hormones
Testosterone	ng/L	21	21	100%	<17.6	<46.3	<59.96	NC	<129	Sterols and Hormones
Equilenin	ng/L	21	21	100%	<0.124	<8.91	<12.71	NC	<51.7	Sterols and Hormones
Mestranol	ng/L	21	5	24%	<12.1	33.9	41	78.3	92.2	Sterols and Hormones
Norethindrone	ng/L	21	21	100%	<9.99	<33.3	<41.46	NC	<150	Sterols and Hormones
17 α-Ethinyl-Estradiol	ng/L	21	19	90%	2.44	<5.26	8	17.1	<49.2	Sterols and Hormones
Progesterone	ng/L	21	21	100%	<8.2	<37	<69.76	NC	<730	Sterols and Hormones
Norgestrel	ng/L	21	18	86%	<16.5	<38.6	58	111.0	<271	Sterols and Hormones
Estriol	ng/L	21	13	62%	<1.99	<9.65	18	72.1	85.2	Sterols and Hormones
β-Estradiol 3-benzoate	ng/L	21	19	90%	<1.43	<8.53	57	246.0	<713	Sterols and Hormones
Coprostanol	ng/L	21	0	0%	14600	27400	28138	38000	48800	Sterols and Hormones
Epicoprostanol	ng/L	21	1	5%	<28.2	742	995	2580	2580	Sterols and Hormones
Cholesterol	ng/L	21	0	0%	15300	27400	28219	39700	44800	Sterols and Hormones
Cholestanol	ng/L	21	0	0%	1810	3890	3860	5630	5980	Sterols and Hormones
Desmosterol	ng/L	21	0	0%	631.0	1430.0	1452	2210.0	2520	Sterols and Hormones
Ergosterol	ng/L	21	0	0%	272.0	1700.0	1710	2980.0	3210	Sterols and Hormones
Campesterol	ng/L	21	0	0%	1830.0	4170.0	4180	6590.0	6750	Sterols and Hormones
Stigmasterol	ng/L	21	0	0%	1970.0	4600.0	5983	8130.0	34700	Sterols and Hormones
β-Sitosterol	ng/L	21	0	0%	8080.0	12200.0	22391	35500.0	185000	Sterols and Hormones
β-Stigmastanol	ng/L	21	0	0%	698.0	1380.0	1373	1940.0	3040	Sterols and Hormones
Aluminum	µg/L	174	0	0%	19.0	45.0	48	80.0	140	Total Metals
Arsenic	µg/L	174	20	11%	0.5	0.70	1	1.00	1.7	Total Metals
Barium	µg/L	174	0	0%	2.7	5.0	5	9.0	15.7	Total Metals
Boron	µg/L	174	0	0%	93.0	153.5	158	239.7	303	Total Metals
Cadmium	µg/L	174	172	99%	<0.2	<0.2	0	NC	3.7	Total Metals
Chromium	µg/L	174	14	8%	0.5	1.00	1	1.70	4.8	Total Metals
Cobalt	µg/L	174	119	68%	0.5	<0.5	0.58333	1.00	1.1	Total Metals
Copper	µg/L	174	0	0%	8.2	18.9	20	33.9	43.2	Total Metals

PARAMETER	Units	# of Samples	# of Samples < MDL	Percent of Samples < MDL	Minimum	Median	Mean	95th Percentile	Maximum	Group
Iron	µg/L	174	0	0%	248.0	507.5	510	779.1	1650	Total Metals
Lead	µg/L	174	81	47%	0.5	0.60	1	1.40	2	Total Metals
Manganese	µg/L	174	0	0%	34.4	62.6	62	78.4	93.7	Total Metals
Mercury	µg/L	174	174	100%	<0.05	<0.05	<0.05	NC	<0.05	Total Metals
Molybdenum	µg/L	174	16	9%	0.8	1.20	1	2.00	15	Total Metals
Nickel	µg/L	174	0	0%	1.7	2.40	3	5.50	22.3	Total Metals
Selenium	µg/L	173	173	100%	<0.5	<0.5	<0.65	NC	<10	Total Metals
Silver	µg/L	173	173	100%	<0.5	<0.5	<0.55	NC	<1	Total Metals
Zinc	µg/L	174	0	0%	12.0	22.0	25	44.4	67	Total Metals
Total Residual Chlorine	mg/l	878	878	100%	<0.02	<0.02	<0.06	NC	<0.1	Physical Parameters
Ammonia (un-ionized)	mg/L	339	0	0%	0.11	0.56	0.54	NC	0.93	Nutrients
[illegible]	mg/L	561	20	4%	<4	7.00	7	10.00	28	Physical Parameters

Appendix B

Summary Statistics for 2011-2014 AIWWTP Effluent Flux Calculations

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PARAMETER	UNITS	Average Daily Flux (kg/day)	Standard Deviation of Average Daily Flux(kg/day)	GROUPING
Aluminium	μg/L	7.11	2.42	Dissolved Metals
Arsenic	μg/L	0.91	1.55	Dissolved Metals
Barium	μg/L	1.68	0.90	Dissolved Metals
Boron	μg/L	71.2	18.7	Dissolved Metals
Cadmium	μg/L	0.12	0.10	Dissolved Metals
Calcium	μg/L	6173	2424	Dissolved Metals
Chromium	μg/L	0.35	0.22	Dissolved Metals
Cobalt	μg/L	0.27	0.09	Dissolved Metals
Copper	μg/L	5.71	2.78	Dissolved Metals
Iron	μg/L	59.9	15.8	Dissolved Metals
Lead	μg/L	0.27	0.09	Dissolved Metals
Magnesium	μg/L	1437	413	Dissolved Metals
Manganese	μg/L	24.4	8.69	Dissolved Metals
Molybdenum	μg/L	0.68	0.83	Dissolved Metals
Nickel	μg/L	1.45	1.31	Dissolved Metals
Selenium	μg/L	0.28	0.10	Dissolved Metals
Silver	μg/L	0.38	0.80	Dissolved Metals
Sodium	μg/L	18719	3949	Dissolved Metals
Zinc	μg/L	10.2	3.94	Dissolved Metals
2,4'-DDD	ng/l	7.78E-05	1.45E-05	Herbicides
2,4'-DDE	ng/l	5.18E-05	1.27E-05	Herbicides
2,4'-DDT	ng/l	7.66E-05	9.20E-06	Herbicides
3[OH] Carbofuran	ng/l	2.44E-04	1.06E-05	Herbicides
4,4'-DDD	ng/l	5.69E-05	5.95E-06	Herbicides
4,4'-DDE	ng/l	2.87E-04	8.79E-05	Herbicides
4,4'-DDT	ng/l	7.47E-05	8.37E-06	Herbicides
Alachlor	ng/l	7.01E-04	7.95E-05	Herbicides
Dacthal	ng/l	2.11E-05	6.92E-07	Herbicides
Diazinon	ng/l	5.94E-04	1.01E-04	Herbicides
Dieldrin	ng/l	1.37E-04	5.56E-05	Herbicides
Dimethenamid	ng/l	5.98E-05	7.24E-06	Herbicides
Dioxacarb	ng/l	2.44E-04	1.06E-05	Herbicides
Endosulphan Sulphate	ng/l	2.25E-04	6.99E-05	Herbicides
Endrin	ng/l	1.29E-04	6.61E-05	Herbicides
Endrin Aldehyde	ng/l	3.55E-04	1.93E-04	Herbicides
Endrin Ketone	ng/l	6.28E-05	2.16E-05	Herbicides
Ethalfluralin	ng/l	1.94E-04	2.06E-05	Herbicides
Flufenacet	ng/l	9.58E-03	2.41E-03	Herbicides
Flutriafol	ng/l	4.47E-04	8.13E-05	Herbicides
Hexachlorobenzene	ng/l	5.23E-05	4.12E-06	Herbicides
Linuron	ng/l	6.02E-04	1.57E-04	Herbicides
Pendimethalin	ng/l	1.11E-03	5.48E-04	Herbicides
Quintozene	ng/l	9.66E-06	3.38E-06	Herbicides
Tebuconazol	ng/l	3.57E-03	2.34E-04	Herbicides
Tecnazene	ng/l	6.29E-06	9.83E-07	Herbicides
Triallate	ng/l	3.90E-05	2.92E-06	Herbicides
Trifluralin	ng/l	5.48E-05	5.81E-07	Herbicides
Aldicarb	ng/l	2.44E-04	1.06E-05	Insecticides
Aldicarb Sulfone	ng/l	4.93E-04	2.12E-05	Insecticides
Aldicarb Sulfoxide	ng/l	2.44E-04	1.06E-05	Insecticides
Aldrin	ng/l	1.74E-04	6.51E-05	Insecticides
Allethrin	ng/L	0.04	0.02	Insecticides
alpha-Endosulphan	ng/l	2.77E-04	4.92E-05	Insecticides
Aminocarb	ng/l	2.44E-04	1.06E-05	Insecticides
Bendiocarb	ng/l	4.88E-04	2.09E-05	Insecticides
beta-Endosulphan	ng/l	2.62E-04	8.25E-05	Insecticides
Bifenthrin	ng/L	1.25E-03	6.30E-04	Insecticides
Butralin	ng/l	9.65E-04	4.65E-05	Insecticides
Butylate	ng/l	1.70E-04	6.11E-05	Insecticides
Captan	ng/l	9.77E-04	2.84E-04	Insecticides

PARAMETER	UNITS	Average Daily Flux (kg/day)	Standard Deviation of Average Daily Flux(kg/day)	GROUPING
Carbaryl	ng/l	1.85E-03	1.86E-04	Insecticides
Carbofuran	ng/l	2.44E-04	1.06E-05	Insecticides
Chlordane, alpha (cis)	ng/l	6.22E-05	3.21E-07	Insecticides
Chlordane, gamma (trans)	ng/l	6.84E-05	1.65E-05	Insecticides
Chlordane, oxy-	ng/l	4.67E-04	1.99E-04	Insecticides
Chlorothalonil	ng/l	3.46E-05	1.46E-05	Insecticides
Chlorpyriphos	ng/l	4.93E-04	2.12E-05	Insecticides
Cinerin I	ng/L	5.10E-03	7.56E-03	Insecticides
Cinerin II	ng/L	3.30E-03	2.73E-03	Insecticides
Cyfluthrin	ng/L	1.92E-03	1.17E-03	Insecticides
Cypermethrin	ng/L	8.35E-04	5.90E-04	Insecticides
Deltamethrin/Tralomethrin	ng/L	8.33E-04	6.69E-04	Insecticides
Fenpropathrin	ng/L	4.55E-03	1.55E-03	Insecticides
Fenvalerate	ng/L	5.96E-04	3.32E-04	Insecticides
Flucythrinate	ng/L	5.45E-04	3.64E-04	Insecticides
HCH, alpha	ng/l	1.56E-04	6.18E-05	Insecticides
HCH, alpha	ng/l	1.56E-04	6.18E-05	Insecticides
HCH, beta	ng/l	2.73E-04	1.36E-05	Insecticides
HCH, delta	ng/l	2.96E-04	6.15E-05	Insecticides
HCH, gamma	ng/l	2.16E-04	3.71E-05	Insecticides
Heptachlor	ng/l	1.67E-04	7.73E-05	Insecticides
Heptachlor Epoxide	ng/l	2.68E-04	3.77E-05	Insecticides
Imidacloprid	ng/l	1.14E-02	2.24E-03	Insecticides
Jasmolin I	ng/L	0.02	0.03	Insecticides
Jasmolin II	ng/L	0.01	0.01	Insecticides
L-Cyhalothrin	ng/L	5.26E-04	3.32E-04	Insecticides
Methiocarb	ng/l	4.93E-04	2.12E-05	Insecticides
Methomyl	ng/l	2.44E-04	1.06E-05	Insecticides
Methoprene	ng/l	2.95E-02	2.41E-03	Insecticides
Methoxychlor	ng/l	2.58E-04	1.09E-04	Insecticides
Metolachlor	ng/l	2.43E-04	1.53E-05	Insecticides
Mexacarbate	ng/l	2.40E-04	1.04E-05	Insecticides
Mirex	ng/l	6.93E-05	1.13E-05	Insecticides
Nonachlor, cis-	ng/l	3.43E-05	5.57E-06	Insecticides
Nonachlor, trans-	ng/l	3.49E-05	5.75E-06	Insecticides
Oxamyl	ng/l	5.03E-04	1.82E-04	Insecticides
Permethrin	ng/L	7.11E-03	9.41E-04	Insecticides
Perthane	ng/l	3.52E-03	3.90E-04	Insecticides
Phenothrin	ng/L	8.64E-04	5.17E-04	Insecticides
Piperonyl butoxide	ng/L	0.22	0.09	Insecticides
Pirimicarb	ng/l	2.44E-04	1.06E-05	Insecticides
Prallethrin	ng/L	0.09	0.04	Insecticides
Promecarb	ng/l	4.88E-04	2.09E-05	Insecticides
Propoxur	ng/l	8.29E-04	1.69E-04	Insecticides
Pyrethrin I	ng/L	0.01	0.01	Insecticides
Pyrethrin II	ng/L	9.34E-03	7.89E-03	Insecticides
Resmethrin	ng/L	4.69E-03	4.38E-03	Insecticides
Tetramethrin	ng/L	2.31E-03	1.71E-03	Insecticides
Calcium Total	µg/L	6431	2316	Major Ions
Fluoride	mg/L	33.9	18.8	Major Ions
Magnesium Total	µg/L	1549	479	Major Ions
Sodium Total	µg/L	19445	4039	Major Ions
Sulfate	mg/L	8250	1918	Major Ions
Cyanide	mg/L	9.72	1.95	Miscellaneous
Hexachlorobutadiene	ng/l	1.47E-04	3.70E-05	Miscellaneous
Octachlorostyrene	ng/l	5.47E-06	8.07E-07	Miscellaneous
WHO 2005 TOTAL (TEQ ND=0)	ng/l	1.02E-06	1.73E-07	Miscellaneous
WHO 2005 TOTAL (TEQ ND=1/2 DL)	ng/l	6.24E-05	3.08E-06	Miscellaneous

PARAMETER	UNITS	Average Daily Flux (kg/day)	Standard Deviation of Average Daily Flux(kg/day)	GROUPING
Ammonia as N	mg/L	14246	1292	Nutrients
Dissolved Organic Carbon	mg/L	5308	984	Nutrients
Nitrogen - Nitrate as N	mg/L	14.8	18.1	Nutrients
Nitrogen - Nitrite as N	mg/L	24.2	18.4	Nutrients
Phosphorus Dissolved	µg/L	1064	242	Nutrients
Phosphorus Total	µg/L	1222	246	Nutrients
Total Kjeldahl Nitrogen	mg/L	15237	1394	Nutrients
Total Organic Carbon	mg/L	6243	1253	Nutrients
UNIONIZED AMMONIA	mg/L	248.1	59.3	Nutrients
4-Nonylphenol diethoxylates	ng/L	0.88	0.65	Phenols
4-Nonylphenol monoethoxylates	ng/L	0.49	0.26	Phenols
4-Nonylphenols	ng/L	0.58	0.24	Phenols
Octylphenol	ng/L	4.24E-03	4.87E-03	Phenols
CBOD	mg/L	3329.9	1436.8	Conventional
Dissolved Oxygen	mg/L	2268	725	Conventional
Oil and Grease	mg/L	2103	1449	Conventional
Total Residual Chlorine	mg/L	45.2	6.2	Conventional
Total Suspended Solids	mg/L	4386	2473	Conventional
Volatile Suspended Solids	mg/L	3848	2375	Conventional
BDE-10	pg/L	2.41E-07	6.09E-08	Polybrominated Diphenyl Ethers
BDE-100	pg/L	3.93E-04	1.93E-04	Polybrominated Diphenyl Ethers
BDE-105	pg/L	1.77E-06	3.32E-07	Polybrominated Diphenyl Ethers
BDE-116	pg/L	5.87E-06	4.89E-06	Polybrominated Diphenyl Ethers
BDE-119 + 120	pg/L	5.51E-06	6.28E-09	Polybrominated Diphenyl Ethers
BDE-12 + 13	pg/L	7.80E-07	2.80E-07	Polybrominated Diphenyl Ethers
BDE-126	pg/L	1.32E-06	4.47E-08	Polybrominated Diphenyl Ethers
BDE-128	pg/L	1.38E-05	1.82E-05	Polybrominated Diphenyl Ethers
BDE-138 + 166	pg/L	2.60E-05	2.11E-05	Polybrominated Diphenyl Ethers
BDE-140	pg/L	6.95E-06	4.43E-06	Polybrominated Diphenyl Ethers
BDE-15	pg/L	3.72E-06	1.44E-06	Polybrominated Diphenyl Ethers
BDE-153	pg/L	1.97E-04	1.10E-04	Polybrominated Diphenyl Ethers
BDE-154	pg/L	1.51E-04	7.68E-05	Polybrominated Diphenyl Ethers
BDE-155	pg/L	1.37E-05	9.31E-06	Polybrominated Diphenyl Ethers
BDE-17 + 25	pg/L	2.10E-05	6.83E-06	Polybrominated Diphenyl Ethers
BDE-181	pg/L	1.54E-06	1.43E-06	Polybrominated Diphenyl Ethers
BDE-183	pg/L	3.15E-05	1.82E-05	Polybrominated Diphenyl Ethers
BDE-190	pg/L	4.85E-06	3.22E-06	Polybrominated Diphenyl Ethers
BDE-203	pg/L	2.79E-05	1.47E-05	Polybrominated Diphenyl Ethers
BDE-206	pg/L	1.25E-04	9.45E-05	Polybrominated Diphenyl Ethers
BDE-207	pg/L	1.22E-04	8.19E-05	Polybrominated Diphenyl Ethers
BDE-208	pg/L	1.03E-04	8.14E-05	Polybrominated Diphenyl Ethers
BDE-209	pg/L	3.29E-03	3.11E-03	Polybrominated Diphenyl Ethers
BDE-28 + 33	pg/L	3.81E-05	1.22E-05	Polybrominated Diphenyl Ethers
BDE-30	pg/L	2.61E-07	3.22E-08	Polybrominated Diphenyl Ethers
BDE-32	pg/L	2.43E-07	5.73E-08	Polybrominated Diphenyl Ethers
BDE-35	pg/L	7.36E-07	2.37E-07	Polybrominated Diphenyl Ethers
BDE-37	pg/L	1.65E-06	1.43E-07	Polybrominated Diphenyl Ethers
BDE-47	pg/L	1.99E-03	8.19E-04	Polybrominated Diphenyl Ethers
BDE-49	pg/L	5.44E-05	2.07E-05	Polybrominated Diphenyl Ethers
BDE-51	pg/L	6.97E-06	2.29E-06	Polybrominated Diphenyl Ethers
BDE-66	pg/L	4.08E-05	1.30E-05	Polybrominated Diphenyl Ethers
BDE-7	pg/L	7.70E-07	2.41E-07	Polybrominated Diphenyl Ethers
BDE-71	pg/L	6.93E-06	2.03E-06	Polybrominated Diphenyl Ethers
BDE-75	pg/L	2.96E-06	9.63E-07	Polybrominated Diphenyl Ethers
BDE-77	pg/L	4.35E-07	5.90E-09	Polybrominated Diphenyl Ethers
BDE-79	pg/L	1.01E-06	1.14E-06	Polybrominated Diphenyl Ethers
BDE-8 + 11	pg/L	1.04E-06	1.79E-07	Polybrominated Diphenyl Ethers
BDE-85	pg/L	8.24E-05	4.92E-05	Polybrominated Diphenyl Ethers

PARAMETER	UNITS	Average Daily Flux (kg/day)	Standard Deviation of Average Daily Flux(kg/day)	GROUPING
BDE-99	pg/L	1.98E-03	1.01E-03	Polybrominated Diphenyl Ethers
Deca-BDE-209	pg/L	3.61E-03	1.08E-03	Polybrominated Diphenyl Ethers
Di-BDE-10	pg/L	8.55E-07	2.36E-08	Polybrominated Diphenyl Ethers
Di-BDE-12 + 13	pg/L	1.80E-06	4.49E-07	Polybrominated Diphenyl Ethers
Di-BDE-15	pg/L	4.71E-06	9.99E-07	Polybrominated Diphenyl Ethers
Di-BDE-7	pg/L	1.16E-06	7.41E-08	Polybrominated Diphenyl Ethers
Di-BDE-8 + 11	pg/L	1.21E-06	3.28E-08	Polybrominated Diphenyl Ethers
Hepta-BDE-181	pg/L	1.38E-06	4.11E-07	Polybrominated Diphenyl Ethers
Hepta-BDE-183	pg/L	4.35E-05	8.03E-06	Polybrominated Diphenyl Ethers
Hepta-BDE-190	pg/L	4.63E-06	3.06E-06	Polybrominated Diphenyl Ethers
Hexa-BDE-128	pg/L	4.27E-06	1.92E-06	Polybrominated Diphenyl Ethers
Hexa-BDE-138 + 166	pg/L	3.35E-05	1.14E-05	Polybrominated Diphenyl Ethers
Hexa-BDE-140	pg/L	9.19E-06	3.17E-06	Polybrominated Diphenyl Ethers
Hexa-BDE-153	pg/L	2.53E-04	7.41E-05	Polybrominated Diphenyl Ethers
Hexa-BDE-154	pg/L	1.98E-04	4.98E-05	Polybrominated Diphenyl Ethers
Hexa-BDE-155	pg/L	1.47E-05	2.85E-06	Polybrominated Diphenyl Ethers
Nona-BDE-206	pg/L	2.62E-04	6.84E-05	Polybrominated Diphenyl Ethers
Nona-BDE-207	pg/L	3.67E-04	9.59E-05	Polybrominated Diphenyl Ethers
Nona-BDE-208	pg/L	2.93E-04	1.17E-04	Polybrominated Diphenyl Ethers
Octa-BDE-203	pg/L	6.45E-05	1.75E-05	Polybrominated Diphenyl Ethers
Penta-BDE-100	pg/L	5.55E-04	1.56E-04	Polybrominated Diphenyl Ethers
Penta-BDE-105	pg/L	5.86E-06	3.64E-07	Polybrominated Diphenyl Ethers
Penta-BDE-116	pg/L	2.91E-05	4.42E-06	Polybrominated Diphenyl Ethers
Penta-BDE-119 + 120	pg/L	8.99E-06	3.99E-07	Polybrominated Diphenyl Ethers
Penta-BDE-126	pg/L	3.25E-06	2.16E-07	Polybrominated Diphenyl Ethers
Penta-BDE-85	pg/L	1.21E-04	3.52E-05	Polybrominated Diphenyl Ethers
Penta-BDE-99	pg/L	2.76E-03	7.85E-04	Polybrominated Diphenyl Ethers
Tetra-BDE-47	pg/L	2.85E-03	7.37E-04	Polybrominated Diphenyl Ethers
Tetra-BDE-49	pg/L	8.02E-05	2.68E-05	Polybrominated Diphenyl Ethers
Tetra-BDE-51	pg/L	1.01E-05	2.34E-06	Polybrominated Diphenyl Ethers
Tetra-BDE-66	pg/L	6.74E-05	2.12E-05	Polybrominated Diphenyl Ethers
Tetra-BDE-71	pg/L	1.11E-05	1.53E-06	Polybrominated Diphenyl Ethers
Tetra-BDE-75	pg/L	4.66E-06	1.35E-06	Polybrominated Diphenyl Ethers
Tetra-BDE-77	pg/L	8.31E-07	1.03E-08	Polybrominated Diphenyl Ethers
Tetra-BDE-79	pg/L	2.10E-05	3.72E-06	Polybrominated Diphenyl Ethers
Tri-BDE-17 + 25	pg/L	3.68E-05	7.49E-06	Polybrominated Diphenyl Ethers
Tri-BDE-28 + 33	pg/L	5.35E-05	1.04E-05	Polybrominated Diphenyl Ethers
Tri-BDE-30	pg/L	8.31E-07	1.03E-08	Polybrominated Diphenyl Ethers
Tri-BDE-32	pg/L	8.31E-07	1.03E-08	Polybrominated Diphenyl Ethers
Tri-BDE-35	pg/L	1.32E-06	6.71E-07	Polybrominated Diphenyl Ethers
Tri-BDE-37	pg/L	3.39E-06	1.08E-06	Polybrominated Diphenyl Ethers
Decachloro Biphenyl	pg/L	2.11E-06	2.32E-06	Polychlorinated Biphenyls
PCB-1	pg/L	1.19E-05	4.55E-06	Polychlorinated Biphenyls
PCB-10	pg/L	2.38E-06	6.45E-07	Polychlorinated Biphenyls
PCB-103	pg/L	7.35E-07	3.61E-07	Polychlorinated Biphenyls
PCB-104	pg/L	4.32E-07	2.81E-07	Polychlorinated Biphenyls
PCB-105	pg/L	8.90E-06	2.49E-06	Polychlorinated Biphenyls
PCB-106	pg/L	7.82E-07	4.65E-07	Polychlorinated Biphenyls
PCB-107 + 124	pg/L	1.15E-06	4.64E-07	Polychlorinated Biphenyls
PCB-109	pg/L	1.39E-06	4.26E-07	Polychlorinated Biphenyls
PCB-11	pg/L	4.65E-05	1.28E-05	Polychlorinated Biphenyls
PCB-110 + 115	pg/L	2.83E-05	8.00E-06	Polychlorinated Biphenyls
PCB-111	pg/L	6.31E-07	3.31E-07	Polychlorinated Biphenyls
PCB-112	pg/L	6.03E-07	3.24E-07	Polychlorinated Biphenyls
PCB-114	pg/L	1.01E-06	3.78E-07	Polychlorinated Biphenyls
PCB-118	pg/L	2.29E-05	6.08E-06	Polychlorinated Biphenyls
PCB-12 + 13	pg/L	2.53E-06	5.64E-07	Polychlorinated Biphenyls
PCB-120	pg/L	5.86E-07	3.07E-07	Polychlorinated Biphenyls
PCB-121	pg/L	6.37E-07	3.34E-07	Polychlorinated Biphenyls
PCB-122	pg/L	8.88E-07	5.30E-07	Polychlorinated Biphenyls

PARAMETER	UNITS	Average Daily Flux (kg/day)	Standard Deviation of Average Daily Flux(kg/day)	GROUPING
PCB-123	pg/L	9.94E-07	4.80E-07	Polychlorinated Biphenyls
PCB-126	pg/L	9.66E-07	5.56E-07	Polychlorinated Biphenyls
PCB-127	pg/L	8.23E-07	5.02E-07	Polychlorinated Biphenyls
PCB-128 + 166	pg/L	3.44E-06	8.98E-07	Polychlorinated Biphenyls
PCB-129 + 138 + 160 + 163	pg/L	2.47E-05	6.54E-06	Polychlorinated Biphenyls
PCB-130	pg/L	1.48E-06	3.72E-07	Polychlorinated Biphenyls
PCB-131	pg/L	1.03E-06	5.72E-07	Polychlorinated Biphenyls
PCB-132	pg/L	7.84E-06	2.01E-06	Polychlorinated Biphenyls
PCB-133	pg/L	1.02E-06	4.79E-07	Polychlorinated Biphenyls
PCB-134 + 143	pg/L	1.35E-06	4.18E-07	Polychlorinated Biphenyls
PCB-135 + 151 + 154	pg/L	7.98E-06	1.21E-06	Polychlorinated Biphenyls
PCB-136	pg/L	2.97E-06	5.39E-07	Polychlorinated Biphenyls
PCB-137	pg/L	1.36E-06	3.64E-07	Polychlorinated Biphenyls
PCB-139 + 140	pg/L	1.01E-06	4.49E-07	Polychlorinated Biphenyls
PCB-14	pg/L	1.98E-06	7.97E-07	Polychlorinated Biphenyls
PCB-141	pg/L	4.04E-06	1.18E-06	Polychlorinated Biphenyls
PCB-142	pg/L	1.02E-06	5.79E-07	Polychlorinated Biphenyls
PCB-144	pg/L	1.20E-06	3.87E-07	Polychlorinated Biphenyls
PCB-145	pg/L	5.78E-07	2.95E-07	Polychlorinated Biphenyls
PCB-146	pg/L	4.01E-06	9.69E-07	Polychlorinated Biphenyls
PCB-147 + 149	pg/L	1.76E-05	3.97E-06	Polychlorinated Biphenyls
PCB-148	pg/L	7.31E-07	3.77E-07	Polychlorinated Biphenyls
PCB-15	pg/L	1.71E-05	5.95E-06	Polychlorinated Biphenyls
PCB-150	pg/L	5.50E-07	2.93E-07	Polychlorinated Biphenyls
PCB-152	pg/L	5.16E-07	2.70E-07	Polychlorinated Biphenyls
PCB-153 + 168	pg/L	2.24E-05	5.89E-06	Polychlorinated Biphenyls
PCB-155	pg/L	1.50E-06	4.55E-07	Polychlorinated Biphenyls
PCB-156 + 157	pg/L	3.28E-06	1.05E-06	Polychlorinated Biphenyls
PCB-158	pg/L	2.35E-06	5.76E-07	Polychlorinated Biphenyls
PCB-159	pg/L	7.24E-07	4.12E-07	Polychlorinated Biphenyls
PCB-16	pg/L	8.56E-06	3.06E-06	Polychlorinated Biphenyls
PCB-161	pg/L	7.10E-07	3.85E-07	Polychlorinated Biphenyls
PCB-162	pg/L	7.28E-07	4.06E-07	Polychlorinated Biphenyls
PCB-164	pg/L	1.36E-06	3.29E-07	Polychlorinated Biphenyls
PCB-165	pg/L	8.05E-07	4.52E-07	Polychlorinated Biphenyls
PCB-167	pg/L	1.02E-06	3.09E-07	Polychlorinated Biphenyls
PCB-169	pg/L	7.20E-07	4.10E-07	Polychlorinated Biphenyls
PCB-17	pg/L	1.15E-05	3.21E-06	Polychlorinated Biphenyls
PCB-170	pg/L	4.06E-06	9.00E-07	Polychlorinated Biphenyls
PCB-171 + 173	pg/L	1.18E-06	4.00E-07	Polychlorinated Biphenyls
PCB-172	pg/L	9.26E-07	3.57E-07	Polychlorinated Biphenyls
PCB-174	pg/L	3.83E-06	1.31E-06	Polychlorinated Biphenyls
PCB-175	pg/L	7.15E-07	3.84E-07	Polychlorinated Biphenyls
PCB-176	pg/L	7.50E-07	2.83E-07	Polychlorinated Biphenyls
PCB-177	pg/L	2.38E-06	6.35E-07	Polychlorinated Biphenyls
PCB-178	pg/L	1.21E-06	2.66E-07	Polychlorinated Biphenyls
PCB-179	pg/L	2.51E-06	8.58E-07	Polychlorinated Biphenyls
PCB-18 + 30	pg/L	1.84E-05	5.53E-06	Polychlorinated Biphenyls
PCB-180 + 193	pg/L	1.02E-05	2.62E-06	Polychlorinated Biphenyls
PCB-181	pg/L	7.57E-07	3.92E-07	Polychlorinated Biphenyls
PCB-182	pg/L	7.27E-07	3.90E-07	Polychlorinated Biphenyls
PCB-183 + 185	pg/L	3.03E-06	1.13E-06	Polychlorinated Biphenyls
PCB-184	pg/L	3.51E-06	1.11E-06	Polychlorinated Biphenyls
PCB-186	pg/L	5.75E-07	2.99E-07	Polychlorinated Biphenyls
PCB-187	pg/L	6.62E-06	1.82E-06	Polychlorinated Biphenyls
PCB-188	pg/L	5.06E-07	2.66E-07	Polychlorinated Biphenyls
PCB-189	pg/L	8.21E-07	5.40E-07	Polychlorinated Biphenyls
PCB-19	pg/L	7.29E-06	2.76E-06	Polychlorinated Biphenyls
PCB-190	pg/L	9.49E-07	3.16E-07	Polychlorinated Biphenyls
PCB-191	pg/L	5.87E-07	3.20E-07	Polychlorinated Biphenyls

PARAMETER	UNITS	Average Daily Flux (kg/day)	Standard Deviation of Average Daily Flux(kg/day)	GROUPING
PCB-192	pg/L	6.55E-07	3.58E-07	Polychlorinated Biphenyls
PCB-194	pg/L	2.25E-06	5.83E-07	Polychlorinated Biphenyls
PCB-195	pg/L	9.86E-07	4.47E-07	Polychlorinated Biphenyls
PCB-196	pg/L	1.14E-06	3.81E-07	Polychlorinated Biphenyls
PCB-197 + 200	pg/L	7.67E-07	2.37E-07	Polychlorinated Biphenyls
PCB-198 + 199	pg/L	2.74E-06	6.48E-07	Polychlorinated Biphenyls
PCB-2	pg/L	1.17E-06	4.24E-07	Polychlorinated Biphenyls
PCB-20 + 28	pg/L	2.46E-05	7.46E-06	Polychlorinated Biphenyls
PCB-201	pg/L	6.12E-07	2.37E-07	Polychlorinated Biphenyls
PCB-202	pg/L	9.10E-07	2.81E-07	Polychlorinated Biphenyls
PCB-203	pg/L	1.72E-06	6.37E-07	Polychlorinated Biphenyls
PCB-204	pg/L	6.30E-07	2.68E-07	Polychlorinated Biphenyls
PCB-205	pg/L	7.04E-07	3.94E-07	Polychlorinated Biphenyls
PCB-206	pg/L	2.08E-06	8.08E-07	Polychlorinated Biphenyls
PCB-207	pg/L	1.50E-06	6.74E-07	Polychlorinated Biphenyls
PCB-208	pg/L	1.80E-06	6.44E-07	Polychlorinated Biphenyls
PCB-209	pg/L	1.29E-06	4.10E-07	Polychlorinated Biphenyls
PCB-21 + 33	pg/L	1.04E-05	3.32E-06	Polychlorinated Biphenyls
PCB-22	pg/L	8.99E-06	2.98E-06	Polychlorinated Biphenyls
PCB-23	pg/L	6.46E-07	5.12E-07	Polychlorinated Biphenyls
PCB-24	pg/L	4.47E-07	2.65E-07	Polychlorinated Biphenyls
PCB-25	pg/L	2.31E-06	8.02E-07	Polychlorinated Biphenyls
PCB-26 + 29	pg/L	4.95E-06	1.66E-06	Polychlorinated Biphenyls
PCB-27	pg/L	2.34E-06	6.48E-07	Polychlorinated Biphenyls
PCB-3	pg/L	3.16E-06	1.28E-06	Polychlorinated Biphenyls
PCB-31	pg/L	2.18E-05	7.37E-06	Polychlorinated Biphenyls
PCB-32	pg/L	7.29E-06	1.83E-06	Polychlorinated Biphenyls
PCB-34	pg/L	6.23E-07	4.81E-07	Polychlorinated Biphenyls
PCB-35	pg/L	1.69E-06	4.67E-07	Polychlorinated Biphenyls
PCB-36	pg/L	6.10E-07	3.29E-07	Polychlorinated Biphenyls
PCB-37	pg/L	4.92E-06	1.97E-06	Polychlorinated Biphenyls
PCB-38	pg/L	5.53E-07	3.79E-07	Polychlorinated Biphenyls
PCB-39	pg/L	5.49E-07	3.84E-07	Polychlorinated Biphenyls
PCB-4	pg/L	8.44E-05	2.69E-05	Polychlorinated Biphenyls
PCB-40 + 41 + 71	pg/L	8.88E-06	2.68E-06	Polychlorinated Biphenyls
PCB-42	pg/L	3.85E-06	1.10E-06	Polychlorinated Biphenyls
PCB-43	pg/L	8.61E-07	4.28E-07	Polychlorinated Biphenyls
PCB-44 + 47 + 65	pg/L	2.45E-05	5.79E-06	Polychlorinated Biphenyls
PCB-45 + 51	pg/L	4.89E-06	1.38E-06	Polychlorinated Biphenyls
PCB-46	pg/L	1.19E-06	3.31E-07	Polychlorinated Biphenyls
PCB-48	pg/L	3.54E-06	8.97E-07	Polychlorinated Biphenyls
PCB-49 + 69	pg/L	1.09E-05	2.60E-06	Polychlorinated Biphenyls
PCB-5	pg/L	2.15E-06	8.54E-07	Polychlorinated Biphenyls
PCB-50 + 53	pg/L	3.07E-06	7.49E-07	Polychlorinated Biphenyls
PCB-52	pg/L	3.48E-05	9.11E-06	Polychlorinated Biphenyls
PCB-54	pg/L	4.85E-07	4.27E-07	Polychlorinated Biphenyls
PCB-55	pg/L	7.42E-07	5.02E-07	Polychlorinated Biphenyls
PCB-56	pg/L	5.85E-06	1.74E-06	Polychlorinated Biphenyls
PCB-57	pg/L	6.88E-07	4.40E-07	Polychlorinated Biphenyls
PCB-58	pg/L	6.98E-07	4.25E-07	Polychlorinated Biphenyls
PCB-59 + 62 + 75	pg/L	1.48E-06	4.52E-07	Polychlorinated Biphenyls
PCB-6	pg/L	4.50E-06	1.37E-06	Polychlorinated Biphenyls
PCB-60	pg/L	3.36E-06	9.68E-07	Polychlorinated Biphenyls
PCB-61 + 70 + 74 + 76	pg/L	3.16E-05	7.97E-06	Polychlorinated Biphenyls
PCB-63	pg/L	7.38E-07	3.55E-07	Polychlorinated Biphenyls
PCB-64	pg/L	7.34E-06	1.99E-06	Polychlorinated Biphenyls
PCB-66	pg/L	1.19E-05	3.60E-06	Polychlorinated Biphenyls
PCB-67	pg/L	6.48E-07	3.57E-07	Polychlorinated Biphenyls
PCB-68	pg/L	1.16E-06	4.49E-07	Polychlorinated Biphenyls
PCB-7	pg/L	2.12E-06	7.81E-07	Polychlorinated Biphenyls

PARAMETER	UNITS	Average Daily Flux (kg/day)	Standard Deviation of Average Daily Flux(kg/day)	GROUPING
PCB-72	pg/L	9.02E-07	9.70E-07	Polychlorinated Biphenyls
PCB-73	pg/L	5.02E-07	3.76E-07	Polychlorinated Biphenyls
PCB-77	pg/L	1.35E-06	5.27E-07	Polychlorinated Biphenyls
PCB-78	pg/L	8.18E-07	6.67E-07	Polychlorinated Biphenyls
PCB-79	pg/L	6.50E-07	4.15E-07	Polychlorinated Biphenyls
PCB-8	pg/L	1.70E-05	5.13E-06	Polychlorinated Biphenyls
PCB-80	pg/L	6.22E-07	3.94E-07	Polychlorinated Biphenyls
PCB-81	pg/L	7.52E-07	4.51E-07	Polychlorinated Biphenyls
PCB-82	pg/L	2.41E-06	8.14E-07	Polychlorinated Biphenyls
PCB-83 + 99	pg/L	1.51E-05	4.65E-06	Polychlorinated Biphenyls
PCB-84	pg/L	7.43E-06	2.08E-06	Polychlorinated Biphenyls
PCB-85 + 116 + 117	pg/L	4.76E-06	1.30E-06	Polychlorinated Biphenyls
PCB-86 + 87 + 97 + 108 + 119 + 125	pg/L	1.90E-05	5.57E-06	Polychlorinated Biphenyls
PCB-88 + 91	pg/L	3.73E-06	9.59E-07	Polychlorinated Biphenyls
PCB-89	pg/L	8.74E-07	4.56E-07	Polychlorinated Biphenyls
PCB-9	pg/L	2.50E-06	6.94E-07	Polychlorinated Biphenyls
PCB-90 + 101 + 113	pg/L	2.85E-05	7.09E-06	Polychlorinated Biphenyls
PCB-92	pg/L	4.66E-06	1.69E-06	Polychlorinated Biphenyls
PCB-93 + 95 + 98 + 100 + 102	pg/L	2.47E-05	4.88E-06	Polychlorinated Biphenyls
PCB-94	pg/L	8.94E-07	4.71E-07	Polychlorinated Biphenyls
PCB-96	pg/L	4.45E-07	2.06E-07	Polychlorinated Biphenyls
Total Dichloro Biphenyls	pg/L	1.78E-04	4.72E-05	Polychlorinated Biphenyls
Total Heptachloro Biphenyls	pg/L	2.86E-05	1.03E-05	Polychlorinated Biphenyls
Total Hexachloro Biphenyls	pg/L	1.03E-04	2.38E-05	Polychlorinated Biphenyls
Total Monochloro Biphenyls	pg/L	1.51E-05	1.44E-06	Polychlorinated Biphenyls
Total Nonachloro Biphenyls	pg/L	6.88E-06	2.60E-08	Polychlorinated Biphenyls
Total Octachloro Biphenyls	pg/L	5.82E-06	1.35E-06	Polychlorinated Biphenyls
Total PCB	pg/L	8.57E-04	2.55E-04	Polychlorinated Biphenyls
Total Pentachloro Biphenyls	pg/L	1.71E-04	4.49E-05	Polychlorinated Biphenyls
Total Tetrachloro Biphenyls	pg/L	1.70E-04	2.79E-05	Polychlorinated Biphenyls
Total Trichloro Biphenyls	pg/L	1.40E-04	3.95E-05	Polychlorinated Biphenyls
1-Methylnaphthalene	µg/L	0.02	0.01	Polycyclic Aromatic Hydrocarbons
2-Methylnaphthalene	µg/L	0.02	0.01	Polycyclic Aromatic Hydrocarbons
Acenaphthene	µg/L	0.02	0.02	Polycyclic Aromatic Hydrocarbons
Acenaphthylene	µg/L	5.32E-03	1.34E-03	Polycyclic Aromatic Hydrocarbons
Acridine	µg/L	1.60E-02	3.04E-03	Polycyclic Aromatic Hydrocarbons
Anthracene	µg/L	5.32E-03	1.34E-03	Polycyclic Aromatic Hydrocarbons
Benz(a)anthracene	µg/L	5.32E-03	1.34E-03	Polycyclic Aromatic Hydrocarbons
Benzo(a)pyrene	µg/L	5.32E-03	1.34E-03	Polycyclic Aromatic Hydrocarbons
Benzo(b)fluoranthene	µg/L	0.01	0.02	Polycyclic Aromatic Hydrocarbons
Benzo(g,h,i)perylene	µg/L	6.07E-03	2.04E-03	Polycyclic Aromatic Hydrocarbons
Benzo(k)fluoranthene	µg/L	5.32E-03	1.34E-03	Polycyclic Aromatic Hydrocarbons
Chrysene	µg/L	5.32E-03	1.34E-03	Polycyclic Aromatic Hydrocarbons
Dibenz(a,h)anthracene	µg/L	5.32E-03	1.34E-03	Polycyclic Aromatic Hydrocarbons
Fluoranthene	µg/L	9.32E-03	5.91E-03	Polycyclic Aromatic Hydrocarbons
Fluorene	µg/L	0.02	0.02	Polycyclic Aromatic Hydrocarbons
Indeno(1,2,3-c,d)pyrene	µg/L	5.95E-03	1.83E-03	Polycyclic Aromatic Hydrocarbons
Naphthalene	µg/L	2.66E-02	6.70E-03	Polycyclic Aromatic Hydrocarbons
Phenanthrene	µg/L	1.13E-02	2.69E-03	Polycyclic Aromatic Hydrocarbons
Pyrene	µg/L	8.97E-03	4.14E-03	Polycyclic Aromatic Hydrocarbons
Quinoline	µg/L	0.14	0.24	Polycyclic Aromatic Hydrocarbons
17 α-Dihydroequilin	ng/L	0.01	0.01	Sterols and Hormones
17 α-Estradiol	ng/L	3.11E-03	1.61E-03	Sterols and Hormones

PARAMETER	UNITS	Average Daily Flux (kg/day)	Standard Deviation of Average Daily Flux(kg/day)	GROUPING
17 α-Ethinyl-Estradiol	ng/L	3.68E-03	3.62E-03	Sterols and Hormones
17 β-Estradiol	ng/L	4.94E-03	2.42E-03	Sterols and Hormones
Androstenedione	ng/L	0.06	0.04	Sterols and Hormones
Androsterone	ng/L	5.92E-03	3.19E-03	Sterols and Hormones
Campesterol	ng/L	2.28	0.89	Sterols and Hormones
Cholestanol	ng/L	2.10	0.77	Sterols and Hormones
Cholesterol	ng/L	15.3	5.19	Sterols and Hormones
Coprostanol	ng/L	15.0	4.21	Sterols and Hormones
Desmosterol	ng/L	0.79	0.28	Sterols and Hormones
Desogestrel	ng/L	0.03	0.01	Sterols and Hormones
Epicoprostanol	ng/L	0.52	0.32	Sterols and Hormones
Equilenin	ng/L	6.33E-03	5.99E-03	Sterols and Hormones
Equilin	ng/L	0.02	0.01	Sterols and Hormones
Ergosterol	ng/L	0.91	0.41	Sterols and Hormones
Estriol	ng/L	9.04E-03	9.44E-03	Sterols and Hormones
Estrone	ng/L	0.05	0.03	Sterols and Hormones
Mestranol	ng/L	0.02	0.01	Sterols and Hormones
Norethindrone	ng/L	0.02	0.02	Sterols and Hormones
Norgestrel	ng/L	0.03	0.02	Sterols and Hormones
Progesterone	ng/L	0.03	0.06	Sterols and Hormones
Stigmasterol	ng/L	3.16	3.08	Sterols and Hormones
Testosterone	ng/L	0.03	0.02	Sterols and Hormones
β-Estradiol 3-benzoate	ng/L	0.03	0.07	Sterols and Hormones
β-Sitosterol	ng/L	11.4	16.8	Sterols and Hormones
β-Stigmastanol	ng/L	0.74	0.27	Sterols and Hormones
Aluminum	µg/L	25.3	14.0	Total Metals
Arsenic	µg/L	0.36	0.16	Total Metals
Barium	µg/L	3.31	4.42	Total Metals
Boron	µg/L	74.9	18.4	Total Metals
Cadmium	µg/L	0.13	0.18	Total Metals
Chromium	µg/L	0.51	0.31	Total Metals
Cobalt	µg/L	0.28	0.10	Total Metals
Copper	µg/L	10.8	3.61	Total Metals
Iron	µg/L	257	107	Total Metals
Lead	µg/L	0.35	0.17	Total Metals
Manganese	µg/L	30.8	9.52	Total Metals
Mercury	µg/L	2.43E-02	5.03E-03	Total Metals
Molybdenum	µg/L	0.75	0.91	Total Metals
Nickel	µg/L	1.56	1.38	Total Metals
Selenium	µg/L	0.38	0.80	Total Metals
Silver	µg/L	0.26	0.09	Total Metals
Zinc	µg/L	14.2	6.48	Total Metals

Appendix C

Hydraulic Design Analysis for Stage V Effluent Discharge

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Memorandum

To: *Project Files*

From: *Ron Miner, PE*

Date: *June 22, 2016*

Subject: ***Stage V*** *Outfall and Diffuser Hydraulic Calculations*

Annacis Outfall and Diffuser Configuration: STAGE V FLOW Q = 18.9 cms

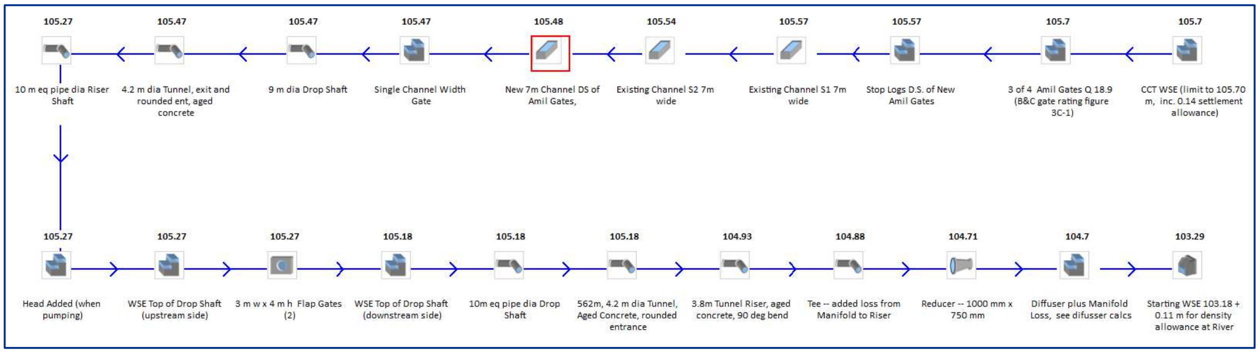
A hydraulic analysis was completed for the Annacis Outfall and Diffuser configuration shown on the attached figure using Visual Hydraulics version 4.2. The analysis and results are presented below.

Flow Path: Chlorine Contact Tanks, Total of 4 Amil Gates (3 in service), new 7m wide channel section, slots for 7m wide stoplogs, existing 7m wide channel section, new 7m wide channel section, one 7m wide by 3m high gate discharging to a 9m diameter drop shaft, 4.2m tunnel from the Chlorine Contact Tanks to the Pump Station shaft, two 3m wide by 4m high flap gates, 16m diameter drop shaft to 4.2 m diameter tunnel, 3.8 m diameter tunnel riser connecting to the mid-point of the diffuser manifold, 2.5m diameter diffuser manifold, 1000 mm tee branch reduced to 750mm diameter risers to each diffuser port.

A Visual Hydraulics flow sheet was created for the piping configuration from the river (WSE 103.18 + 0.11 = **103.29m**) upstream to the chlorine contact tanks (Max WSE 105.84 – 0.14 m = **105.70m**). The WSE at the river was raised by 0.11m to account for higher river water density from saline and temperature effects. The maximum WSE at the chlorine contact tank was lowered by 0.14m to account for future settlement. The manifold/diffuser tool in Visual Hydraulics was used to determine manifold/diffuser flows, head losses and velocities.

The roughness values for the diffuser manifold, shafts and riser, concrete lined tunnel and piping upstream to the chlorine contact basin are based on an aged concrete absolute roughness value of 0.003m. The roughness values for the diffusers are based on plastic pipe increased to an absolute roughness of 0.003m to account for possible slime buildup in the future.

The Visual Hydraulics Flow Sheet "Annacis Hyd Profile 4.2 m tunnel with PS_06-22-16.vhf" is attached and itemizes the head loss calculations summarized below:

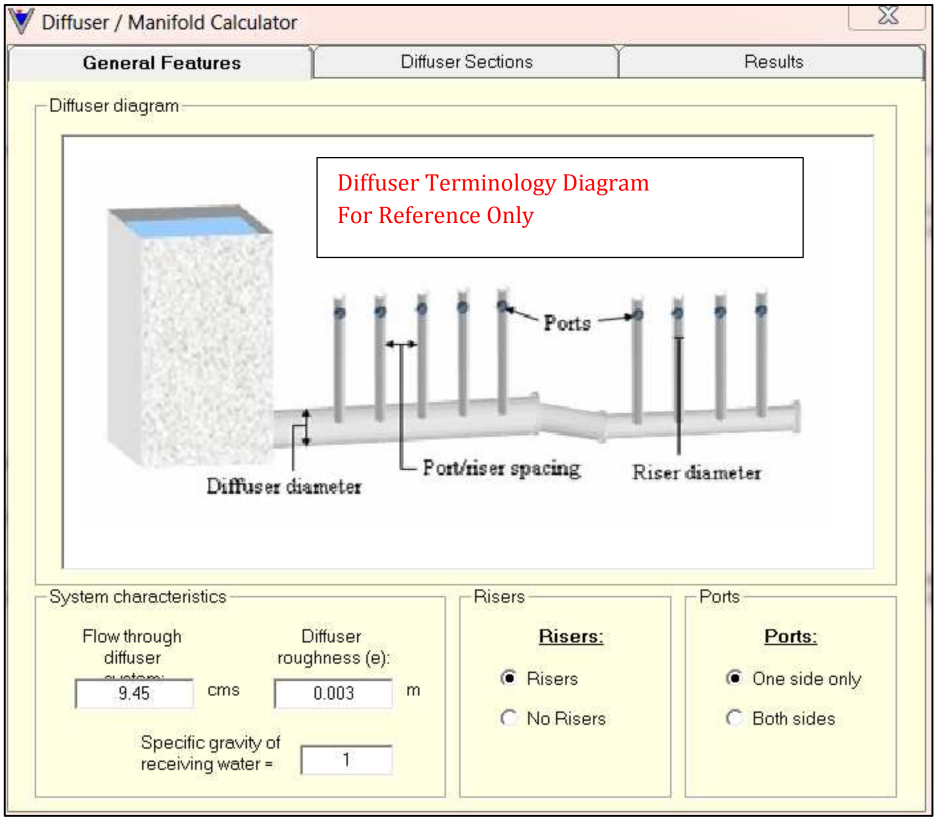


The calculated available headloss for the manifold and diffusers is **1.41m** at 18.9 cms with the above configuration.

The manifold/diffuser tool in Visual Hydraulics was used to determine manifold/diffuser flows, head loss, and velocities. Screen clips present the system characteristics, manifold, riser and diffuser port parameters and resulting flows, head loss and discharge velocities.

The following configurations were evaluated:

Diffuser Length (m)	Port Spacing (m)	Total Number of Ports	Number of Ports Open (Stage V)	Max Stage V Flow per Port (m3/s)	Number of Ports open (Stage VIII)	Max Stage VIII Flow per Port, all Ports Open (m3/s)	Fixed Port Diameter (mm) at 1.41 m Available Head
240	10	24	**18**	1.05	24	1.05	522
300	10	30	**22**	0.86	30	0.84	469
240	5	48	**36**	0.53	48	0.53	362
300	5	60	**44**	0.43	60	0.42	327



Diffuser Terminology Diagram
For Reference Only

Flow through diffuser system: 9.45 cms

Diffuser roughness (e): 0.003 m

Specific gravity of receiving water = 1

Risers:

● Risers

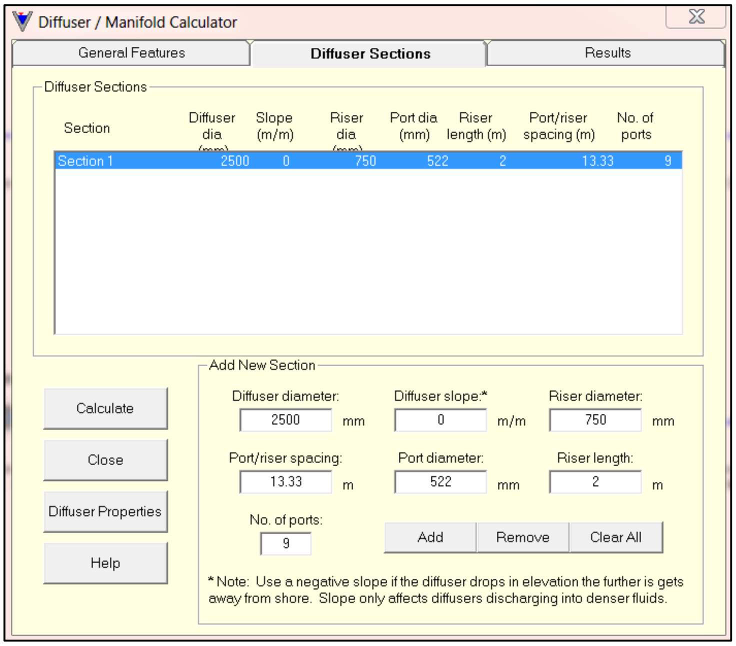
○ No Risers

Ports:

● One side only

○ Both sides

Figure 1: Flow through 2.5m manifold, ports discharging on one side only



Diffuser Sections

Section	Diffuser dia (mm)	Slope (m/m)	Riser dia (mm)	Port dia (mm)	Riser length (m)	Port/riser spacing (m)	No. of ports
Section 1	2500	0	750	522	2	13.33	9

Add New Section

Diffuser diameter: 2500 mm

Diffuser slope:* 0 m/m

Riser diameter: 750 mm

Port/riser spacing: 13.33 m

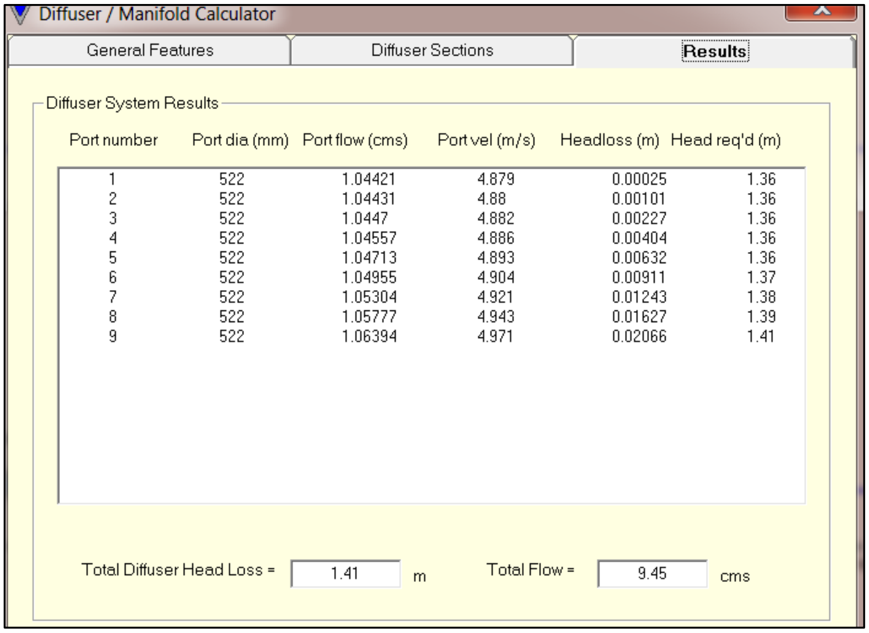
Port diameter: 522 mm

Riser length: 2 m

No. of ports: 9

* Note: Use a negative slope if the diffuser drops in elevation the further is gets away from shore. Slope only affects diffusers discharging into denser fluids.

Figure 2: Diffuser Parameters: 240m long, 10m spacing, 18 of 24 @ 522mm ports open



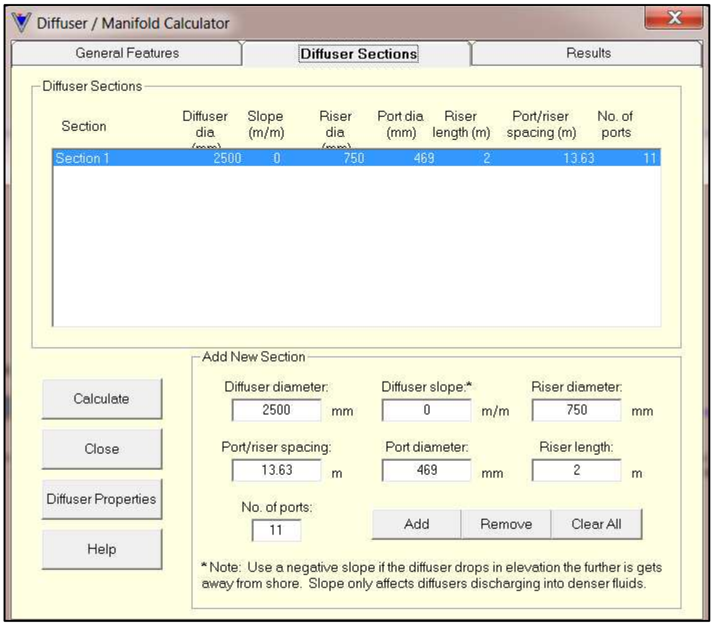
Diffuser System Results

Port number	Port dia (mm)	Port flow (cms)	Port vel (m/s)	Headloss (m)	Head req'd (m)
1	522	1.04421	4.879	0.00025	1.36
2	522	1.04431	4.88	0.00101	1.36
3	522	1.0447	4.882	0.00227	1.36
4	522	1.04557	4.886	0.00404	1.36
5	522	1.04713	4.893	0.00632	1.36
6	522	1.04955	4.904	0.00911	1.37
7	522	1.05304	4.921	0.01243	1.38
8	522	1.05777	4.943	0.01627	1.39
9	522	1.06394	4.971	0.02066	1.41

Total Diffuser Head Loss = 1.41 m

Total Flow = 9.45 cms

Figure 3: Results showing flow, velocity and head required through manifold, risers and diffuser ports: 240m long, 10m spacing, 18 of 24 ports @ 522mm diameter open



Diffuser Sections

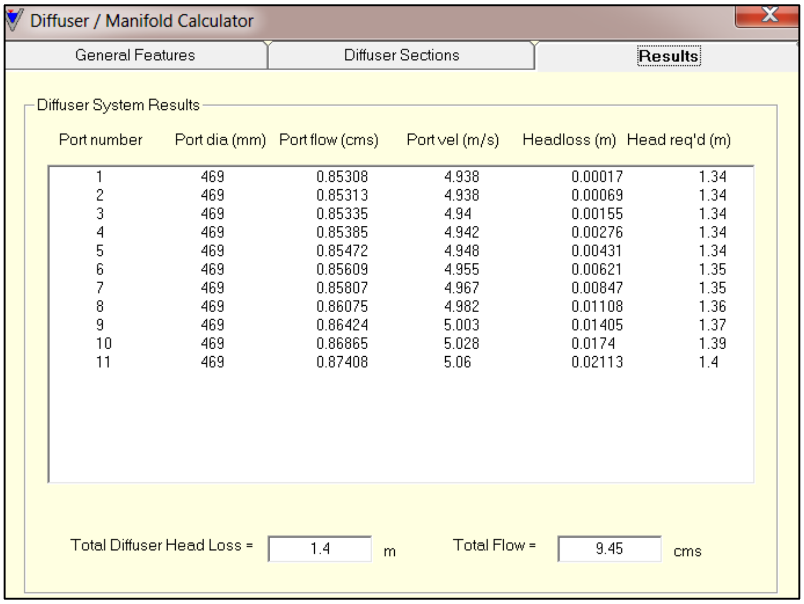
Section	Diffuser dia	Slope (m/m)	Riser dia	Port dia (mm)	Riser length (m)	Port/riser spacing (m)	No. of ports
Section 1	2500	0	750	469	2	13.63	11

Add New Section

Diffuser diameter: 2500 mm
Diffuser slope:* 0 m/m
Riser diameter: 750 mm
Port/riser spacing: 13.63 m
Port diameter: 469 mm
Riser length: 2 m
No. of ports: 11

* Note: Use a negative slope if the diffuser drops in elevation the further is gets away from shore. Slope only affects diffusers discharging into denser fluids.

Figure 4: Diffuser Parameters: 300m long, 10m spacing, 22 of 30 @ 469mm ports open

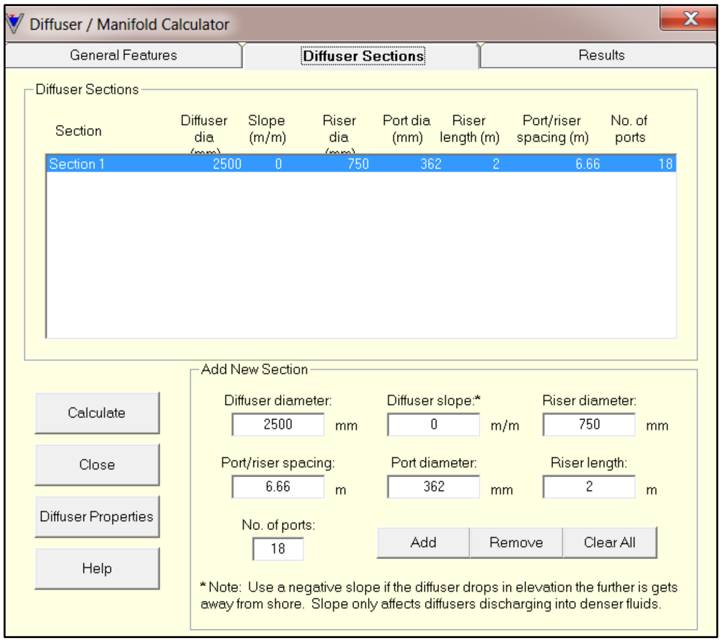


Diffuser System Results

Port number	Port dia (mm)	Port flow (cms)	Port vel (m/s)	Headloss (m)	Head req'd (m)
1	469	0.85308	4.938	0.00017	1.34
2	469	0.85313	4.938	0.00069	1.34
3	469	0.85335	4.94	0.00155	1.34
4	469	0.85385	4.942	0.00276	1.34
5	469	0.85472	4.948	0.00431	1.34
6	469	0.85609	4.955	0.00621	1.35
7	469	0.85807	4.967	0.00847	1.35
8	469	0.86075	4.982	0.01108	1.36
9	469	0.86424	5.003	0.01405	1.37
10	469	0.86865	5.028	0.0174	1.39
11	469	0.87408	5.06	0.02113	1.4

Total Diffuser Head Loss = 1.4 m
Total Flow = 9.45 cms

Figure 5: Results showing flow, velocity and head required through manifold, risers and diffuser ports: 300m long, 10m spacing, 22 of 30 ports @ 469mm diameter open



Section	Diffuser dia (mm)	Slope (m/m)	Riser dia (mm)	Port dia (mm)	Riser length (m)	Port/riser spacing (m)	No. of ports
Section 1	2500	0	750	362	2	6.66	18

Diffuser diameter: 2500 mm

Diffuser slope:* 0 m/m

Riser diameter: 750 mm

Port/riser spacing: 6.66 m

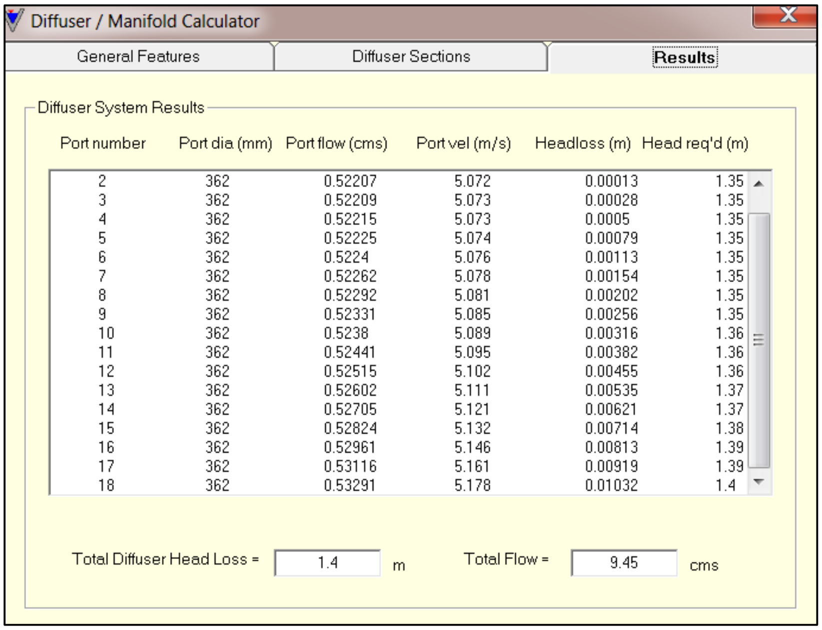
Port diameter: 362 mm

Riser length: 2 m

No. of ports: 18

* Note: Use a negative slope if the diffuser drops in elevation the further is gets away from shore. Slope only affects diffusers discharging into denser fluids.

Figure 6: Diffuser Parameters: 240m long, 5m spacing, 36 of 48 @ 362mm ports open

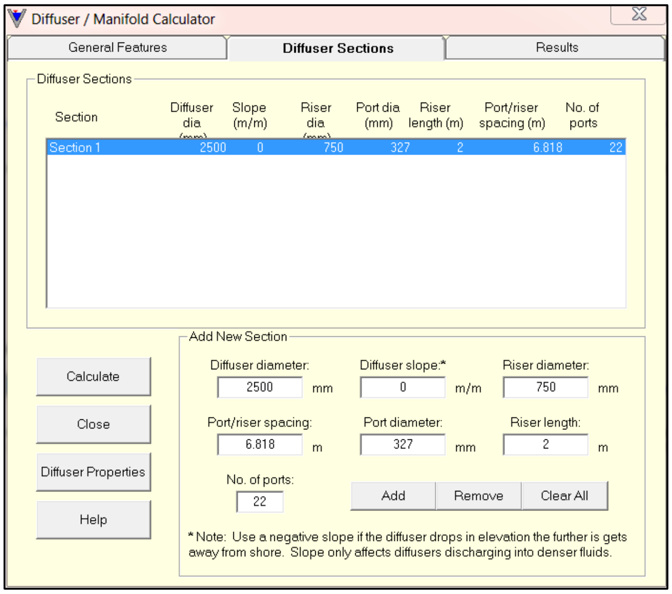


Port number	Port dia (mm)	Port flow (cms)	Port vel (m/s)	Headloss (m)	Head req'd (m)
2	362	0.52207	5.072	0.00013	1.35
3	362	0.52209	5.073	0.00028	1.35
4	362	0.52215	5.073	0.0005	1.35
5	362	0.52225	5.074	0.00079	1.35
6	362	0.5224	5.076	0.00113	1.35
7	362	0.52262	5.078	0.00154	1.35
8	362	0.52292	5.081	0.00202	1.35
9	362	0.52331	5.085	0.00256	1.35
10	362	0.5238	5.089	0.00316	1.36
11	362	0.52441	5.095	0.00382	1.36
12	362	0.52515	5.102	0.00455	1.36
13	362	0.52602	5.111	0.00535	1.37
14	362	0.52705	5.121	0.00621	1.37
15	362	0.52824	5.132	0.00714	1.38
16	362	0.52961	5.146	0.00813	1.39
17	362	0.53116	5.161	0.00919	1.39
18	362	0.53291	5.178	0.01032	1.4

Total Diffuser Head Loss = 1.4 m

Total Flow = 9.45 cms

Figure 7: Results showing flow, velocity and head required through manifold, risers and diffuser ports: 240m long, 5m spacing, 36 of 48 ports @ 362mm diameter open



Diffuser Sections

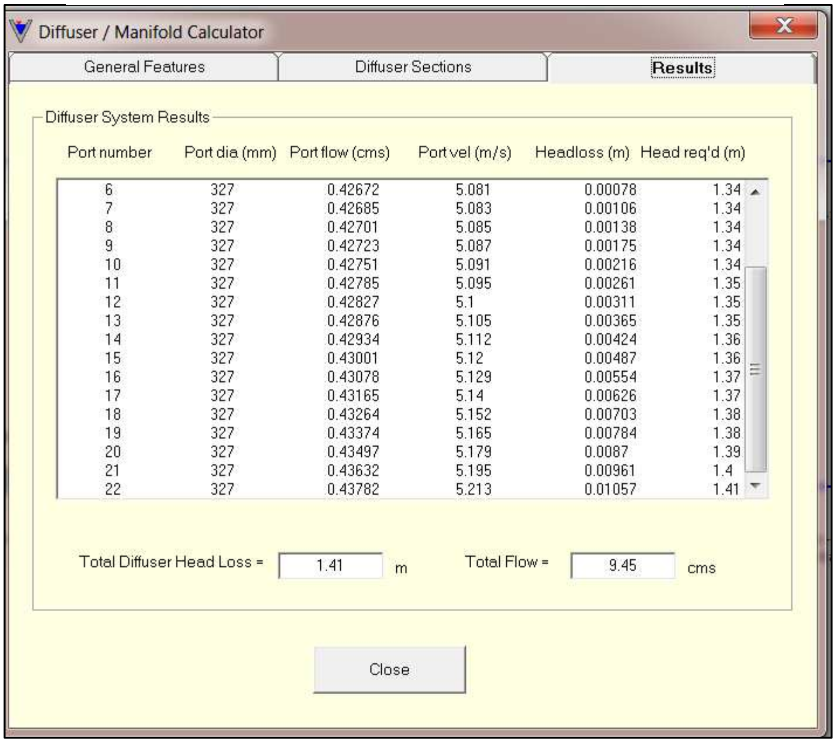
Section	Diffuser dia (mm)	Slope (m/m)	Riser dia (mm)	Port dia (mm)	Riser length (m)	Port/riser spacing (m)	No. of ports
Section 1	2500	0	750	327	2	6.818	22

Add New Section

Diffuser diameter: 2500 mm
Diffuser slope:* 0 m/m
Riser diameter: 750 mm
Port/riser spacing: 6.818 m
Port diameter: 327 mm
Riser length: 2 m
No. of ports: 22

* Note: Use a negative slope if the diffuser drops in elevation the further is gets away from shore. Slope only affects diffusers discharging into denser fluids.

Figure 8: Diffuser Parameters: 300m long, 5 m spacing, 44 of 60 @ 327mm ports open



Diffuser System Results

Port number	Port dia (mm)	Port flow (cms)	Port vel (m/s)	Headloss (m)	Head req'd (m)
6	327	0.42672	5.081	0.00078	1.34
7	327	0.42685	5.083	0.00106	1.34
8	327	0.42701	5.085	0.00138	1.34
9	327	0.42723	5.087	0.00175	1.34
10	327	0.42751	5.091	0.00216	1.34
11	327	0.42785	5.095	0.00261	1.35
12	327	0.42827	5.1	0.00311	1.35
13	327	0.42876	5.105	0.00365	1.35
14	327	0.42934	5.112	0.00424	1.36
15	327	0.43001	5.12	0.00487	1.36
16	327	0.43078	5.129	0.00554	1.37
17	327	0.43165	5.14	0.00626	1.37
18	327	0.43264	5.152	0.00703	1.38
19	327	0.43374	5.165	0.00784	1.38
20	327	0.43497	5.179	0.0087	1.39
21	327	0.43632	5.195	0.00961	1.4
22	327	0.43782	5.213	0.01057	1.41

Total Diffuser Head Loss = 1.41 m
Total Flow = 9.45 cms

Figure 9: Results showing flow, velocity and head required through manifold, risers and diffuser ports: 300m long, 5m spacing, 44 of 60 ports @ 327mm diameter open

Results

Results summary table:

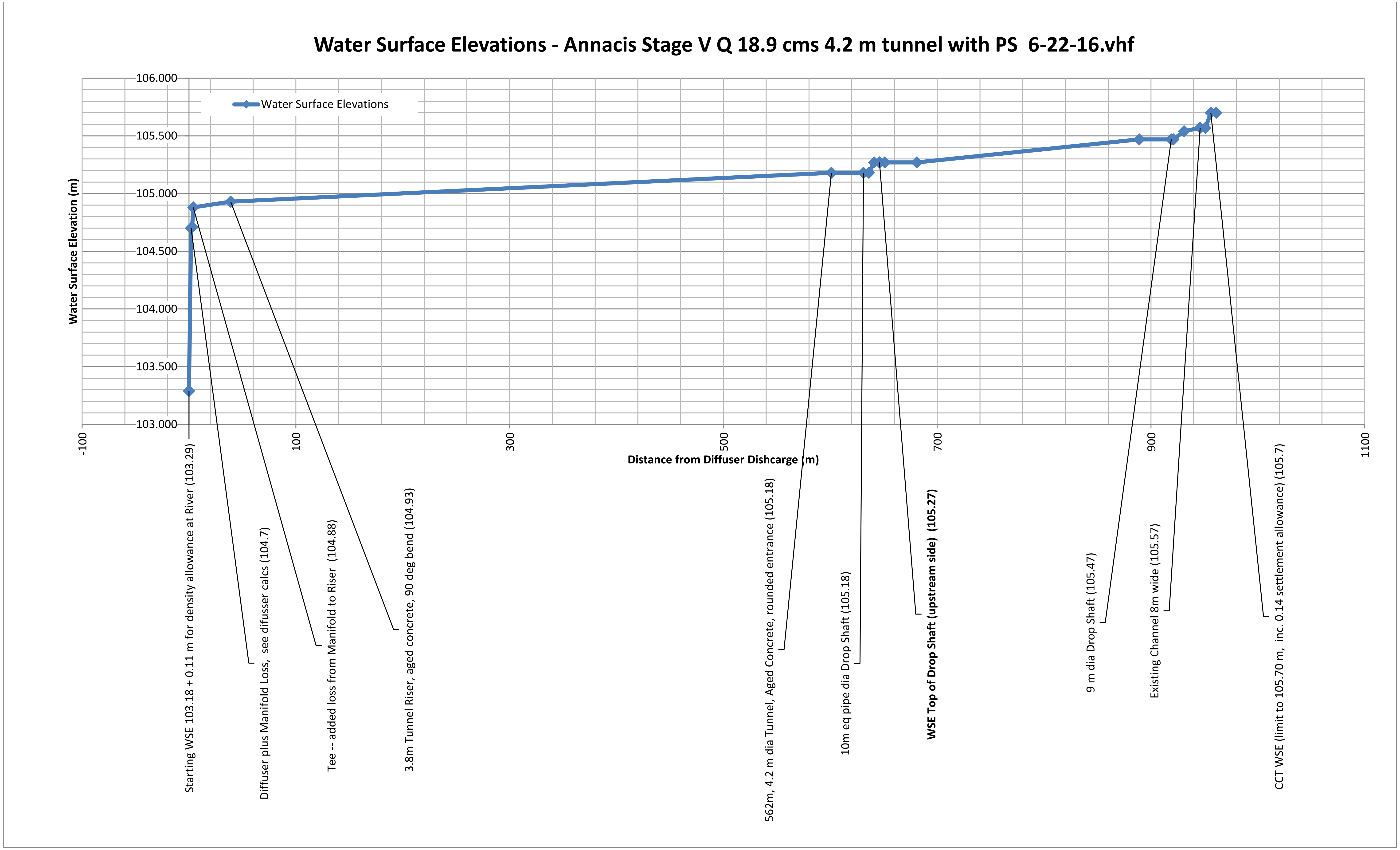
Diffuser Length (m)	Port Spacing (m)	Total Number of Ports	Number of Ports Open (Stage V)	Fixed Port Diameter (mm) at 1.41 m Available Head	Range of Flow Per Port (m3/s)	Range of Port Velocities (m/s)
240	10	24	18	522	1.04 - 1.06	4.9 - 5.0
300	10	30	22	469	0.85 - 0.87	4.9 - 5.1
240	5	48	36	362	0.52 - 0.53	5.1 - 5.2
300	5	60	44	327	0.43 - 0.44	5.1 - 5.2

The summary table shows even distribution of diffuser port flow with port velocities ranging **4.9 to 5.2 m/s** with a head requirement of **1.41m**. The head requirement for the manifold, riser and diffuser system of 1.41m matches the available 1.41m head.

cc:
Bernie Kolb, John Newby, Francis Bui, Brian Caufield; CDM Smith

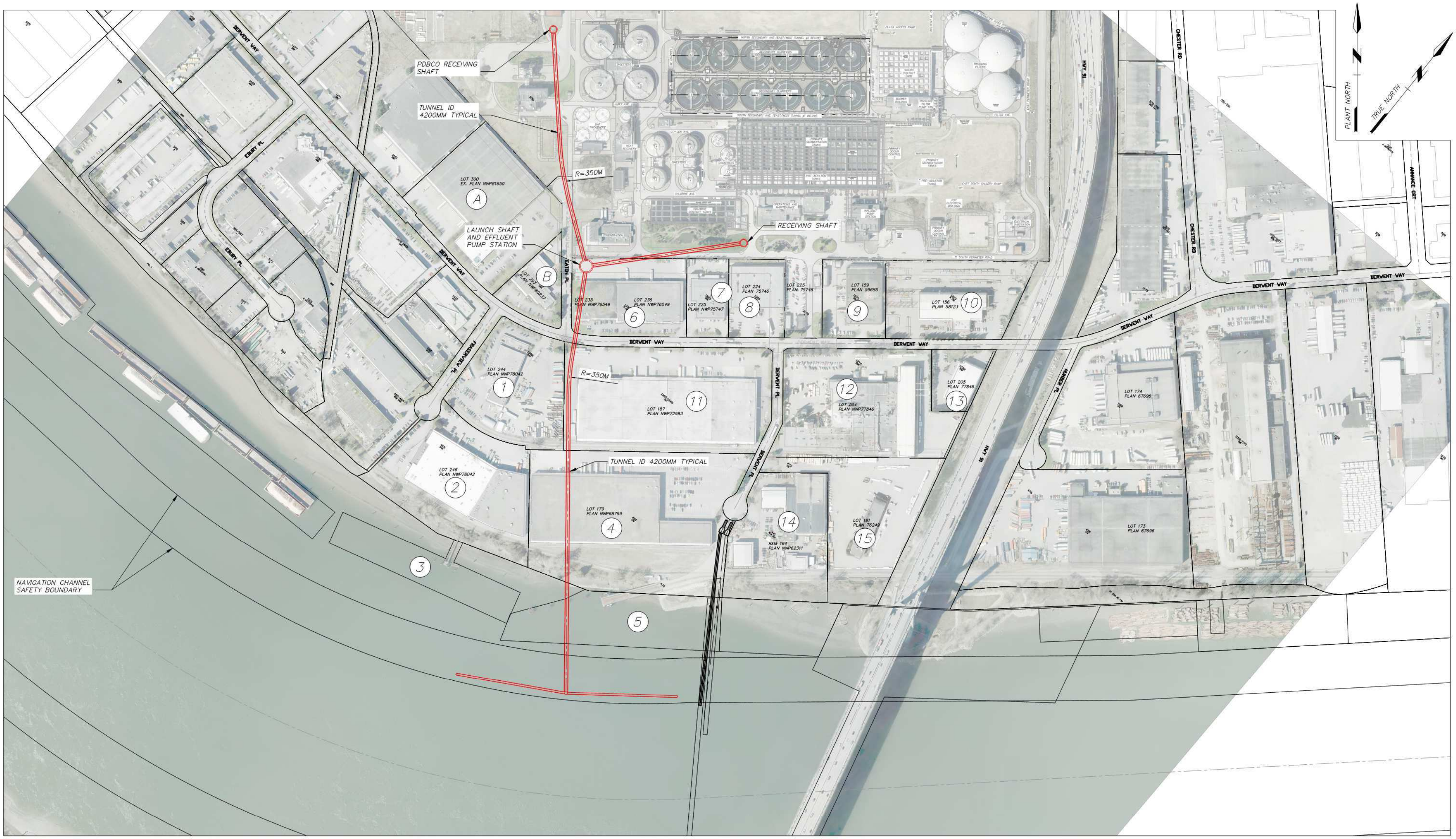
Attachments:
A. Hydraulic Profile Plot
B. Outfall Alignment Figure
C. Visual Hydraulics Calculations
D. Tideflex Diffuser System Data Analysis

Attachment A. Hydraulic Profile Plot



Water Surface Elevations - Annacis Stage V Q 18.9 cms 4.2 m tunnel with PS 6-22-16.vhf

Attachment B. Outfall Alignment Figure



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PRELIMINARY DRAWING

NOT FOR CONSTRUCTION

Professional Seal

Issue	Date	Des'n	Dr'n	Chkd	App'd	Description

0 20 Bar is 20mm On Original Drawing. If Not On This Sheet, Adjust Scales Accordingly.

GREATER VANCOUVER SEWERAGE AND DRAINAGE DISTRICT

Design: INT.
Drawn: INT.
Checked: INT.
Approved
INT.
Manager

ANNACIS ISLAND WWTP
TRANSIENT MITIGATION AND OUTFALL
CONTRACT XXXX – NEW OUTFALL SYSTEM
PACKAGE 5

A10 – GENERAL SITE WORKS
AERIAL MAP 1
ALIGNMENT OPTION 6

SCALE: 1:2500
DISTRICT FILE SF-1933
DRAWING NUMBER A10 X-C-02-6

SUPERSEDES PRINTS OF THIS DRAWING NUMBER WITH LETTERS PREVIOUS TO ➡ A

C:\cdmxm\kabilkumarg\d2571109\ A10 X-C-02-6.dwg Jun/22/2016 12:27pm kabilkumarg

Attachment C. Visual Hydraulics Calculations

Visual Hydraulics Summary Report - Hydraulic Analysis

Stage V 18.9 cms

Project: **Annacis Hyd Profile 4.2 m tunnel with PS 06-22-16.vhf**
Company:
Date:

Current flow conditions

Forward Flow =	18.9 cms
Return I Flow =	-----
Return II Flow =	-----
Return III Flow =	-----

Section Description	Water Surface Elevation
Starting WSE 103.18 + 0.11 m for density allowance at River	**103.29**
Diffuser plus Manifold Loss, see difusser calcs	**104.7**

Change in elevation = 1.41 m

Reducer -- 1000 mm x 750 mm	**104.71**

Diameter of smaller pipe = 750 mm
Diameter of larger pipe = 1000 mm
Flow through pipe = 1.05 cms
Transition angle = 14.3 degrees
Overall head loss = 0.01 m
Transition K value = 0.04
Area of smaller pipe = 0.44 m^2
Area of larger pipe = 0.79 m^2
Velocity in smaller pipe = 2.38 m/s
Velocity in larger pipe = 1.34 m/s
Overall head loss = 0.01 m

Tee -- added loss from Manifold to Riser	**104.88**

Pipe shape = Circular
Diameter = 1000 mm
Length = 2 m
Flow = 1.05 cms
Friction method = Colebrook-White
Friction factor = 0.003
Total fitting K value = 1.8
Pipe area = 0.79 m^2
Pipe hydraulic radius = 0.25
Age factor = 1

Section Description **Water Surface Elevation**

Solids factor = 1
Velocity = 1.34 m/s
Friction loss = 0 m
Fitting loss = 0.16 m
Total loss = 0.17 m

3.8m Tunnel Riser, aged concrete, 90 deg bend **104.93**

Pipe shape = Circular
Diameter = 3800 mm
Length = 20 m
Flow = 18.9 cms
Friction method = Colebrook-White
Friction factor = 0.003
Total fitting K value = 0.25
Pipe area = 11.34 m²
Pipe hydraulic radius = 0.95
Age factor = 1
Solids factor = 1
Velocity = 1.67 m/s
Friction loss = 0.01 m
Fitting loss = 0.04 m
Total loss = 0.05 m

562m, 4.2 m dia Tunnel, Aged Concrete, rounded entrance **105.18**

Pipe shape = Circular
Diameter = 4200 mm
Length = 562 m
Flow = 18.9 cms
Friction method = Colebrook-White
Friction factor = 0.003
Total fitting K value = 0.23
Pipe area = 13.85 m²
Pipe hydraulic radius = 1.05
Age factor = 1
Solids factor = 1
Velocity = 1.36 m/s
Friction loss = 0.23 m
Fitting loss = 0.02 m
Total loss = 0.25 m

10m eq pipe dia Drop Shaft **105.18**

Pipe shape = Circular
Diameter = 10617 mm
Length = 30 m
Flow = 18.9 cms
Friction method = Colebrook-White
Friction factor = 0.003

Section Description **Water Surface Elevation**

Total fitting K value = 0
Pipe area = 88.53 m²
Pipe hydraulic radius = 2.654
Age factor = 1
Solids factor = 1
Velocity = 0.21 m/s
Friction loss = 0 m
Fitting loss = 0 m
Total loss = 0 m

WSE Top of Drop Shaft (downstream side) **105.18**
Change in elevation = 0 m

3 m w x 4 m h Flap Gates (2) **105.27**
Opening type = rectangular orifice
Opening diameter/width = 3000 mm
Opening height = 4000 mm
Invert = 100
Number of openings = 2
Flow through opening(s) = 18.9 cms
Total area of opening(s) = 24 m^2
Velocity through opening(s) = 0.79 m/s
Flow behavior = orifice, downstream control
Orifice loss = 0.08 m
Downstream water level = 105.18
Upstream water level = 105.27

WSE Top of Drop Shaft (upstream side) **105.27**
Change in elevation = 0 m

Head Added (when pumping) **105.27**
Change in elevation = 0 m

10 m eq pipe dia Riser Shaft **105.27**
Pipe shape = Circular
Diameter = 10617 mm
Length = 30 m
Flow = 18.9 cms
Friction method = Colebrook-White
Friction factor = 0.003
Total fitting K value = 0
Pipe area = 88.53 m²
Pipe hydraulic radius = 2.654
Age factor = 1
Solids factor = 1
Velocity = 0.21 m/s
Friction loss = 0 m
Fitting loss = 0 m

Section Description	Water Surface Elevation
Total loss = 0 m	
4.2 m dia Tunnel, exit and rounded ent, aged concrete	**105.47**

Pipe shape = Circular
Diameter = 4200 mm
Length = 208 m
Flow = 18.9 cms
Friction method = Colebrook-White
Friction factor = 0.003
Total fitting K value = 1.23
Pipe area = 13.85 m²
Pipe hydraulic radius = 1.05
Age factor = 1
Solids factor = 1
Velocity = 1.36 m/s
Friction loss = 0.09 m
Fitting loss = 0.12 m
Total loss = 0.2 m

9 m dia Drop Shaft **105.47**

Pipe shape = Circular
Diameter = 9000 mm
Length = 30 m
Flow = 18.9 cms
Friction method = Colebrook-White
Friction factor = 0.003
Total fitting K value = 0
Pipe area = 63.62 m²
Pipe hydraulic radius = 2.25
Age factor = 1
Solids factor = 1
Velocity = 0.3 m/s
Friction loss = 0 m
Fitting loss = 0 m
Total loss = 0 m

Single Channel Width Gate **105.47**

Change in elevation = 0 m

New 7m Channel DS of Amil Gates, **105.48**

Channel shape = Rectangular
Manning's 'n' = 0.013
Channel length = 10 m
Channel width/diameter = 7 m
Flow = 18.9 cms
Downstream channel invert = 103.87
Channel slope = 0 m/m
Channel side slope = not applicable

Section Description **Water Surface Elevation**

Area of flow = 11.22 m^2
Hydraulic radius = 1.099
Normal depth = infinite
Critical depth = 0.91 m
Depth downstream = 1.6 m
Bend loss = 0 m
Depth upstream = 1.61 m
Velocity = 1.69 m/s
Flow profile = Horizontal

Existing Channel S2 7m wide **105.54**
Channel shape = Rectangular
Manning's 'n' = 0.013
Channel length = 15.5 m
Channel width/diameter = 7 m
Flow = 18.9 cms
Downstream channel invert = 103.87
Channel slope = 0 m/m
Channel side slope = not applicable
Area of flow = 11.28 m^2
Hydraulic radius = 1.103
Normal depth = infinite
Critical depth = 0.91 m
Depth downstream = 1.61 m
Bend loss = 0.06 m
Depth upstream = 1.67 m
Velocity = 1.68 m/s
Flow profile = Horizontal

Existing Channel S1 7m wide **105.57**
Channel shape = Rectangular
Manning's 'n' = 0.013
Channel length = 15.24 m
Channel width/diameter = 7 m
Flow = 12.6 cms
Downstream channel invert = 103.87
Channel slope = 0 m/m
Channel side slope = not applicable
Area of flow = 11.73 m^2
Hydraulic radius = 1.133
Normal depth = infinite
Critical depth = 0.69 m
Depth downstream = 1.67 m
Bend loss = 0.02 m
Depth upstream = 1.7 m
Velocity = 1.08 m/s
Flow profile = Horizontal

Section Description	Water Surface Elevation
Stop Logs D.S. of New Amil Gates Change in elevation = 0 m	**105.57**
3 of 4 Amil Gates Q 18.9 (B&C gate rating figure 3C-1) Change in elevation = 0.13 m	**105.7**
CCT WSE (limit to 105.70 m, inc. 0.14 settlement allowance) Change in elevation = 0 m	**105.7**

Attachment D. Tideflex Diffuser System Data Analysis

TIDEFLEX DIFFUSER (TFD) SYSTEM DATA ANALYSIS

MEDIA: Effluent

Density or Kg/m^3

Spec. Gravity 1

FLOWS:

m3/s = litres/sec

18.9 m3/s = 18900 litres/sec

m3/s = litres/sec

AVAILABLE HEADLOSS @ DIFFUSER:

Minimum metres

Design metres

Maximum metres

MAX. BACKPRESSURE: metres

DATE: 16-Jun-2016

CLIENT: Metro Vancouver

CONTACT:

ENGINEER: CDM Smith

CONTACT: Ron Miner

PROJECT: Annacis Island WWTP Outfall Diffuser

REP: Summit Valve & Controls

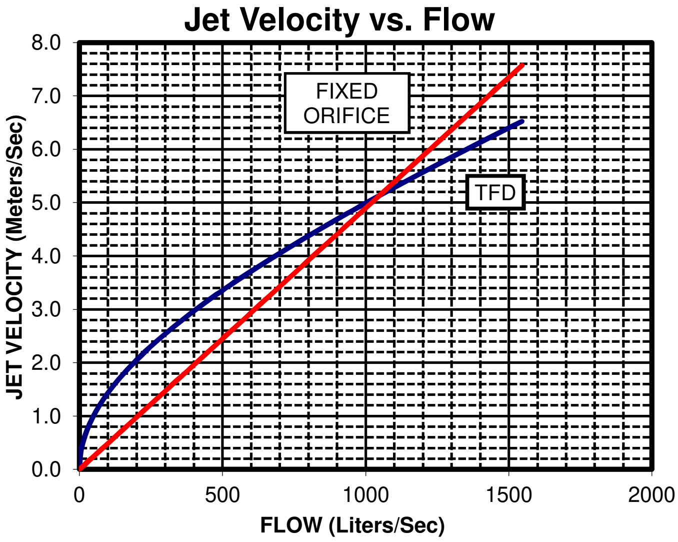
CONTACT: Craig Bridger

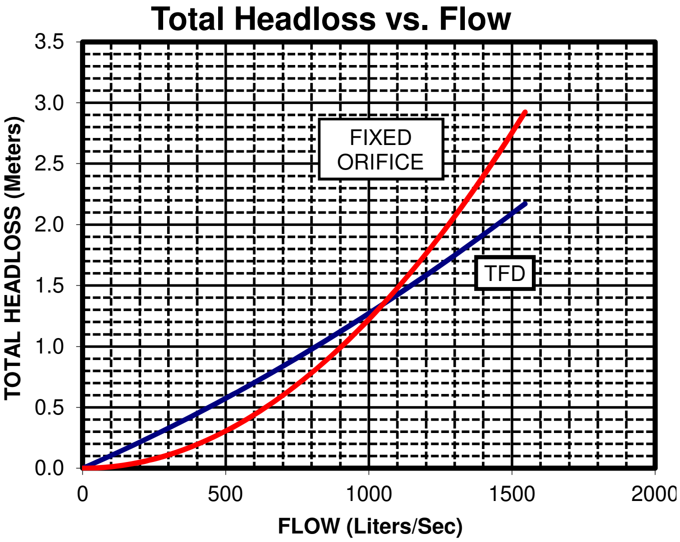
TFD SIZE (mm)	HYDRAULIC CODE
750	**4710**

		PER TIDEFLEX DIFFUSER			
*** TOTAL QUANTITY**	TOTAL FLOW (litres/sec)	FLOW (litres/sec)	**JET VELOCITY (metres/sec)**	**TOTAL HEADLOSS @ DIFFUSER (metres)**	EFFECTIVE AREA (cm^2)
18	18900.0	1050.0	5.1	1.35	2041.3

FIXED ORIFICE DIA. * Cd = 1

			PER FIXED ORIFICE			
510 mm 20.06	**18**	18900.0	1050.0	**5.1**	**1.35**	2039.2





TIDEFLEX DIFFUSER (TFD) SYSTEM DATA ANALYSIS

MEDIA: Effluent

Density or Spec. Gravity: 1 (Kg/m^3)

FLOWS:

	m3/s =		litres/sec
18.92	m3/s =	18920	litres/sec
	m3/s =		litres/sec

AVAILABLE HEADLOSS @ DIFFUSER:		
Minimum		metres
Design		metres
Maximum		metres

MAX. BACKPRESSURE: metres

DATE: 16-Jun-2016

CLIENT: Metro Vancouver
CONTACT:

ENGINEER: CDM Smith
CONTACT: Ron Miner

PROJECT: Annacis Island WWTP Outfall Diffuser

REP: Summit Valve & Controls
CONTACT: Craig Bridger

TFD SIZE (mm)	HYDRAULIC CODE
750	**3546**

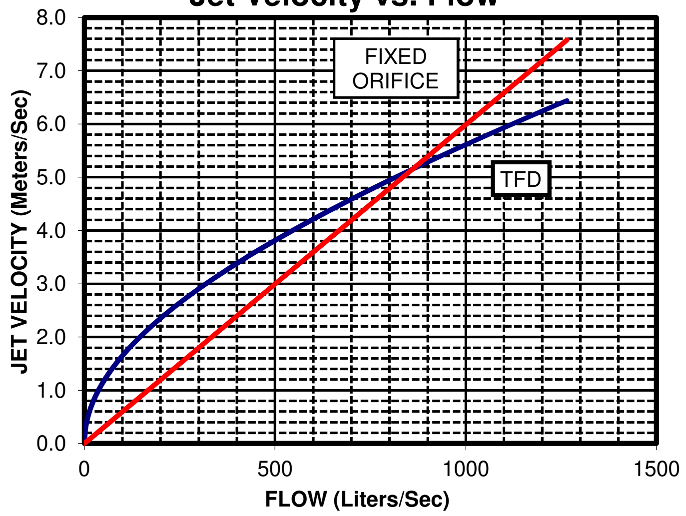
PER TIDEFLEX DIFFUSER

* TOTAL QUANTITY	TOTAL FLOW (litres/sec)	FLOW (litres/sec)	JET VELOCITY (metres/sec)	TOTAL HEADLOSS @ DIFFUSER (metres)	EFFECTIVE AREA (cm^2)
22	18920.0	860.0	5.1	1.35	1668.3

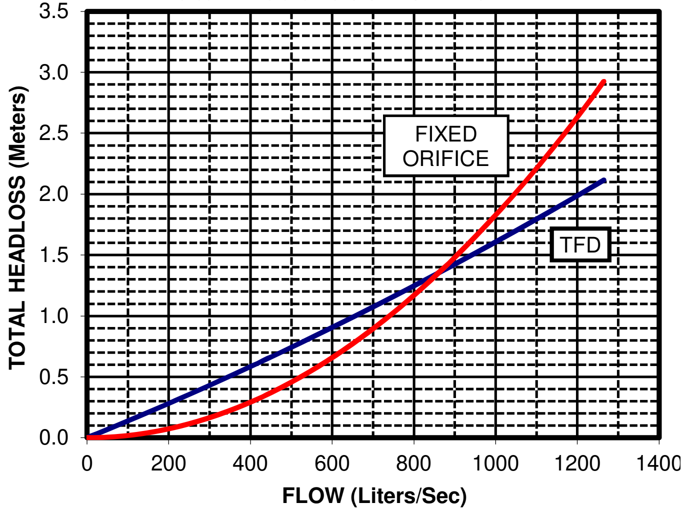
PER FIXED ORIFICE

FIXED ORIFICE DIA. * Cd = 1						
461 mm 18.14	**22**	18920.0	860.0	**5.2**	**1.35**	1668.3

Jet Velocity vs. Flow



Total Headloss vs. Flow



TIDEFLEX DIFFUSER (TFD) SYSTEM DATA ANALYSIS

MEDIA:	Effluent	
Density or		Kg/m^3
Spec. Gravity	1	

FLOWS:

	m3/s	=		litres/sec
19.08	m3/s	=	19080	litres/sec
	m3/s	=		litres/sec

AVAILABLE	Minimum		metres
HEADLOSS @	Design		metres
DIFFUSER:	Maximum		metres

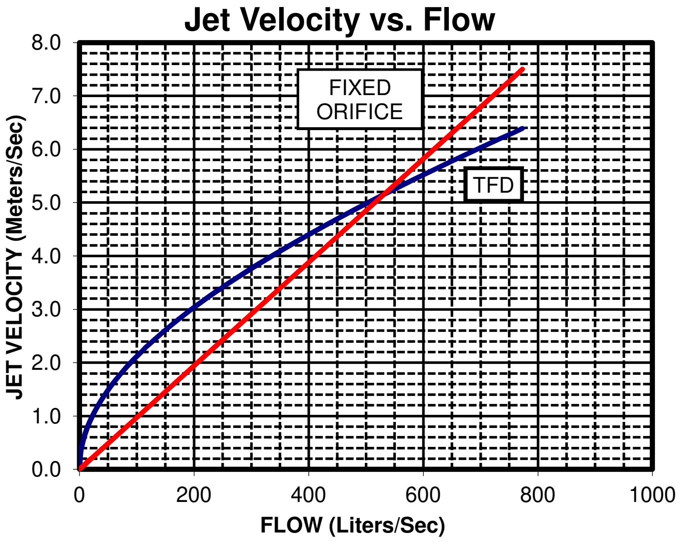
MAX. BACKPRESSURE: ______ metres

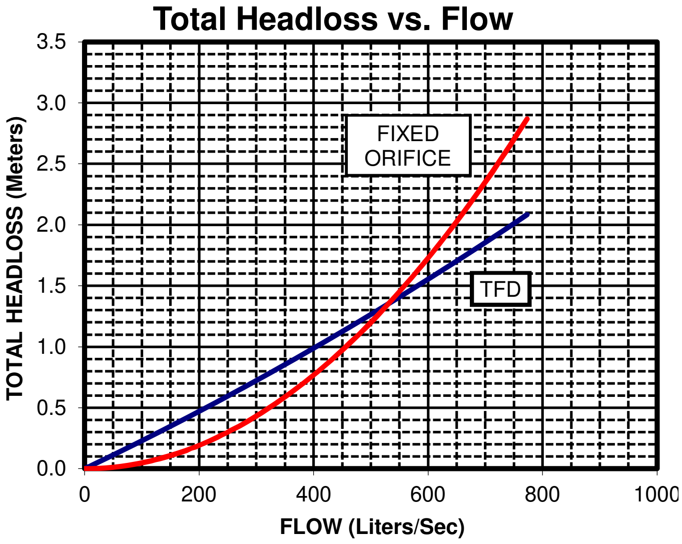
TFD SIZE (mm)	HYDRAULIC CODE
600	**2165**

DATE:	16-Jun-2016
CLIENT:	Metro Vancouver
CONTACT:	
ENGINEER:	CDM Smith
CONTACT:	Ron Miner
PROJECT:	Annacis Island WWTP Outfall Diffuser
REP:	Summit Valve & Controls
CONTACT:	Craig Bridger

		PER TIDEFLEX DIFFUSER			
*** TOTAL QUANTITY**	TOTAL FLOW (litres/sec)	FLOW (litres/sec)	**JET VELOCITY (metres/sec)**	**TOTAL HEADLOSS @ DIFFUSER (metres)**	EFFECTIVE AREA (cm^2)
36	19080.0	530.0	5.1	1.35	1029.0

FIXED ORIFICE DIA. * Cd = 1			***PER FIXED ORIFICE***			
362 mm 14.25	**36**	19080.0	530.0	**5.1**	**1.35**	1029.4





TIDEFLEX DIFFUSER (TFD) SYSTEM DATA ANALYSIS

MEDIA:	Effluent	
Density or		Kg/m^3
Spec. Gravity	1	

FLOWS:

	m3/s =		litres/sec
18.92	m3/s =	18920	litres/sec
	m3/s =		litres/sec

AVAILABLE	Minimum		metres
HEADLOSS @	Design		metres
DIFFUSER:	Maximum		metres

MAX. BACKPRESSURE: metres

TFD SIZE (mm)	HYDRAULIC CODE
500	**1851**

DATE: 16-Jun-2016

CLIENT: Metro Vancouver
CONTACT:

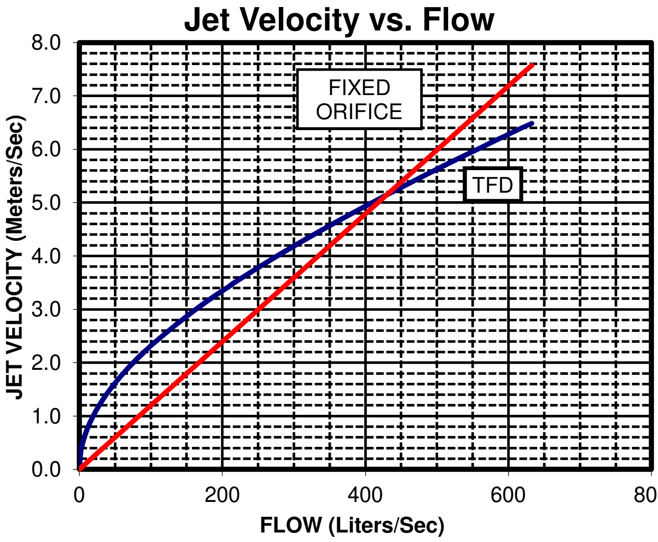
ENGINEER: CDM Smith
CONTACT: Ron Miner

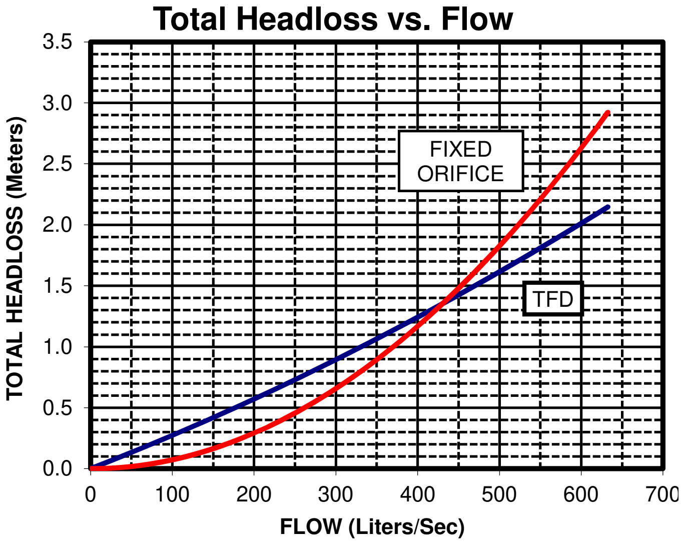
PROJECT: Annacis Island WWTP Outfall Diffuser

REP: Summit Valve & Controls
CONTACT: Craig Bridger

		PER TIDEFLEX DIFFUSER			
*** TOTAL QUANTITY**	TOTAL FLOW (litres/sec)	FLOW (litres/sec)	**JET VELOCITY (metres/sec)**	**TOTAL HEADLOSS @ DIFFUSER (metres)**	EFFECTIVE AREA (cm^2)
44	18920.0	430.0	5.1	1.35	834.5

FIXED ORIFICE DIA. * Cd = 1			***PER FIXED ORIFICE***			
326 mm 12.83	**44**	18920.0	430.0	**5.2**	**1.35**	834.5





Appendix D

Hydraulic Design Analysis for Stage VIII Effluent Discharge

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CDM Smith

Memorandum

To: *Project Files*

From: *Ron Miner, PE*

Date: *June 22, 2016*

Subject: ***Stage VIII** Outfall and Diffuser Hydraulic Calculations*

Annacis Outfall and Diffuser Configuration: STAGE VIII FLOW Q = 25.3 cms

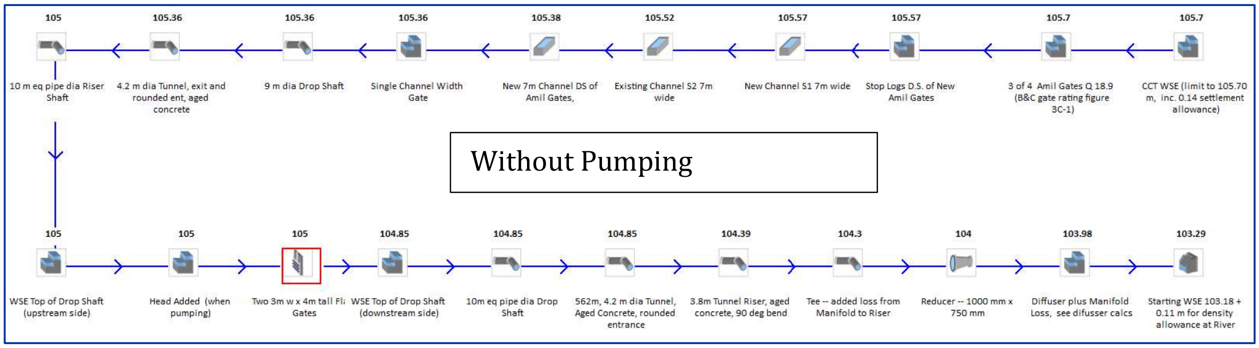
A hydraulic analysis was completed for the Annacis Outfall and Diffuser configuration shown on the attached figure using Visual Hydraulics version 4.2. The analysis and results are presented below.

Flow Path: Chlorine Contact Tanks, Total of 4 Amil Gates (4 in service), new 7m wide channel section, slots for 7m wide stoplogs, existing 7m wide channel section, new 7m wide channel section, one 7m wide by 3m high gate discharging to a 9m diameter drop shaft, 4.2m tunnel from the Chlorine Contact Tanks to the Pump Station shaft, Pumps, two 3m wide by 4m high flap gates (closed when pumping), 16m diameter drop shaft to 4.2m diameter tunnel, 3.8m diameter tunnel riser connecting to the mid-point of the diffuser manifold, 2.5m diameter diffuser manifold, 1000 mm tee branch reduced to 750mm risers to each diffuser port.

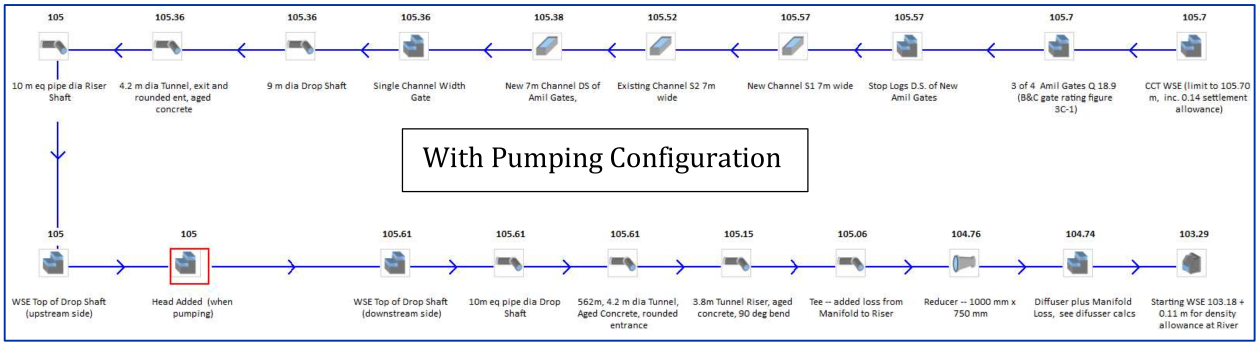
A Visual Hydraulics flow sheet was created for the piping configuration from the river (WSE 103.18 + 0.11 = **103.29m**) upstream to the chlorine contact tanks (Max WSE 105.84 – 0.14 m = **105.70m**). The WSE at the river was raised by 0.11m to account for higher river water density from saline and temperature effects. The maximum WSE at the chlorine contact tank was lowered by 0.14m to account for future settlement. The manifold/diffuser tool in Visual Hydraulics was used to determine manifold/diffuser flows, head losses and velocities.

The roughness values for the diffuser manifold, shafts and risers, concrete lined tunnel and piping upstream to the chlorine contact basin are based on an aged concrete absolute roughness value of 0.003m. The roughness values for the diffusers are based on plastic pipe increased to an absolute roughness of 0.003m to account for possible slime buildup in the future.

The Visual Hydraulics Flow Sheet "Annacis Hyd Profile 4.2 m tunnel with PS 06-22-16.vhf" is attached and itemizes the head loss calculations summarized below:



The calculated available headloss without pumping for the manifold and diffusers is **0.69m** at 25.3 cms with the above configuration. The head required for the manifold and diffusers is 1.45 m at 25.3 cms therefore additional head (pumping) will be required.

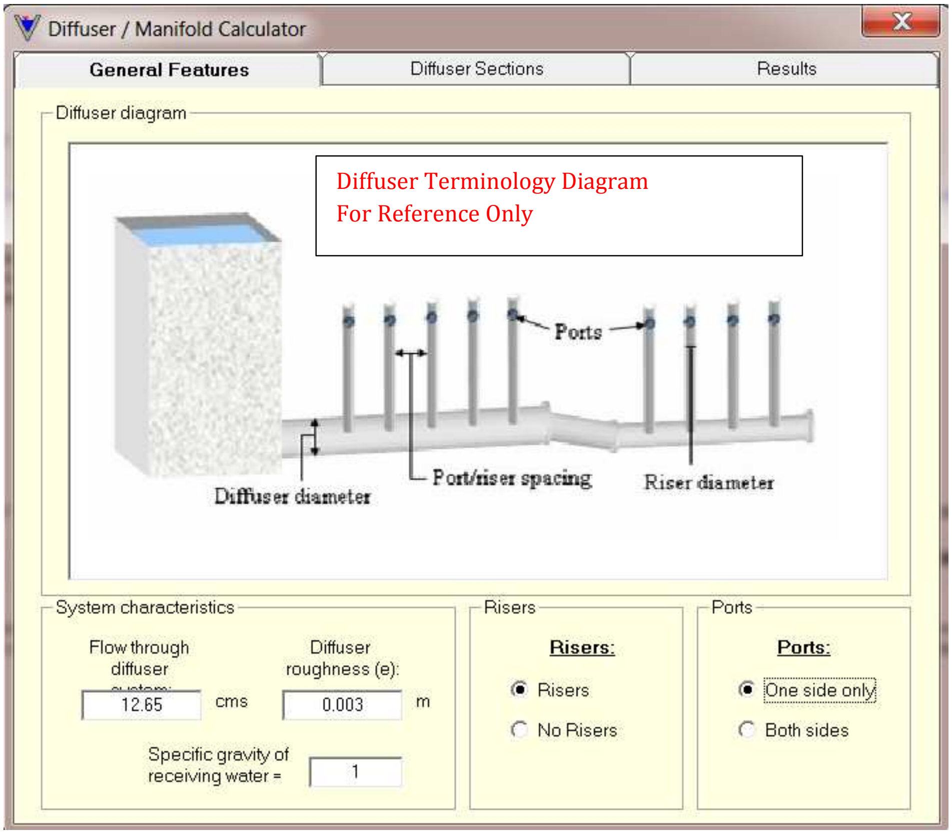


The calculated available headloss provided with pumping for the manifold and diffusers is **1.45** at 25.3 cms with the above configuration.

The manifold/diffuser tool in Visual Hydraulics was used to determine manifold/diffuser flows, head loss, and velocities. Screen clips present the system characteristics, manifold, riser and diffuser port parameters and resulting flows, head loss and discharge velocities.

The following configurations were evaluated:

Diffuser Length (m)	Port Spacing (m)	Total Number of Ports	Number of Ports Open (Stage V)	Max Stage V Flow per Port (m3/s)	Number of Ports open (Stage VIII)	Max Stage VIII Flow per Port, all Ports Open (m3/s)	Fixed Port Diameter (mm) at 1.41 m Available Head
240	10	24	18	1.05	**24**	1.05	522
300	10	30	22	0.86	**30**	0.84	469
240	5	48	36	0.53	**48**	0.53	362
300	5	60	44	0.43	**60**	0.42	327



Flow through diffuser system: 12.65 cms

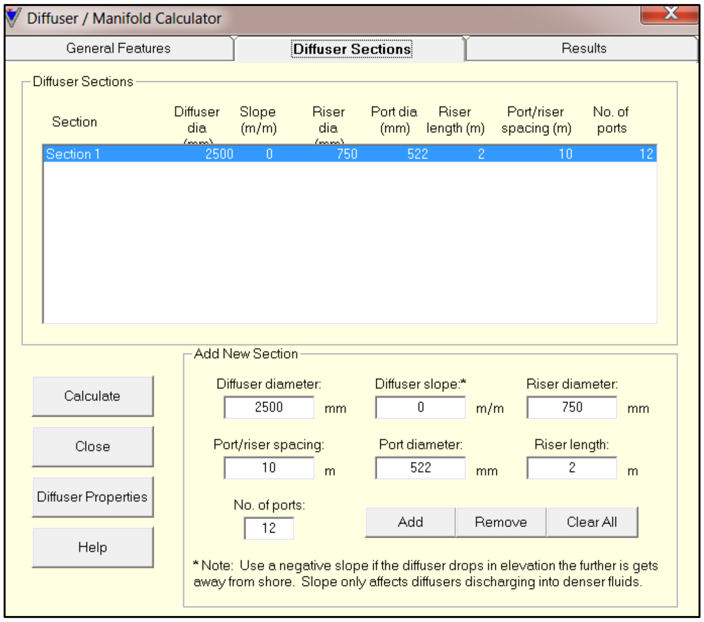
Diffuser roughness (e): 0.003 m

Specific gravity of receiving water = 1

Risers:
● Risers
○ No Risers

Ports:
● One side only
○ Both sides

Figure 1: Flow through 2.5m manifold, ports discharging on one side only



Diffuser Sections

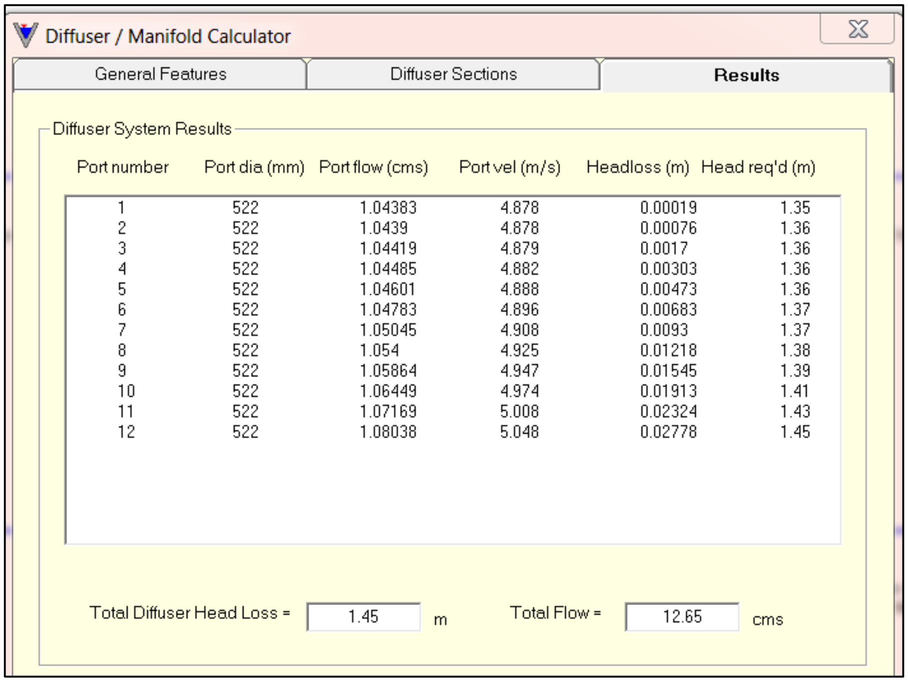
Section	Diffuser dia (mm)	Slope (m/m)	Riser dia (mm)	Port dia (mm)	Riser length (m)	Port/riser spacing (m)	No. of ports
Section 1	2500	0	750	522	2	10	12

Add New Section

Diffuser diameter: 2500 mm
Diffuser slope:* 0 m/m
Riser diameter: 750 mm
Port/riser spacing: 10 m
Port diameter: 522 mm
Riser length: 2 m
No. of ports: 12

* Note: Use a negative slope if the diffuser drops in elevation the further is gets away from shore. Slope only affects diffusers discharging into denser fluids.

Figure 2: Diffuser Parameters: 240 m long, 10 m spacing, 24 of 24 @ 522mm ports open

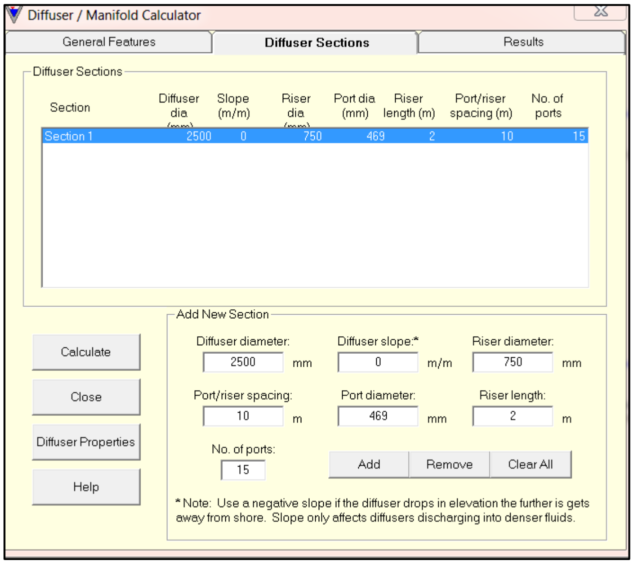


Diffuser System Results

Port number	Port dia (mm)	Port flow (cms)	Port vel (m/s)	Headloss (m)	Head req'd (m)
1	522	1.04383	4.878	0.00019	1.35
2	522	1.0439	4.878	0.00076	1.36
3	522	1.04419	4.879	0.0017	1.36
4	522	1.04485	4.882	0.00303	1.36
5	522	1.04601	4.888	0.00473	1.36
6	522	1.04783	4.896	0.00683	1.37
7	522	1.05045	4.908	0.0093	1.37
8	522	1.054	4.925	0.01218	1.38
9	522	1.05864	4.947	0.01545	1.39
10	522	1.06449	4.974	0.01913	1.41
11	522	1.07169	5.008	0.02324	1.43
12	522	1.08038	5.048	0.02778	1.45

Total Diffuser Head Loss = 1.45 m
Total Flow = 12.65 cms

Figure 3: Results showing flow, velocity and head required through manifold, risers and diffuser ports: 240 m long, 10 m spacing, 24 of 24 ports @ 522mm dia. open



Diffuser Sections

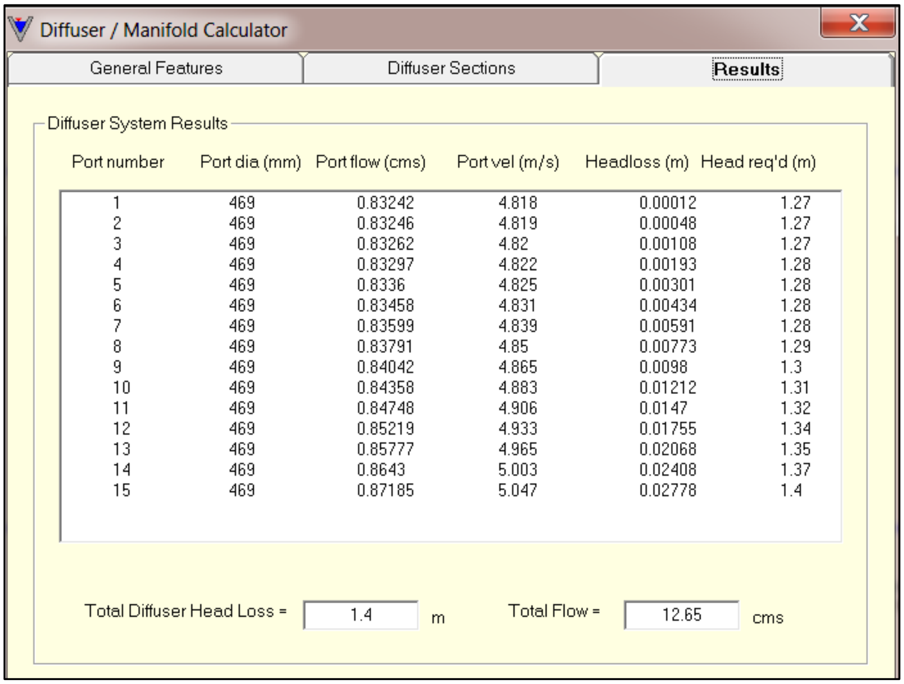
Section	Diffuser dia	Slope (m/m)	Riser dia	Port dia (mm)	Riser length (m)	Port/riser spacing (m)	No. of ports
Section 1	2500	0	750	469	2	10	15

Add New Section

Diffuser diameter: 2500 mm
Diffuser slope:* 0 m/m
Riser diameter: 750 mm
Port/riser spacing: 10 m
Port diameter: 469 mm
Riser length: 2 m
No. of ports: 15

* Note: Use a negative slope if the diffuser drops in elevation the further is gets away from shore. Slope only affects diffusers discharging into denser fluids.

Figure 4: Diffuser Parameters: 300m long, 10m spacing, 30 of 30 @ 469mm ports open

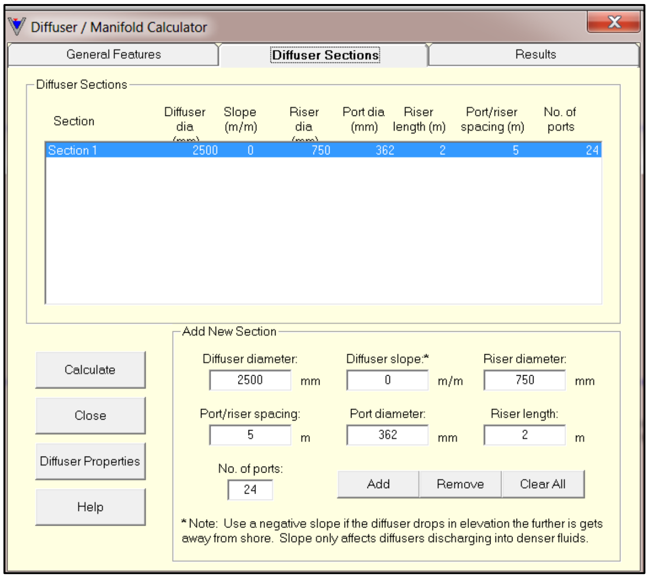


Diffuser System Results

Port number	Port dia (mm)	Port flow (cms)	Port vel (m/s)	Headloss (m)	Head req'd (m)
1	469	0.83242	4.818	0.00012	1.27
2	469	0.83246	4.819	0.00048	1.27
3	469	0.83262	4.82	0.00108	1.27
4	469	0.83297	4.822	0.00193	1.28
5	469	0.8336	4.825	0.00301	1.28
6	469	0.83458	4.831	0.00434	1.28
7	469	0.83599	4.839	0.00591	1.28
8	469	0.83791	4.85	0.00773	1.29
9	469	0.84042	4.865	0.0098	1.3
10	469	0.84358	4.883	0.01212	1.31
11	469	0.84748	4.906	0.0147	1.32
12	469	0.85219	4.933	0.01755	1.34
13	469	0.85777	4.965	0.02068	1.35
14	469	0.8643	5.003	0.02408	1.37
15	469	0.87185	5.047	0.02778	1.4

Total Diffuser Head Loss = 1.4 m
Total Flow = 12.65 cms

Figure 5: Results showing flow, velocity and head required through manifold, risers and diffuser ports: 300m long, 10m spacing, 30 of 30 ports @ 469mm diameter open



Diffuser Sections

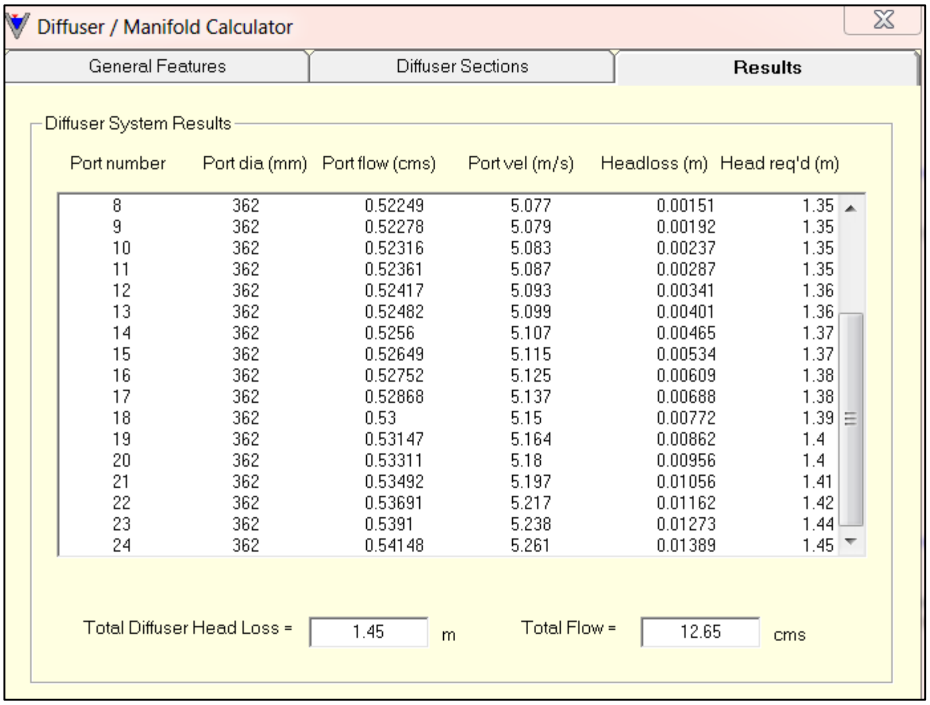
Section	Diffuser dia (mm)	Slope (m/m)	Riser dia (mm)	Port dia (mm)	Riser length (m)	Port/riser spacing (m)	No. of ports
Section 1	2500	0	750	362	2	5	24

Add New Section

Diffuser diameter: 2500 mm
Diffuser slope:* 0 m/m
Riser diameter: 750 mm
Port/riser spacing: 5 m
Port diameter: 362 mm
Riser length: 2 m
No. of ports: 24

* Note: Use a negative slope if the diffuser drops in elevation the further is gets away from shore. Slope only affects diffusers discharging into denser fluids.

Figure 6: Diffuser Parameters: 240m long, 5m spacing, 48 of 48 @ 362mm ports open



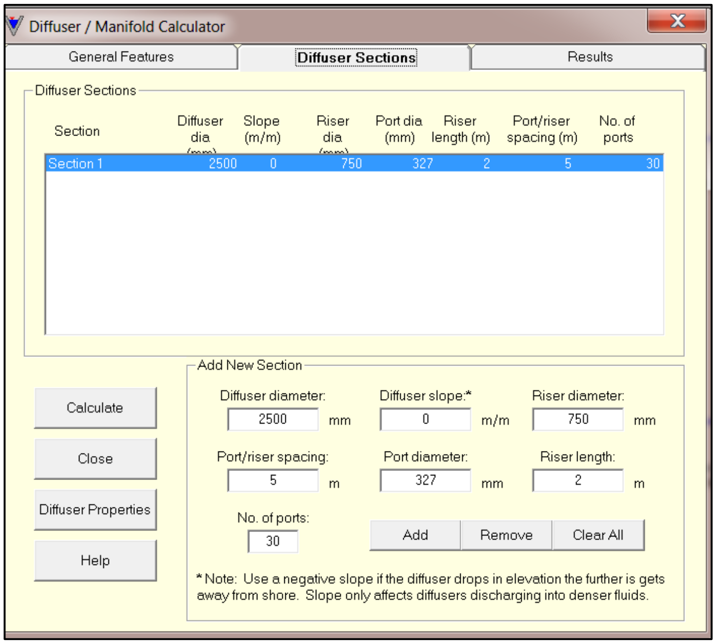
Diffuser System Results

Port number	Port dia (mm)	Port flow (cms)	Port vel (m/s)	Headloss (m)	Head req'd (m)
8	362	0.52249	5.077	0.00151	1.35
9	362	0.52278	5.079	0.00192	1.35
10	362	0.52316	5.083	0.00237	1.35
11	362	0.52361	5.087	0.00287	1.35
12	362	0.52417	5.093	0.00341	1.36
13	362	0.52482	5.099	0.00401	1.36
14	362	0.5256	5.107	0.00465	1.37
15	362	0.52649	5.115	0.00534	1.37
16	362	0.52752	5.125	0.00609	1.38
17	362	0.52868	5.137	0.00688	1.38
18	362	0.53	5.15	0.00772	1.39
19	362	0.53147	5.164	0.00862	1.4
20	362	0.53311	5.18	0.00956	1.4
21	362	0.53492	5.197	0.01056	1.41
22	362	0.53691	5.217	0.01162	1.42
23	362	0.5391	5.238	0.01273	1.44
24	362	0.54148	5.261	0.01389	1.45

Total Diffuser Head Loss = 1.45 m

Total Flow = 12.65 cms

Figure 7: Results showing flow, velocity and head required through manifold, risers and diffuser ports: 240m long, 5m spacing, 48 of 48 ports @ 362mm diameter open



Diffuser Sections

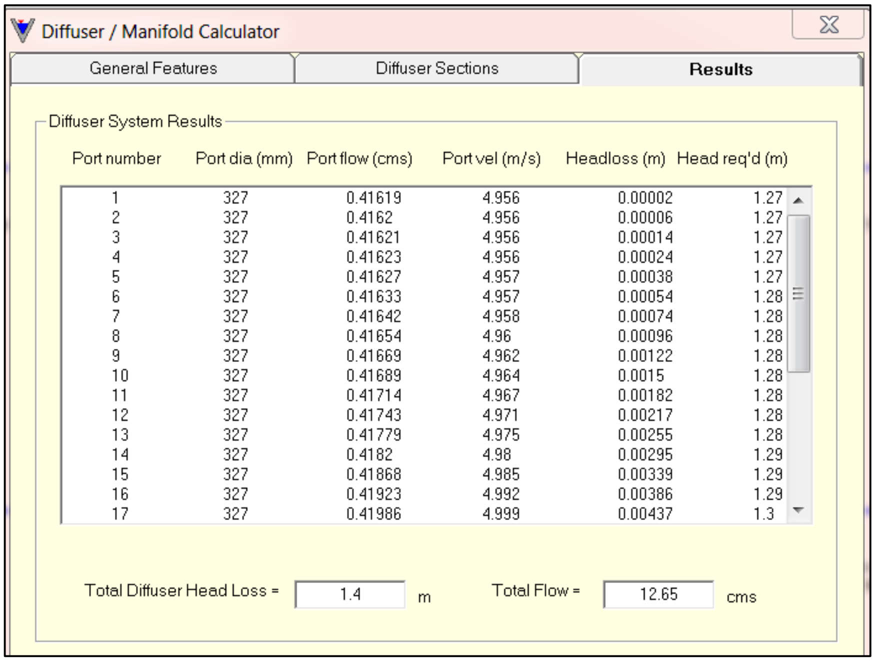
Section	Diffuser dia (mm)	Slope (m/m)	Riser dia (mm)	Port dia (mm)	Riser length (m)	Port/riser spacing (m)	No. of ports
Section 1	2500	0	750	327	2	5	30

Add New Section

Diffuser diameter: 2500 mm
Diffuser slope:* 0 m/m
Riser diameter: 750 mm
Port/riser spacing: 5 m
Port diameter: 327 mm
Riser length: 2 m
No. of ports: 30

* Note: Use a negative slope if the diffuser drops in elevation the further is gets away from shore. Slope only affects diffusers discharging into denser fluids.

Figure 8: Diffuser Parameters: 300m long, 5m spacing, 60 of 60 @ 327mm ports open

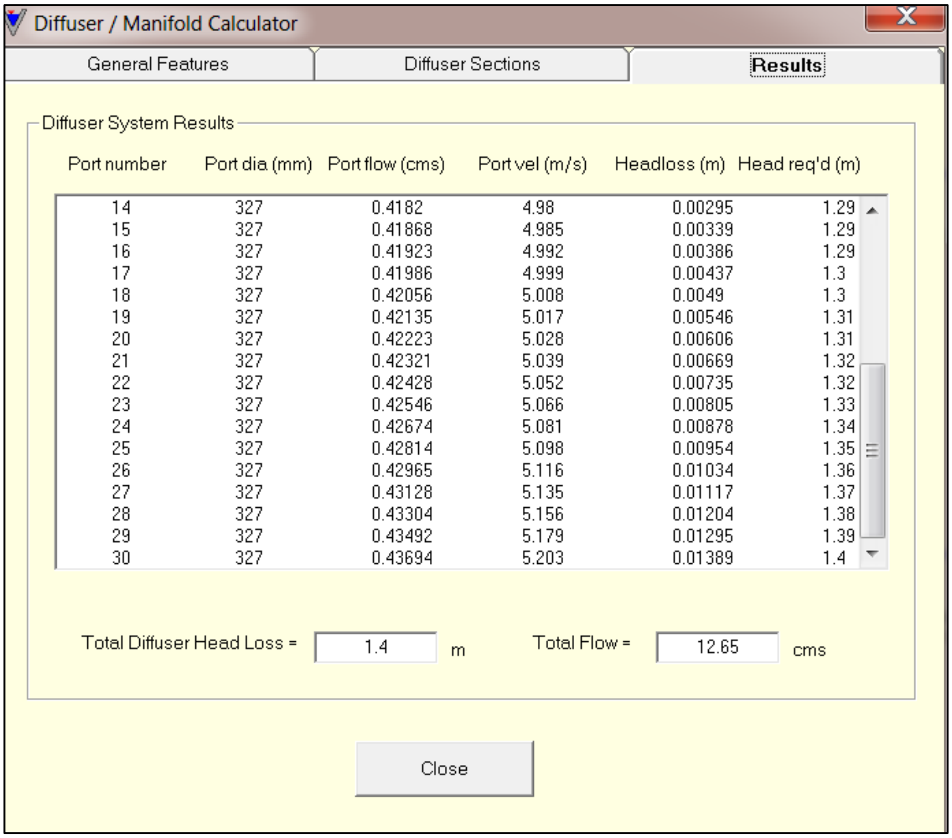


Diffuser System Results

Port number	Port dia (mm)	Port flow (cms)	Port vel (m/s)	Headloss (m)	Head req'd (m)
1	327	0.41619	4.956	0.00002	1.27
2	327	0.4162	4.956	0.00006	1.27
3	327	0.41621	4.956	0.00014	1.27
4	327	0.41623	4.956	0.00024	1.27
5	327	0.41627	4.957	0.00038	1.27
6	327	0.41633	4.957	0.00054	1.28
7	327	0.41642	4.958	0.00074	1.28
8	327	0.41654	4.96	0.00096	1.28
9	327	0.41669	4.962	0.00122	1.28
10	327	0.41689	4.964	0.0015	1.28
11	327	0.41714	4.967	0.00182	1.28
12	327	0.41743	4.971	0.00217	1.28
13	327	0.41779	4.975	0.00255	1.28
14	327	0.4182	4.98	0.00295	1.29
15	327	0.41868	4.985	0.00339	1.29
16	327	0.41923	4.992	0.00386	1.29
17	327	0.41986	4.999	0.00437	1.3

Total Diffuser Head Loss = 1.4 m
Total Flow = 12.65 cms

Figure 9a: Results showing flow, velocity and head required through manifold, risers and diffuser ports 1 through 17: 300m long, 5m spacing, 60 of 60 ports @ 327mm diameter open



Diffuser System Results

Port number	Port dia (mm)	Port flow (cms)	Port vel (m/s)	Headloss (m)	Head req'd (m)
14	327	0.4182	4.98	0.00295	1.29
15	327	0.41868	4.985	0.00339	1.29
16	327	0.41923	4.992	0.00386	1.29
17	327	0.41986	4.999	0.00437	1.3
18	327	0.42056	5.008	0.0049	1.3
19	327	0.42135	5.017	0.00546	1.31
20	327	0.42223	5.028	0.00606	1.31
21	327	0.42321	5.039	0.00669	1.32
22	327	0.42428	5.052	0.00735	1.32
23	327	0.42546	5.066	0.00805	1.33
24	327	0.42674	5.081	0.00878	1.34
25	327	0.42814	5.098	0.00954	1.35
26	327	0.42965	5.116	0.01034	1.36
27	327	0.43128	5.135	0.01117	1.37
28	327	0.43304	5.156	0.01204	1.38
29	327	0.43492	5.179	0.01295	1.39
30	327	0.43694	5.203	0.01389	1.4

Total Diffuser Head Loss = 1.4 m

Total Flow = 12.65 cms

Figure 9b: Results showing flow, velocity and head required through manifold, risers and diffuser ports 14 through 30: 300m long, 5m spacing, 60 of 60 ports @ 327mm diameter open

Results

Results summary table:

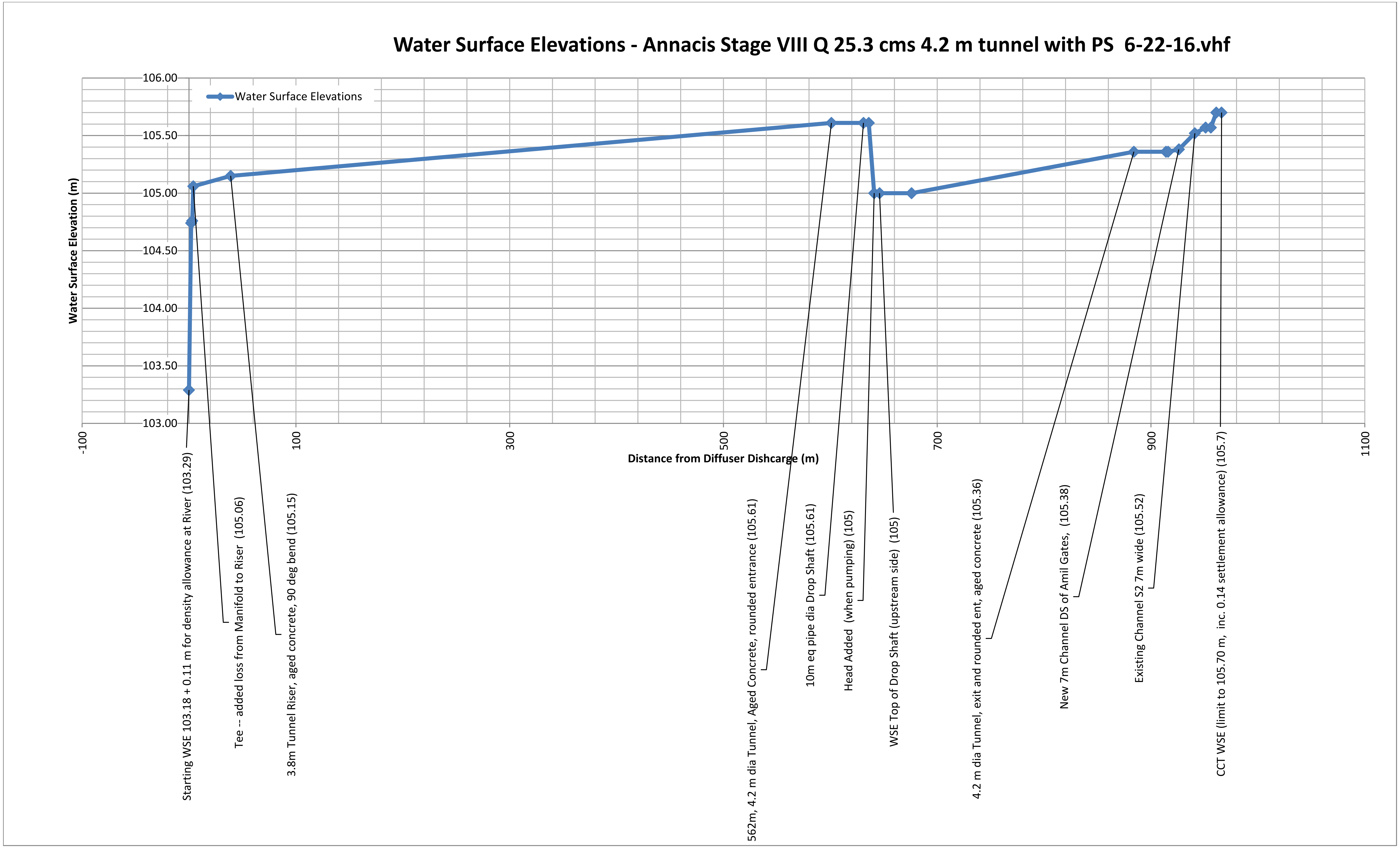
Diffuser Length (m)	Port Spacing (m)	Total Number of Ports	Number of Ports open (Stage VIII)	Fixed Port Diameter (mm) at 1.41 m Available Head	Range of Flow Per Port (m3/s)	Range of Port Velocities (m/s)
240	10	24	24	522	1.04 - 1.08	4.9 - 5.0
300	10	30	30	469	0.83 - 0.87	4.8 - 5.0
240	5	48	48	362	0.52 - 0.54	5.0 - 5.2
300	5	60	60	327	0.42 - 0.44	5.0 - 5.2

The summary table shows even distribution of diffuser port flow with port velocities ranging **4.9 to 5.2 m/s** with a head requirement of **1.45m**. The head requirement for the manifold, riser and diffuser system of 1.45m matches the available 1.45m head (with pumping).

cc:
Bernie Kolb, John Newby, Francis Bui, Brian Caufield; CDM Smith

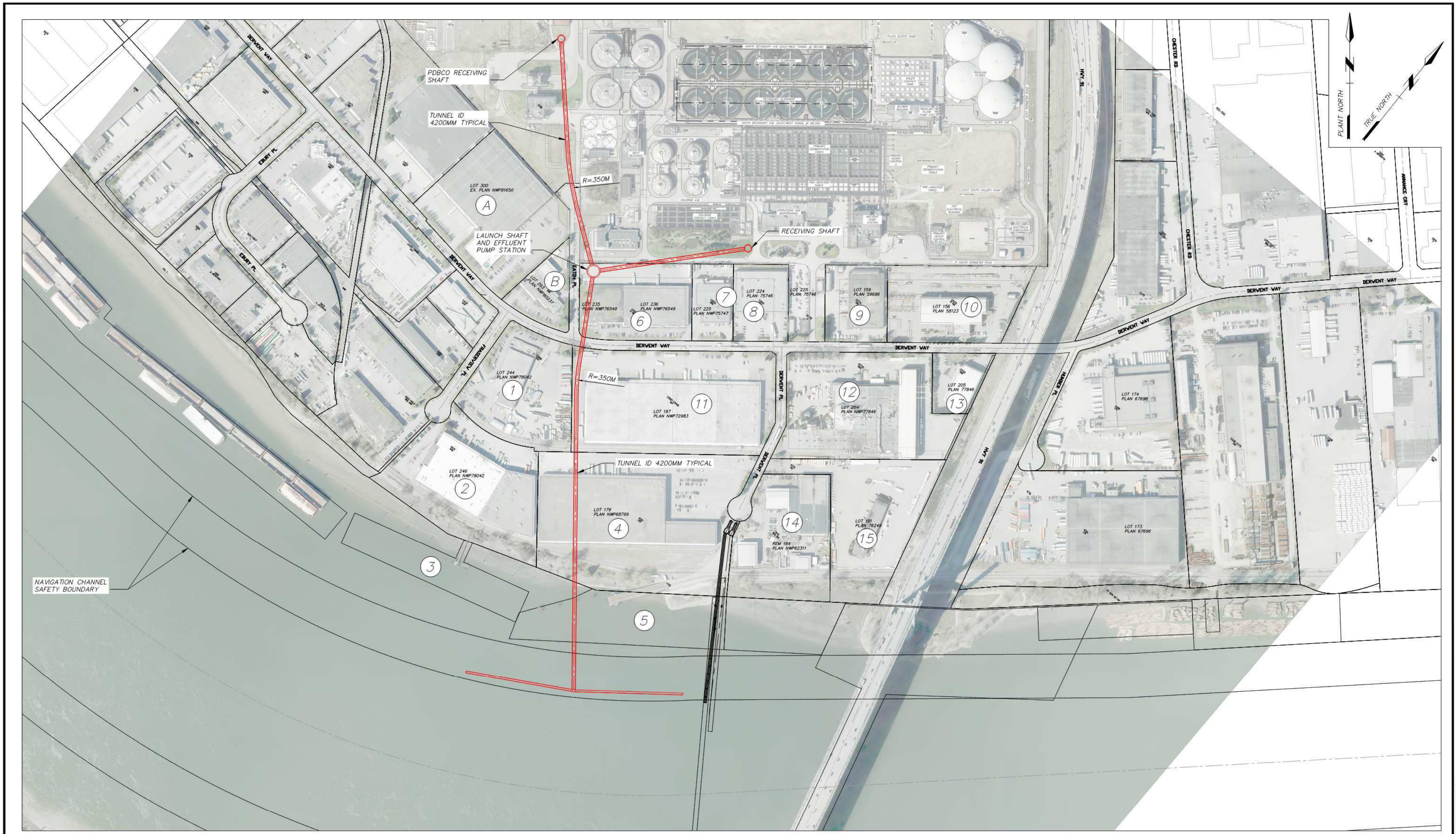
Attachments:
A. Hydraulic Profile Plot
B. Outfall Alignment Figure
C. Visual Hydraulics Calculations
D. Tideflex Diffuser System Data Analysis

Attachment A. Hydraulic Profile Plot



Water Surface Elevations - Annacis Stage VIII Q 25.3 cms 4.2 m tunnel with PS 6-22-16.vhf

Attachment B. Outfall Alignment Figure



CDM Smith

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PRELIMINARY DRAWING

NOT FOR CONSTRUCTION

Professional Seal

Issue	Date	Des'n	Dr'n	Chkd	App'd	Description

0 20 Bar is 20mm On Original Drawing. If Not On This Sheet, Adjust Scales Accordingly.

GREATER VANCOUVER SEWERAGE AND DRAINAGE DISTRICT

Design: INT.
Drawn: INT.
Checked: INT.
Approved
INT.
Manager

ANNACIS ISLAND WWTP
TRANSIENT MITIGATION AND OUTFALL
CONTRACT XXXX – NEW OUTFALL SYSTEM
PACKAGE 5

A10 – GENERAL SITE WORKS
AERIAL MAP 1
ALIGNMENT OPTION 6

SCALE: 1:2500

DISTRICT FILE SF-1933

DRAWING NUMBER A10 X-C-02-6

SUPERSEDES PRINTS OF THIS DRAWING NUMBER WITH LETTERS PREVIOUS TO ➡ A

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Attachment C. Visual Hydraulics Calculations

Visual Hydraulics Summary Report - Hydraulic Analysis

Project: **Annacis Hyd Profile 4.2 m tunnel with PS 06-22-16.vhf**
Company:
Date:

Stage VIII 25.3 cms
With No Pumping

Current flow conditions

Forward Flow =	25.3 cms
Return I Flow =	-----
Return II Flow =	-----
Return III Flow =	-----

Section Description	Water Surface Elevation
Starting WSE 103.18 + 0.11 m for density allowance at River	**103.29**
Diffuser plus Manifold Loss, see difusser calcs Change in elevation = 0.69 m	**103.98**
Reducer -- 1000 mm x 750 mm Diameter of smaller pipe = 750 mm Diameter of larger pipe = 1000 mm Flow through pipe = 1.406 cms Transition angle = 14.3 degrees Overall head loss = 0.02 m Transition K value = 0.04 Area of smaller pipe = 0.44 m^2 Area of larger pipe = 0.79 m^2 Velocity in smaller pipe = 2.38 m/s Velocity in larger pipe = 1.34 m/s Overall head loss = 0.01 m	**104**
Tee -- added loss from Manifold to Riser Pipe shape = Circular Diameter = 1000 mm Length = 2 m Flow = 1.406 cms Friction method = Colebrook-White Friction factor = 0.003 Total fitting K value = 1.8 Pipe area = 0.79 m² Pipe hydraulic radius = 0.25 Age factor = 1	**104.3**

Section Description **Water Surface Elevation**

Solids factor = 1
Velocity = 1.79 m/s
Friction loss = 0.01 m
Fitting loss = 0.29 m
Total loss = 0.3 m

3.8m Tunnel Riser, aged concrete, 90 deg bend **104.39**

Pipe shape = Circular
Diameter = 3800 mm
Length = 20 m
Flow = 25.3 cms
Friction method = Colebrook-White
Friction factor = 0.003
Total fitting K value = 0.25
Pipe area = 11.34 m²
Pipe hydraulic radius = 0.95
Age factor = 1
Solids factor = 1
Velocity = 2.23 m/s
Friction loss = 0.02 m
Fitting loss = 0.06 m
Total loss = 0.09 m

562m, 4.2 m dia Tunnel, Aged Concrete, rounded entrance **104.85**

Pipe shape = Circular
Diameter = 4200 mm
Length = 562 m
Flow = 25.3 cms
Friction method = Colebrook-White
Friction factor = 0.003
Total fitting K value = 0.23
Pipe area = 13.85 m²
Pipe hydraulic radius = 1.05
Age factor = 1
Solids factor = 1
Velocity = 1.83 m/s
Friction loss = 0.42 m
Fitting loss = 0.04 m
Total loss = 0.46 m

10m eq pipe dia Drop Shaft **104.85**

Pipe shape = Circular
Diameter = 10617 mm
Length = 30 m
Flow = 25.3 cms
Friction method = Colebrook-White
Friction factor = 0.003

Section Description **Water Surface Elevation**

Total fitting K value = 0
Pipe area = 88.53 m²
Pipe hydraulic radius = 2.654
Age factor = 1
Solids factor = 1
Velocity = 0.29 m/s
Friction loss = 0 m
Fitting loss = 0 m
Total loss = 0 m

WSE Top of Drop Shaft (downstream side) **104.85**
Change in elevation = 0 m

Two 3m w x 4m tall Flap Gates **105**
Opening type = rectangular gate
Opening diameter/width = 3000 mm
Gate height = 4000 mm
Invert = 97
Number of gates = 2
Flow through gate(s) = 25.3 cms
Total area of opening(s) = 24 m^2
Velocity through gate(s) = 1.05 m/s
Flow behavior = orifice, downstream control
Gate loss = 0.15 m
Downstream water level = 104.85
Upstream water level = 105

Head Added (when pumping) **105**
Change in elevation = 0 m

WSE Top of Drop Shaft (upstream side) **105**
Change in elevation = 0 m

10 m eq pipe dia Riser Shaft **105**
Pipe shape = Circular
Diameter = 10617 mm
Length = 30 m
Flow = 25.3 cms
Friction method = Colebrook-White
Friction factor = 0.003
Total fitting K value = 0
Pipe area = 88.53 m²
Pipe hydraulic radius = 2.654
Age factor = 1
Solids factor = 1
Velocity = 0.29 m/s
Friction loss = 0 m
Fitting loss = 0 m

Section Description	Water Surface Elevation
Total loss = 0 m	
4.2 m dia Tunnel, exit and rounded ent, aged concrete Pipe shape = Circular Diameter = 4200 mm Length = 208 m Flow = 25.3 cms Friction method = Colebrook-White Friction factor = 0.003 Total fitting K value = 1.23 Pipe area = 13.85 m^2 Pipe hydraulic radius = 1.05 Age factor = 1 Solids factor = 1 Velocity = 1.83 m/s Friction loss = 0.15 m Fitting loss = 0.21 m Total loss = 0.36 m	**105.36**
9 m dia Drop Shaft Pipe shape = Circular Diameter = 9000 mm Length = 30 m Flow = 25.3 cms Friction method = Colebrook-White Friction factor = 0.003 Total fitting K value = 0 Pipe area = 63.62 m^2 Pipe hydraulic radius = 2.25 Age factor = 1 Solids factor = 1 Velocity = 0.4 m/s Friction loss = 0 m Fitting loss = 0 m Total loss = 0 m	**105.36**
Single Channel Width Gate Change in elevation = 0 m	**105.36**
New 7m Channel DS of Amil Gates, Channel shape = Rectangular Manning's 'n' = 0.013 Channel length = 10 m Channel width/diameter = 7 m Flow = 25.3 cms Downstream channel invert = 103.87 Channel slope = 0 m/m Channel side slope = not applicable	**105.38**

Section Description **Water Surface Elevation**

Area of flow = 10.48 m^2
Hydraulic radius = 1.049
Normal depth = infinite
Critical depth = 1.1 m
Depth downstream = 1.49 m
Bend loss = 0 m
Depth upstream = 1.51 m
Velocity = 2.43 m/s
Flow profile = Horizontal

Existing Channel S2 7m wide **105.52**

Channel shape = Rectangular
Manning's 'n' = 0.013
Channel length = 15.5 m
Channel width/diameter = 7 m
Flow = 25.3 cms
Downstream channel invert = 103.87
Channel slope = 0 m/m
Channel side slope = not applicable
Area of flow = 10.63 m^2
Hydraulic radius = 1.059
Normal depth = infinite
Critical depth = 1.1 m
Depth downstream = 1.51 m
Bend loss = 0.12 m
Depth upstream = 1.65 m
Velocity = 2.4 m/s
Flow profile = Horizontal

New Channel S1 7m wide **105.57**

Channel shape = Rectangular
Manning's 'n' = 0.013
Channel length = 15.24 m
Channel width/diameter = 7 m
Flow = 16.867 cms
Downstream channel invert = 103.87
Channel slope = 0 m/m
Channel side slope = not applicable
Area of flow = 11.56 m^2
Hydraulic radius = 1.122
Normal depth = infinite
Critical depth = 0.84 m
Depth downstream = 1.65 m
Bend loss = 0.04 m
Depth upstream = 1.7 m
Velocity = 1.46 m/s
Flow profile = Horizontal

Section Description	Water Surface Elevation
Stop Logs D.S. of New Amil Gates Change in elevation = 0 m	**105.57**
3 of 4 Amil Gates Q 18.9 (B&C gate rating figure 3C-1) Change in elevation = 0.13 m	**105.7**
CCT WSE (limit to 105.70 m, inc. 0.14 settlement allowance) Change in elevation = 0 m	**105.7**

Visual Hydraulics Summary Report - Hydraulic Analysis

Stage VIII 25.3 cms
With Pumping

Project: **Annacis Hyd Profile 4.2 m tunnel with PS 06-22-16.vhf**
Company:
Date:

Current flow conditions

Forward Flow =	25.3 cms
Return I Flow =	-----
Return II Flow =	-----
Return III Flow =	-----

Section Description	Water Surface Elevation
Starting WSE 103.18 + 0.11 m for density allowance at River	**103.29**
Diffuser plus Manifold Loss, see difusser calcs Change in elevation = 1.45 m	**104.74**
Reducer -- 1000 mm x 750 mm Diameter of smaller pipe = 750 mm Diameter of larger pipe = 1000 mm Flow through pipe = 1.406 cms Transition angle = 14.3 degrees Overall head loss = 0.02 m Transition K value = 0.04 Area of smaller pipe = 0.44 m^2 Area of larger pipe = 0.79 m^2 Velocity in smaller pipe = 2.38 m/s Velocity in larger pipe = 1.34 m/s Overall head loss = 0.01 m	**104.76**
Tee -- added loss from Manifold to Riser Pipe shape = Circular Diameter = 1000 mm Length = 2 m Flow = 1.406 cms Friction method = Colebrook-White Friction factor = 0.003 Total fitting K value = 1.8 Pipe area = 0.79 m² Pipe hydraulic radius = 0.25 Age factor = 1	**105.06**

Section Description **Water Surface Elevation**

Solids factor = 1
Velocity = 1.79 m/s
Friction loss = 0.01 m
Fitting loss = 0.29 m
Total loss = 0.3 m

3.8m Tunnel Riser, aged concrete, 90 deg bend **105.15**

Pipe shape = Circular
Diameter = 3800 mm
Length = 20 m
Flow = 25.3 cms
Friction method = Colebrook-White
Friction factor = 0.003
Total fitting K value = 0.25
Pipe area = 11.34 m²
Pipe hydraulic radius = 0.95
Age factor = 1
Solids factor = 1
Velocity = 2.23 m/s
Friction loss = 0.02 m
Fitting loss = 0.06 m
Total loss = 0.09 m

562m, 4.2 m dia Tunnel, Aged Concrete, rounded entrance **105.61**

Pipe shape = Circular
Diameter = 4200 mm
Length = 562 m
Flow = 25.3 cms
Friction method = Colebrook-White
Friction factor = 0.003
Total fitting K value = 0.23
Pipe area = 13.85 m²
Pipe hydraulic radius = 1.05
Age factor = 1
Solids factor = 1
Velocity = 1.83 m/s
Friction loss = 0.42 m
Fitting loss = 0.04 m
Total loss = 0.46 m

10m eq pipe dia Drop Shaft **105.61**

Pipe shape = Circular
Diameter = 10617 mm
Length = 30 m
Flow = 25.3 cms
Friction method = Colebrook-White
Friction factor = 0.003

Section Description	Water Surface Elevation
Total fitting K value = 0	
Pipe area = 88.53 m²	
Pipe hydraulic radius = 2.654	
Age factor = 1	
Solids factor = 1	
Velocity = 0.29 m/s	
Friction loss = 0 m	
Fitting loss = 0 m	
Total loss = 0 m	
WSE Top of Drop Shaft (downstream side)	**105.61**
Change in elevation = 0 m	
Head Added (when pumping)	**105**
Change in elevation = -0.61 m	
WSE Top of Drop Shaft (upstream side)	**105**
Change in elevation = 0 m	
10 m eq pipe dia Riser Shaft	**105**
Pipe shape = Circular	
Diameter = 10617 mm	
Length = 30 m	
Flow = 25.3 cms	
Friction method = Colebrook-White	
Friction factor = 0.003	
Total fitting K value = 0	
Pipe area = 88.53 m²	
Pipe hydraulic radius = 2.654	
Age factor = 1	
Solids factor = 1	
Velocity = 0.29 m/s	
Friction loss = 0 m	
Fitting loss = 0 m	
Total loss = 0 m	
4.2 m dia Tunnel, exit and rounded ent, aged concrete	**105.36**
Pipe shape = Circular	
Diameter = 4200 mm	
Length = 208 m	
Flow = 25.3 cms	
Friction method = Colebrook-White	
Friction factor = 0.003	
Total fitting K value = 1.23	
Pipe area = 13.85 m²	
Pipe hydraulic radius = 1.05	
Age factor = 1	
Solids factor = 1	

Section Description **Water Surface Elevation**

Velocity = 1.83 m/s
Friction loss = 0.15 m
Fitting loss = 0.21 m
Total loss = 0.36 m

9 m dia Drop Shaft **105.36**
Pipe shape = Circular
Diameter = 9000 mm
Length = 30 m
Flow = 25.3 cms
Friction method = Colebrook-White
Friction factor = 0.003
Total fitting K value = 0
Pipe area = 63.62 m^2
Pipe hydraulic radius = 2.25
Age factor = 1
Solids factor = 1
Velocity = 0.4 m/s
Friction loss = 0 m
Fitting loss = 0 m
Total loss = 0 m

Single Channel Width Gate **105.36**
Change in elevation = 0 m

New 7m Channel DS of Amil Gates, **105.38**
Channel shape = Rectangular
Manning's 'n' = 0.013
Channel length = 10 m
Channel width/diameter = 7 m
Flow = 25.3 cms
Downstream channel invert = 103.87
Channel slope = 0 m/m
Channel side slope = not applicable
Area of flow = 10.5 m^2
Hydraulic radius = 1.05
Normal depth = infinite
Critical depth = 1.1 m
Depth downstream = 1.49 m
Bend loss = 0 m
Depth upstream = 1.51 m
Velocity = 2.42 m/s
Flow profile = Horizontal

Existing Channel S2 7m wide **105.52**
Channel shape = Rectangular
Manning's 'n' = 0.013
Channel length = 15.5 m

Section Description **Water Surface Elevation**

Channel width/diameter = 7 m
Flow = 25.3 cms
Downstream channel invert = 103.87
Channel slope = 0 m/m
Channel side slope = not applicable
Area of flow = 10.65 m^2
Hydraulic radius = 1.06
Normal depth = infinite
Critical depth = 1.1 m
Depth downstream = 1.51 m
Bend loss = 0.12 m
Depth upstream = 1.65 m
Velocity = 2.39 m/s
Flow profile = Horizontal

New Channel S1 7m wide **105.57**

Channel shape = Rectangular
Manning's 'n' = 0.013
Channel length = 15.24 m
Channel width/diameter = 7 m
Flow = 16.867 cms
Downstream channel invert = 103.87
Channel slope = 0 m/m
Channel side slope = not applicable
Area of flow = 11.57 m^2
Hydraulic radius = 1.123
Normal depth = infinite
Critical depth = 0.84 m
Depth downstream = 1.65 m
Bend loss = 0.04 m
Depth upstream = 1.7 m
Velocity = 1.46 m/s
Flow profile = Horizontal

Stop Logs D.S. of New Amil Gates **105.57**

Change in elevation = 0 m

3 of 4 Amil Gates Q 18.9 (B&C gate rating figure 3C-1) **105.7**

Change in elevation = 0.13 m

CCT WSE (limit to 105.70 m, inc. 0.14 settlement allowance) **105.7**

Change in elevation = 0 m

Attachment D. Tideflex Diffuser System Data Analysis

TIDEFLEX DIFFUSER (TFD) SYSTEM DATA ANALYSIS

MEDIA: Effluent

Density or Kg/m^3

Spec. Gravity 1

FLOWS:

	m3/s	=		litres/sec
25.2	m3/s	=	25200	litres/sec
	m3/s	=		litres/sec

AVAILABLE	Minimum		metres
HEADLOSS @	Design		metres
DIFFUSER:	Maximum		metres

MAX. BACKPRESSURE: metres

TFD SIZE (mm)	**HYDRAULIC CODE**
750	**4710**

DATE: 16-Jun-2016

CLIENT: Metro Vancouver
CONTACT:

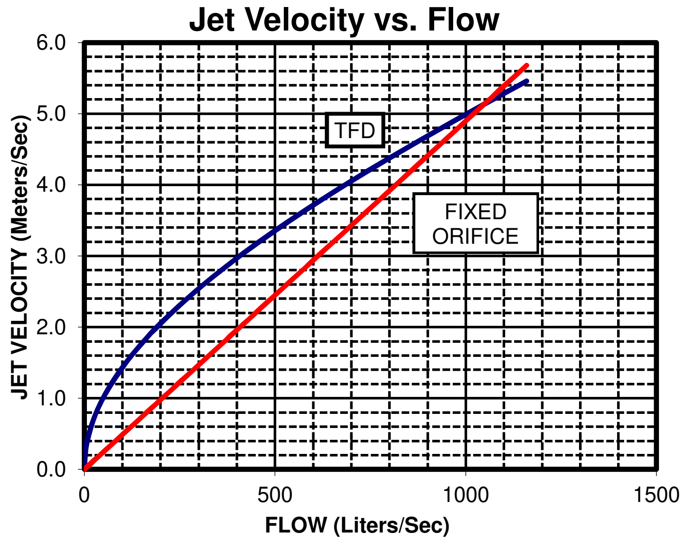
ENGINEER: CDM Smith
CONTACT: Ron Miner

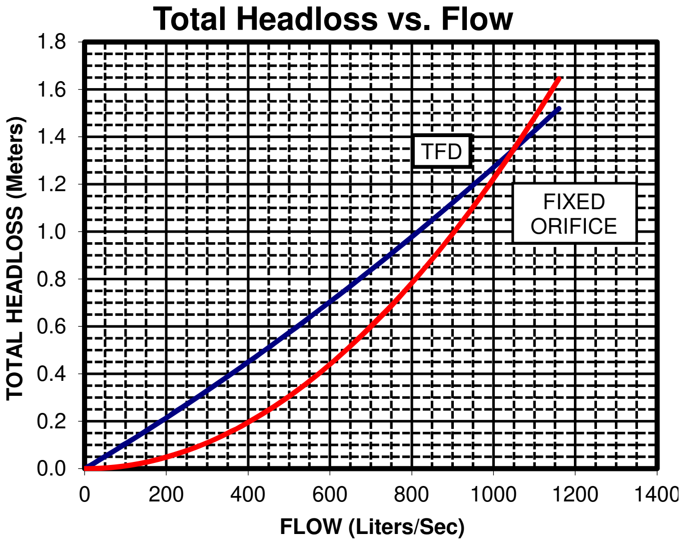
PROJECT: Annacis Island WWTP Outfall Diffuser

REP: Summit Valve & Controls
CONTACT: Craig Bridger

		PER TIDEFLEX DIFFUSER			
*** TOTAL QUANTITY**	TOTAL FLOW (litres/sec)	FLOW (litres/sec)	**JET VELOCITY (metres/sec)**	**TOTAL HEADLOSS @ DIFFUSER (metres)**	EFFECTIVE AREA (cm^2)
24	25200.0	1050.0	5.1	1.35	2041.3

FIXED ORIFICE DIA. * Cd = 1			***PER FIXED ORIFICE***			
510 mm 20.06	**24**	25200.0	1050.0	**5.1**	**1.35**	2039.3





TIDEFLEX DIFFUSER (TFD) SYSTEM DATA ANALYSIS

MEDIA: Effluent

Density or Spec. Gravity: 1 Kg/m^3

FLOWS:

m3/s = litres/sec
25.8 m3/s = 25800 litres/sec
m3/s = litres/sec

AVAILABLE HEADLOSS @ DIFFUSER:
Minimum metres
Design metres
Maximum metres

MAX. BACKPRESSURE: metres

TFD SIZE (mm)	HYDRAULIC CODE
750	**3546**

DATE: 16-Jun-2016

CLIENT: Metro Vancouver
CONTACT:

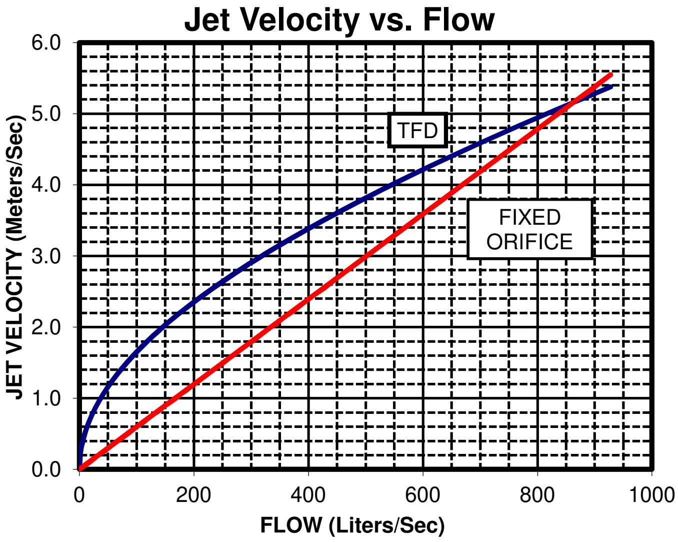
ENGINEER: CDM Smith
CONTACT: Ron Miner

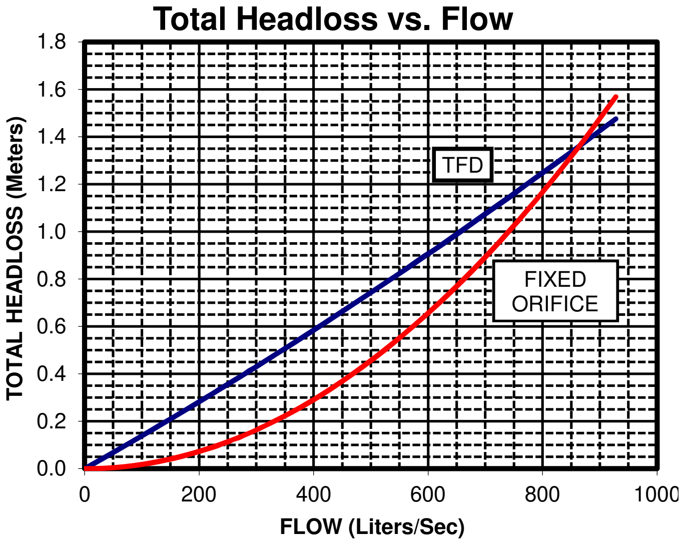
PROJECT: Annacis Island WWTP Outfall Diffuser

REP: Summit Valve & Controls
CONTACT: Craig Bridger

		PER TIDEFLEX DIFFUSER			
*** TOTAL QUANTITY**	TOTAL FLOW (litres/sec)	FLOW (litres/sec)	**JET VELOCITY (metres/sec)**	**TOTAL HEADLOSS @ DIFFUSER (metres)**	EFFECTIVE AREA (cm^2)
30	25800.0	860.0	5.1	1.35	1668.3

FIXED ORIFICE DIA.	* Cd = 1		***PER FIXED ORIFICE***			
461 mm 18.16	**30**	25800.0	860.0	**5.1**	**1.35**	1670.8





TIDEFLEX DIFFUSER (TFD) SYSTEM DATA ANALYSIS

MEDIA: Effluent

Density or [ ] Kg/m^3

Spec. Gravity 1

FLOWS:

	m3/s =		litres/sec
25.44	m3/s =	25440	litres/sec
	m3/s =		litres/sec

AVAILABLE	Minimum		metres
HEADLOSS @	Design		metres
DIFFUSER:	Maximum		metres

MAX. BACKPRESSURE: [ ] metres

DATE:	16-Jun-2016
CLIENT:	Metro Vancouver
CONTACT:	
ENGINEER:	CDM Smith
CONTACT:	Ron Miner
PROJECT:	Annacis Island WWTP Outfall Diffuser
REP:	Summit Valve & Controls
CONTACT:	Craig Bridger

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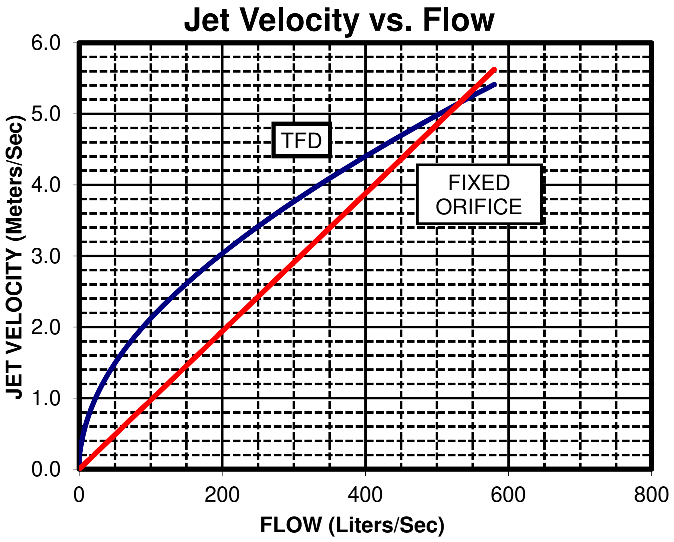
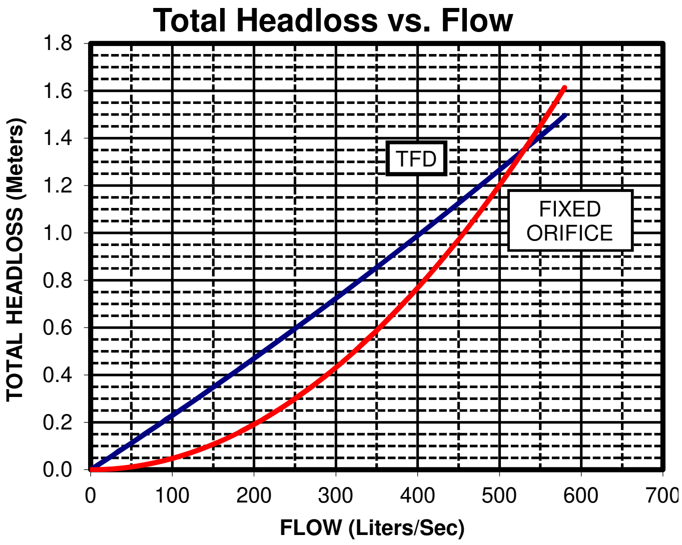
TFD SIZE (mm)	**HYDRAULIC CODE**
600	**2165**

		PER TIDEFLEX DIFFUSER			
*** TOTAL QUANTITY**	TOTAL FLOW (litres/sec)	FLOW (litres/sec)	**JET VELOCITY (metres/sec)**	**TOTAL HEADLOSS @ DIFFUSER (metres)**	EFFECTIVE AREA (cm^2)
48	25440.0	530.0	5.1	1.35	1029.0

FIXED ORIFICE DIA. * Cd = 1			***PER FIXED ORIFICE***			
362 mm 14.25	**48**	25440.0	530.0	**5.1**	**1.35**	1029.4





TIDEFLEX DIFFUSER (TFD) SYSTEM DATA ANALYSIS

MEDIA:		Effluent	
	Density or		Kg/m^3
	Spec. Gravity	1	

FLOWS:

	m3/s =		litres/sec
25.8	m3/s =	25800	litres/sec
	m3/s =		litres/sec

AVAILABLE	Minimum		metres
HEADLOSS @	Design		metres
DIFFUSER:	Maximum		metres

MAX. BACKPRESSURE: metres

TFD SIZE (mm)	HYDRAULIC CODE
500	**1851**

DATE: 16-Jun-2016

CLIENT: Metro Vancouver
CONTACT:

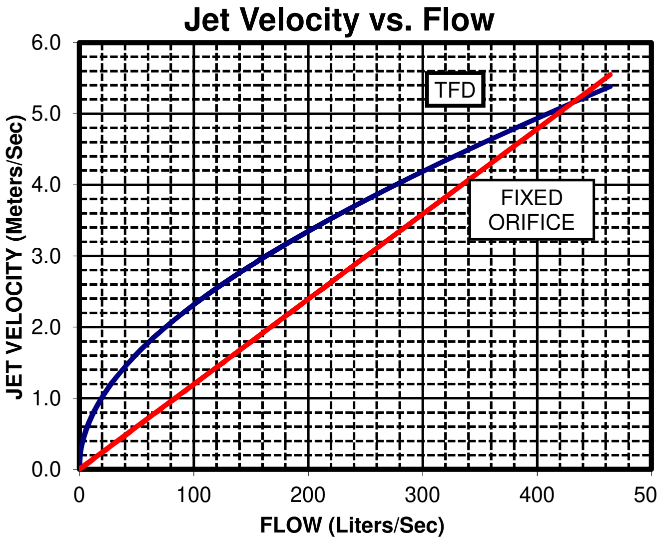
ENGINEER: CDM Smith
CONTACT: Ron Miner

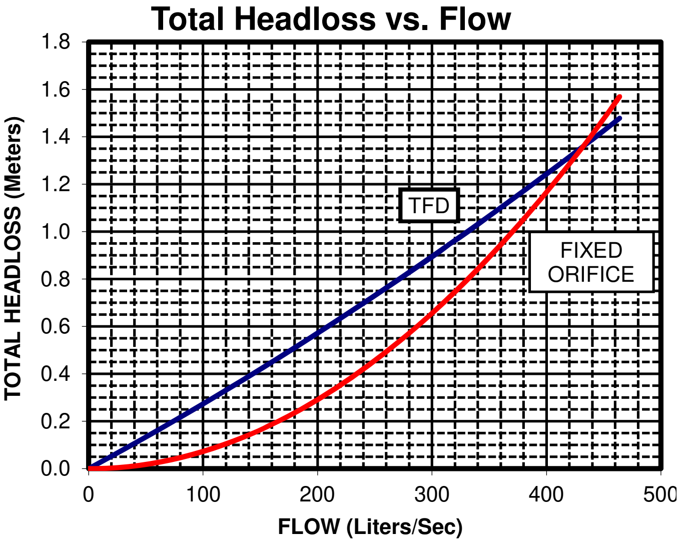
PROJECT: Annacis Island WWTP Outfall Diffuser

REP: Summit Valve & Controls
CONTACT: Craig Bridger

		PER TIDEFLEX DIFFUSER			
*** TOTAL QUANTITY**	TOTAL FLOW (litres/sec)	FLOW (litres/sec)	**JET VELOCITY (metres/sec)**	**TOTAL HEADLOSS @ DIFFUSER (metres)**	EFFECTIVE AREA (cm^2)
60	25800.0	430.0	5.1	1.35	834.5

FIXED ORIFICE DIA. * Cd = 1			***PER FIXED ORIFICE***			
326 mm 12.84	**60**	25800.0	430.0	**5.1**	**1.35**	835.4





Appendix E

Summary of Model Inputs and Results for a Fixed Orifice, Multiport Diffuser

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Flow Classification	Percent of Time Ambient Flow Occurs	Density Profile	Percent of Time Profile Occurs	Depth (m)	Percent of Time Depth Occurs	Effluent Flow (m³/s)	Percent of Time Effluent Flow Occurs	Ambient Current Speed (m/s)	Percent of Time Current Speed Occurs	Flux-Averaged Initial Dilution	Probability of Occurrence
BATCH 3 (<1000)	23.3%	SALINE	35%	10.9	50%	8.8	4%	0.03	5.0%	15.57	0.01%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	10.9	50%	7.9	10%	0.03	5.0%	16.61	0.16%
BATCH 3 (<1000)	23.3%	SALINE	35%	10.9	50%	10.3	61%	0.03	5.0%	16.64	0.12%
BATCH 3 (<1000)	23.3%	FRESH	65%	10.9	50%	8.8	4%	0.03	5.0%	16.74	0.02%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	10.9	50%	9.7	65%	0.03	5.0%	16.86	1.03%
BATCH 3 (<1000)	23.3%	FRESH	65%	10.9	50%	10.3	61%	0.03	5.0%	16.94	0.23%
BATCH 3 (<1000)	23.3%	FRESH	65%	10.9	50%	13.3	25%	0.03	5.0%	17.28	0.09%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	10.9	50%	13.7	24%	0.03	5.0%	17.32	0.38%
BATCH 3 (<1000)	23.3%	FRESH	65%	10.9	50%	16.2	10%	0.03	5.0%	17.52	0.04%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	10.9	50%	18.9	1%	0.03	5.0%	17.69	0.02%
BATCH 1 (>6000)	13.2%	FRESH	100%	12.1	50%	12.3	4%	0.07	1.5%	17.71	0.00%
BATCH 1 (>6000)	13.2%	FRESH	100%	12.1	50%	10.4	26%	0.07	1.5%	17.74	0.03%
BATCH 1 (>6000)	13.2%	FRESH	100%	12.1	50%	9.5	55%	0.07	1.5%	17.79	0.05%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	10.9	50%	18.9	1%	0.30	55.0%	17.85	0.17%
BATCH 1 (>6000)	13.2%	FRESH	100%	12.1	50%	8.6	15%	0.07	1.5%	17.89	0.01%
BATCH 3 (<1000)	23.3%	SALINE	35%	14.4	50%	8.8	4%	0.03	5.0%	18.33	0.01%
BATCH 3 (<1000)	23.3%	FRESH	65%	10.9	50%	16.2	10%	0.30	55.0%	18.47	0.42%
BATCH 3 (<1000)	23.3%	SALINE	35%	10.9	50%	13.3	25%	0.03	5.0%	18.52	0.05%
BATCH 3 (<1000)	23.3%	SALINE	35%	14.4	50%	10.3	61%	0.03	5.0%	19.19	0.12%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	10.9	50%	13.7	24%	0.30	55.0%	19.26	4.19%
BATCH 3 (<1000)	23.3%	FRESH	65%	10.9	50%	13.3	25%	0.30	55.0%	19.41	1.04%
BATCH 3 (<1000)	23.3%	SALINE	35%	10.9	50%	16.2	10%	0.03	5.0%	19.84	0.02%
BATCH 1 (>6000)	13.2%	FRESH	100%	14.4	50%	12.3	4%	0.07	1.5%	20.37	0.00%
BATCH 1 (>6000)	13.2%	FRESH	100%	14.4	50%	10.4	26%	0.07	1.5%	20.47	0.03%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	14.4	50%	7.9	10%	0.03	5.0%	20.48	0.16%
BATCH 3 (<1000)	23.3%	SALINE	35%	14.4	50%	13.3	25%	0.03	5.0%	20.56	0.05%
BATCH 3 (<1000)	23.3%	FRESH	65%	14.4	50%	8.8	4%	0.03	5.0%	20.57	0.02%
BATCH 1 (>6000)	13.2%	FRESH	100%	14.4	50%	9.5	55%	0.07	1.5%	20.58	0.05%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	14.4	50%	9.7	65%	0.03	5.0%	20.67	1.03%
BATCH 3 (<1000)	23.3%	FRESH	65%	14.4	50%	10.3	61%	0.03	5.0%	20.73	0.23%
BATCH 1 (>6000)	13.2%	FRESH	100%	14.4	50%	8.6	15%	0.07	1.5%	20.74	0.01%
BATCH 3 (<1000)	23.3%	FRESH	65%	10.9	50%	10.3	61%	0.30	55.0%	20.82	2.54%
BATCH 3 (<1000)	23.3%	FRESH	65%	14.4	50%	13.3	25%	0.03	5.0%	21.01	0.09%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	14.4	50%	13.7	24%	0.03	5.0%	21.04	0.38%

Flow Classification	Percent of Time Ambient Flow Occurs	Density Profile	Percent of Time Profile Occurs	Depth (m)	Percent of Time Depth Occurs	Effluent Flow (m³/s)	Percent of Time Effluent Flow Occurs	Ambient Current Speed (m/s)	Percent of Time Current Speed Occurs	Flux-Averaged Initial Dilution	Probability of Occurrence
BATCH 3 (<1000)	23.3%	SALINE	35%	10.9	50%	10.3	61%	0.78	35.0%	21.06	0.87%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	10.9	50%	9.7	65%	0.30	55.0%	21.18	11.35%
BATCH 3 (<1000)	23.3%	FRESH	65%	14.4	50%	16.2	10%	0.03	5.0%	21.21	0.04%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	14.4	50%	18.9	1%	0.03	5.0%	21.35	0.02%
BATCH 3 (<1000)	23.3%	SALINE	35%	10.9	50%	13.3	25%	0.78	35.0%	21.45	0.36%
BATCH 3 (<1000)	23.3%	SALINE	35%	14.4	50%	16.2	10%	0.03	5.0%	21.68	0.02%
BATCH 3 (<1000)	23.3%	FRESH	65%	10.9	50%	8.8	4%	0.30	55.0%	21.79	0.17%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	10.9	50%	7.9	10%	0.30	55.0%	22.49	1.75%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	14.4	50%	18.9	1%	0.30	55.0%	23.01	0.17%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	10.9	50%	18.9	1%	0.78	35.0%	23.04	0.11%
BATCH 1 (>6000)	13.2%	FRESH	100%	12.1	50%	12.3	4%	0.37	23.5%	23.12	0.06%
BATCH 3 (<1000)	23.3%	SALINE	35%	10.9	50%	10.3	61%	0.30	55.0%	23.23	1.37%
BATCH 3 (<1000)	23.3%	SALINE	35%	10.9	50%	8.8	4%	0.78	35.0%	23.34	0.06%
BATCH 3 (<1000)	23.3%	SALINE	35%	10.9	50%	16.2	10%	0.78	35.0%	23.36	0.14%
BATCH 3 (<1000)	23.3%	SALINE	35%	10.9	50%	13.3	25%	0.30	55.0%	23.37	0.56%
BATCH 3 (<1000)	23.3%	SALINE	35%	10.9	50%	8.8	4%	0.30	55.0%	23.57	0.09%
BATCH 3 (<1000)	23.3%	FRESH	65%	14.4	50%	16.2	10%	0.30	55.0%	23.84	0.42%
BATCH 3 (<1000)	23.3%	FRESH	65%	10.9	50%	16.2	10%	0.78	35.0%	24.09	0.27%
BATCH 3 (<1000)	23.3%	SALINE	35%	10.9	50%	16.2	10%	0.30	55.0%	24.10	0.22%
BATCH 1 (>6000)	13.2%	FRESH	100%	12.1	50%	10.4	26%	0.37	23.5%	24.24	0.40%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	14.4	50%	13.7	24%	0.30	55.0%	24.84	4.19%
BATCH 1 (>6000)	13.2%	FRESH	100%	12.1	50%	9.5	55%	0.37	23.5%	24.87	0.85%
BATCH 3 (<1000)	23.3%	FRESH	65%	14.4	50%	13.3	25%	0.30	55.0%	25.02	1.04%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	10.9	50%	13.7	24%	0.78	35.0%	25.27	2.67%
BATCH 3 (<1000)	23.3%	SALINE	35%	10.9	50%	16.2	10%	1.41	5.0%	25.40	0.02%
BATCH 3 (<1000)	23.3%	FRESH	65%	10.9	50%	13.3	25%	0.78	35.0%	25.48	0.66%
BATCH 1 (>6000)	13.2%	FRESH	100%	12.1	50%	8.6	15%	0.37	23.5%	25.57	0.23%
BATCH 3 (<1000)	23.3%	SALINE	35%	14.4	50%	13.3	25%	0.78	35.0%	25.63	0.36%
BATCH 3 (<1000)	23.3%	SALINE	35%	14.4	50%	10.3	61%	0.78	35.0%	26.18	0.87%
BATCH 3 (<1000)	23.3%	FRESH	65%	14.4	50%	10.3	61%	0.30	55.0%	26.75	2.54%
BATCH 3 (<1000)	23.3%	SALINE	35%	14.4	50%	16.2	10%	0.78	35.0%	26.82	0.14%
BATCH 3 (<1000)	23.3%	SALINE	35%	14.4	50%	8.8	4%	0.30	55.0%	26.86	0.09%
BATCH 1 (>6000)	13.2%	FRESH	100%	14.4	50%	12.3	4%	0.37	23.5%	26.98	0.06%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	14.4	50%	9.7	65%	0.30	55.0%	27.18	11.35%

Flow Classification	Percent of Time Ambient Flow Occurs	Density Profile	Percent of Time Profile Occurs	Depth (m)	Percent of Time Depth Occurs	Effluent Flow (m^3/s)	Percent of Time Effluent Flow Occurs	Ambient Current Speed (m/s)	Percent of Time Current Speed Occurs	Flux-Averaged Initial Dilution	Probability of Occurrence
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	10.9	50%	18.9	1%	1.41	5.0%	27.20	0.02%
BATCH 3 (<1000)	23.3%	FRESH	65%	10.9	50%	10.3	61%	0.78	35.0%	27.30	1.62%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	10.9	50%	9.7	65%	0.78	35.0%	27.73	7.22%
BATCH 3 (<1000)	23.3%	SALINE	35%	14.4	50%	16.2	10%	0.30	55.0%	27.79	0.22%
BATCH 3 (<1000)	23.3%	FRESH	65%	14.4	50%	8.8	4%	0.30	55.0%	27.89	0.17%
BATCH 3 (<1000)	23.3%	SALINE	35%	14.4	50%	13.3	25%	0.30	55.0%	27.96	0.56%
BATCH 1 (>6000)	13.2%	FRESH	100%	14.4	50%	10.4	26%	0.37	23.5%	28.21	0.40%
BATCH 1 (>6000)	13.2%	FRESH	100%	12.1	50%	12.3	4%	0.76	63.0%	28.21	0.17%
BATCH 3 (<1000)	23.3%	FRESH	65%	10.9	50%	16.2	10%	1.41	5.0%	28.30	0.04%
BATCH 3 (<1000)	23.3%	FRESH	65%	10.9	50%	8.8	4%	0.78	35.0%	28.43	0.11%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	14.4	50%	7.9	10%	0.30	55.0%	28.70	1.75%
BATCH 1 (>6000)	13.2%	FRESH	100%	14.4	50%	9.5	55%	0.37	23.5%	28.89	0.85%
BATCH 3 (<1000)	23.3%	SALINE	35%	14.4	50%	10.3	61%	0.30	55.0%	28.96	1.37%
BATCH 3 (<1000)	23.3%	SALINE	35%	14.4	50%	8.8	4%	0.78	35.0%	29.00	0.06%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	10.9	50%	7.9	10%	0.78	35.0%	29.19	1.11%
BATCH 3 (<1000)	23.3%	SALINE	35%	10.9	50%	13.3	25%	1.41	5.0%	29.33	0.05%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	14.4	50%	18.9	1%	0.78	35.0%	29.34	0.11%
BATCH 1 (>6000)	13.2%	FRESH	100%	12.1	50%	10.4	26%	0.76	63.0%	29.46	1.08%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	10.9	50%	13.7	24%	1.41	5.0%	29.49	0.38%
BATCH 1 (>6000)	13.2%	FRESH	100%	14.4	50%	8.6	15%	0.37	23.5%	29.66	0.23%
BATCH 3 (<1000)	23.3%	FRESH	65%	10.9	50%	13.3	25%	1.41	5.0%	29.70	0.09%
BATCH 1 (>6000)	13.2%	FRESH	100%	12.1	50%	9.5	55%	0.76	63.0%	30.12	2.28%
BATCH 3 (<1000)	23.3%	FRESH	65%	14.4	50%	16.2	10%	0.78	35.0%	30.53	0.27%
BATCH 1 (>6000)	13.2%	FRESH	100%	12.1	50%	8.6	15%	0.76	63.0%	30.86	0.62%
BATCH 3 (<1000)	23.3%	SALINE	35%	14.4	50%	16.2	10%	1.41	5.0%	30.96	0.02%
BATCH 1 (>6000)	13.2%	FRESH	100%	12.1	50%	12.3	4%	1.13	12.0%	31.14	0.03%
BATCH 3 (<1000)	23.3%	FRESH	65%	10.9	50%	10.3	61%	1.41	5.0%	31.46	0.23%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	14.4	50%	13.7	24%	0.78	35.0%	31.83	2.67%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	10.9	50%	9.7	65%	1.41	5.0%	31.87	1.03%
BATCH 3 (<1000)	23.3%	FRESH	65%	14.4	50%	13.3	25%	0.78	35.0%	32.07	0.66%
BATCH 1 (>6000)	13.2%	FRESH	100%	12.1	50%	10.4	26%	1.13	12.0%	32.35	0.21%
BATCH 1 (>6000)	13.2%	FRESH	100%	14.4	50%	12.3	4%	0.76	63.0%	32.47	0.17%
BATCH 3 (<1000)	23.3%	FRESH	65%	10.9	50%	8.8	4%	1.41	5.0%	32.52	0.02%
BATCH 1 (>6000)	13.2%	FRESH	100%	12.1	50%	9.5	55%	1.13	12.0%	33.00	0.43%

Flow Classification	Percent of Time Ambient Flow Occurs	Density Profile	Percent of Time Profile Occurs	Depth (m)	Percent of Time Depth Occurs	Effluent Flow (m^3/s)	Percent of Time Effluent Flow Occurs	Ambient Current Speed (m/s)	Percent of Time Current Speed Occurs	Flux-Averaged Initial Dilution	Probability of Occurrence
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	10.9	50%	7.9	10%	1.41	5.0%	33.23	0.16%
BATCH 1 (>6000)	13.2%	FRESH	100%	12.1	50%	8.6	15%	1.13	12.0%	33.70	0.12%
BATCH 1 (>6000)	13.2%	FRESH	100%	14.4	50%	10.4	26%	0.76	63.0%	33.78	1.08%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	14.4	50%	18.9	1%	1.41	5.0%	33.94	0.02%
BATCH 3 (<1000)	23.3%	FRESH	65%	14.4	50%	10.3	61%	0.78	35.0%	34.06	1.62%
BATCH 1 (>6000)	13.2%	FRESH	100%	14.4	50%	9.5	55%	0.76	63.0%	34.48	2.28%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	14.4	50%	9.7	65%	0.78	35.0%	34.52	7.22%
BATCH 3 (<1000)	23.3%	SALINE	35%	10.9	50%	10.3	61%	1.41	5.0%	34.60	0.12%
BATCH 3 (<1000)	23.3%	SALINE	35%	14.4	50%	13.3	25%	1.41	5.0%	35.03	0.05%
BATCH 3 (<1000)	23.3%	FRESH	65%	14.4	50%	16.2	10%	1.41	5.0%	35.12	0.04%
BATCH 1 (>6000)	13.2%	FRESH	100%	14.4	50%	8.6	15%	0.76	63.0%	35.24	0.62%
BATCH 3 (<1000)	23.3%	FRESH	65%	14.4	50%	8.8	4%	0.78	35.0%	35.26	0.11%
BATCH 1 (>6000)	13.2%	FRESH	100%	14.4	50%	12.3	4%	1.13	12.0%	35.54	0.03%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	14.4	50%	7.9	10%	0.78	35.0%	36.08	1.11%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	14.4	50%	13.7	24%	1.41	5.0%	36.39	0.38%
BATCH 3 (<1000)	23.3%	FRESH	65%	14.4	50%	13.3	25%	1.41	5.0%	36.61	0.09%
BATCH 1 (>6000)	13.2%	FRESH	100%	14.4	50%	10.4	26%	1.13	12.0%	36.79	0.21%
BATCH 1 (>6000)	13.2%	FRESH	100%	14.4	50%	9.5	55%	1.13	12.0%	37.46	0.43%
BATCH 1 (>6000)	13.2%	FRESH	100%	14.4	50%	8.6	15%	1.13	12.0%	38.18	0.12%
BATCH 3 (<1000)	23.3%	SALINE	35%	10.9	50%	8.8	4%	1.41	5.0%	38.21	0.01%
BATCH 3 (<1000)	23.3%	FRESH	65%	14.4	50%	10.3	61%	1.41	5.0%	38.47	0.23%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	14.4	50%	9.7	65%	1.41	5.0%	38.90	1.03%
BATCH 3 (<1000)	23.3%	FRESH	65%	14.4	50%	8.8	4%	1.41	5.0%	39.58	0.02%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	14.4	50%	7.9	10%	1.41	5.0%	40.32	0.16%
BATCH 3 (<1000)	23.3%	SALINE	35%	14.4	50%	10.3	61%	1.41	5.0%	41.17	0.12%
BATCH 3 (<1000)	23.3%	SALINE	35%	14.4	50%	8.8	4%	1.41	5.0%	44.72	0.01%

Appendix F

Summary of Model Inputs and Results for a Variable Orifice, Multiport Diffuser

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Flow Classification	Percent of Time Ambient Flow Occurs	Density Profile	Percent of Time Profile Occurs	Depth (m)	Percent of Time Depth Occurs	Effluent Flow (m^3/s)	Percent of Time Effluent Flow Occurs	Ambient Current Speed (m/s)	Percent of Time Current Speed Occurs	Flux-Averaged Initial Dilution	Probability of Occurrence
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	10.9	50%	18.9	1%	0.03	5.0%	17.77	0.02%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	10.9	50%	18.9	1%	0.30	55.0%	17.91	0.17%
BATCH 3 (<1000)	23.3%	FRESH	65%	10.9	50%	16.2	10%	0.03	5.0%	18.31	0.04%
BATCH 3 (<1000)	23.3%	FRESH	65%	10.9	50%	13.3	25%	0.03	5.0%	18.54	0.09%
BATCH 3 (<1000)	23.3%	FRESH	65%	10.9	50%	16.2	10%	0.30	55.0%	19.06	0.42%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	10.9	50%	13.7	24%	0.03	5.0%	19.28	0.38%
BATCH 1 (>6000)	13.2%	FRESH	100%	12.1	50%	12.3	4%	0.07	1.5%	19.67	0.00%
BATCH 3 (<1000)	23.3%	FRESH	65%	10.9	50%	10.3	61%	0.03	5.0%	19.77	0.23%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	10.9	50%	9.7	65%	0.03	5.0%	19.93	1.03%
BATCH 3 (<1000)	23.3%	SALINE	35%	10.9	50%	8.8	4%	0.03	5.0%	19.96	0.01%
BATCH 3 (<1000)	23.3%	FRESH	65%	10.9	50%	8.8	4%	0.03	5.0%	20.30	0.02%
BATCH 3 (<1000)	23.3%	FRESH	65%	10.9	50%	13.3	25%	0.30	55.0%	20.37	1.04%
BATCH 1 (>6000)	13.2%	FRESH	100%	12.1	50%	10.4	26%	0.07	1.5%	20.39	0.03%
BATCH 3 (<1000)	23.3%	SALINE	35%	10.9	50%	10.3	61%	0.03	5.0%	20.44	0.12%
BATCH 3 (<1000)	23.3%	SALINE	35%	10.9	50%	13.3	25%	0.03	5.0%	20.55	0.05%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	10.9	50%	7.9	10%	0.03	5.0%	20.75	0.16%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	10.9	50%	13.7	24%	0.30	55.0%	20.75	4.19%
BATCH 1 (>6000)	13.2%	FRESH	100%	12.1	50%	9.5	55%	0.07	1.5%	20.87	0.05%
BATCH 3 (<1000)	23.3%	SALINE	35%	10.9	50%	16.2	10%	0.03	5.0%	21.06	0.02%
BATCH 1 (>6000)	13.2%	FRESH	100%	12.1	50%	8.6	15%	0.07	1.5%	21.40	0.01%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	14.4	50%	18.9	1%	0.03	5.0%	21.44	0.02%
BATCH 3 (<1000)	23.3%	FRESH	65%	14.4	50%	16.2	10%	0.03	5.0%	22.14	0.04%
BATCH 3 (<1000)	23.3%	SALINE	35%	14.4	50%	13.3	25%	0.03	5.0%	22.32	0.05%
BATCH 3 (<1000)	23.3%	FRESH	65%	14.4	50%	13.3	25%	0.03	5.0%	22.50	0.09%
BATCH 1 (>6000)	13.2%	FRESH	100%	14.4	50%	12.3	4%	0.07	1.5%	22.57	0.00%
BATCH 3 (<1000)	23.3%	SALINE	35%	14.4	50%	16.2	10%	0.03	5.0%	22.88	0.02%
BATCH 3 (<1000)	23.3%	SALINE	35%	14.4	50%	10.3	61%	0.03	5.0%	22.99	0.12%
BATCH 3 (<1000)	23.3%	SALINE	35%	14.4	50%	8.8	4%	0.03	5.0%	23.05	0.01%
BATCH 3 (<1000)	23.3%	FRESH	65%	10.9	50%	10.3	61%	0.30	55.0%	23.08	2.54%
BATCH 3 (<1000)	23.3%	SALINE	35%	10.9	50%	13.3	25%	0.78	35.0%	23.09	0.36%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	14.4	50%	18.9	1%	0.30	55.0%	23.09	0.17%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	10.9	50%	18.9	1%	0.78	35.0%	23.11	0.11%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	14.4	50%	13.7	24%	0.03	5.0%	23.37	0.38%
BATCH 1 (>6000)	13.2%	FRESH	100%	14.4	50%	10.4	26%	0.07	1.5%	23.46	0.03%

Flow Classification	Percent of Time Ambient Flow Occurs	Density Profile	Percent of Time Profile Occurs	Depth (m)	Percent of Time Depth Occurs	Effluent Flow (m^3/s)	Percent of Time Effluent Flow Occurs	Ambient Current Speed (m/s)	Percent of Time Current Speed Occurs	Flux-Averaged Initial Dilution	Probability of Occurrence
BATCH 3 (<1000)	23.3%	SALINE	35%	10.9	50%	10.3	61%	0.78	35.0%	23.50	0.87%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	10.9	50%	9.7	65%	0.30	55.0%	23.67	11.35%
BATCH 3 (<1000)	23.3%	SALINE	35%	10.9	50%	8.8	4%	0.78	35.0%	23.93	0.06%
BATCH 1 (>6000)	13.2%	FRESH	100%	14.4	50%	9.5	55%	0.07	1.5%	24.06	0.05%
BATCH 3 (<1000)	23.3%	FRESH	65%	14.4	50%	10.3	61%	0.03	5.0%	24.10	0.23%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	14.4	50%	9.7	65%	0.03	5.0%	24.32	1.03%
BATCH 3 (<1000)	23.3%	FRESH	65%	14.4	50%	16.2	10%	0.30	55.0%	24.60	0.42%
BATCH 1 (>6000)	13.2%	FRESH	100%	14.4	50%	8.6	15%	0.07	1.5%	24.71	0.01%
BATCH 3 (<1000)	23.3%	SALINE	35%	10.9	50%	16.2	10%	0.78	35.0%	24.71	0.14%
BATCH 3 (<1000)	23.3%	FRESH	65%	10.9	50%	8.8	4%	0.30	55.0%	24.75	0.17%
BATCH 3 (<1000)	23.3%	FRESH	65%	10.9	50%	16.2	10%	0.78	35.0%	24.81	0.27%
BATCH 3 (<1000)	23.3%	FRESH	65%	14.4	50%	8.8	4%	0.03	5.0%	24.82	0.02%
BATCH 1 (>6000)	13.2%	FRESH	100%	12.1	50%	12.3	4%	0.37	23.5%	24.92	0.06%
BATCH 3 (<1000)	23.3%	SALINE	35%	10.9	50%	13.3	25%	0.30	55.0%	25.08	0.56%
BATCH 3 (<1000)	23.3%	SALINE	35%	10.9	50%	16.2	10%	0.30	55.0%	25.22	0.22%
BATCH 3 (<1000)	23.3%	SALINE	35%	10.9	50%	16.2	10%	1.41	5.0%	25.28	0.02%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	14.4	50%	7.9	10%	0.03	5.0%	25.43	0.16%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	10.9	50%	7.9	10%	0.30	55.0%	26.05	1.75%
BATCH 3 (<1000)	23.3%	SALINE	35%	10.9	50%	10.3	61%	0.30	55.0%	26.17	1.37%
BATCH 3 (<1000)	23.3%	FRESH	65%	14.4	50%	13.3	25%	0.30	55.0%	26.28	1.04%
BATCH 3 (<1000)	23.3%	FRESH	65%	10.9	50%	13.3	25%	0.78	35.0%	26.71	0.66%
BATCH 3 (<1000)	23.3%	SALINE	35%	10.9	50%	8.8	4%	0.30	55.0%	26.75	0.09%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	14.4	50%	13.7	24%	0.30	55.0%	26.78	4.19%
BATCH 1 (>6000)	13.2%	FRESH	100%	12.1	50%	10.4	26%	0.37	23.5%	26.83	0.40%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	10.9	50%	13.7	24%	0.78	35.0%	27.15	2.67%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	10.9	50%	18.9	1%	1.41	5.0%	27.28	0.02%
BATCH 3 (<1000)	23.3%	SALINE	35%	14.4	50%	13.3	25%	0.78	35.0%	27.58	0.36%
BATCH 1 (>6000)	13.2%	FRESH	100%	12.1	50%	9.5	55%	0.37	23.5%	27.98	0.85%
BATCH 3 (<1000)	23.3%	SALINE	35%	14.4	50%	10.3	61%	0.78	35.0%	28.07	0.87%
BATCH 3 (<1000)	23.3%	SALINE	35%	14.4	50%	16.2	10%	0.78	35.0%	28.37	0.14%
BATCH 3 (<1000)	23.3%	SALINE	35%	14.4	50%	16.2	10%	0.30	55.0%	28.56	0.22%
BATCH 1 (>6000)	13.2%	FRESH	100%	14.4	50%	12.3	4%	0.37	23.5%	29.11	0.06%
BATCH 3 (<1000)	23.3%	FRESH	65%	10.9	50%	16.2	10%	1.41	5.0%	29.18	0.04%
BATCH 3 (<1000)	23.3%	SALINE	35%	14.4	50%	13.3	25%	0.30	55.0%	29.23	0.56%

Flow Classification	Percent of Time Ambient Flow Occurs	Density Profile	Percent of Time Profile Occurs	Depth (m)	Percent of Time Depth Occurs	Effluent Flow (m^3/s)	Percent of Time Effluent Flow Occurs	Ambient Current Speed (m/s)	Percent of Time Current Speed Occurs	Flux-Averaged Initial Dilution	Probability of Occurrence
BATCH 1 (>6000)	13.2%	FRESH	100%	12.1	50%	8.6	15%	0.37	23.5%	29.27	0.23%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	14.4	50%	18.9	1%	0.78	35.0%	29.43	0.11%
BATCH 3 (<1000)	23.3%	SALINE	35%	10.9	50%	13.3	25%	1.41	5.0%	29.44	0.05%
BATCH 3 (<1000)	23.3%	FRESH	65%	14.4	50%	10.3	61%	0.30	55.0%	29.73	2.54%
BATCH 3 (<1000)	23.3%	SALINE	35%	14.4	50%	8.8	4%	0.78	35.0%	29.75	0.06%
BATCH 3 (<1000)	23.3%	FRESH	65%	10.9	50%	10.3	61%	0.78	35.0%	30.33	1.62%
BATCH 1 (>6000)	13.2%	FRESH	100%	12.1	50%	12.3	4%	0.76	63.0%	30.44	0.17%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	14.4	50%	9.7	65%	0.30	55.0%	30.46	11.35%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	10.9	50%	9.7	65%	0.78	35.0%	31.09	7.22%
BATCH 3 (<1000)	23.3%	FRESH	65%	10.9	50%	13.3	25%	1.41	5.0%	31.21	0.09%
BATCH 1 (>6000)	13.2%	FRESH	100%	14.4	50%	10.4	26%	0.37	23.5%	31.29	0.40%
BATCH 3 (<1000)	23.3%	SALINE	35%	14.4	50%	10.3	61%	0.30	55.0%	31.36	1.37%
BATCH 3 (<1000)	23.3%	SALINE	35%	14.4	50%	16.2	10%	1.41	5.0%	31.42	0.02%
BATCH 3 (<1000)	23.3%	FRESH	65%	14.4	50%	16.2	10%	0.78	35.0%	31.48	0.27%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	10.9	50%	13.7	24%	1.41	5.0%	31.81	0.38%
BATCH 3 (<1000)	23.3%	FRESH	65%	14.4	50%	8.8	4%	0.30	55.0%	31.82	0.17%
BATCH 3 (<1000)	23.3%	FRESH	65%	10.9	50%	8.8	4%	0.78	35.0%	32.48	0.11%
BATCH 1 (>6000)	13.2%	FRESH	100%	14.4	50%	9.5	55%	0.37	23.5%	32.60	0.85%
BATCH 1 (>6000)	13.2%	FRESH	100%	12.1	50%	10.4	26%	0.76	63.0%	32.71	1.08%
BATCH 3 (<1000)	23.3%	SALINE	35%	14.4	50%	8.8	4%	0.30	55.0%	33.34	0.09%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	14.4	50%	7.9	10%	0.30	55.0%	33.43	1.75%
BATCH 3 (<1000)	23.3%	FRESH	65%	14.4	50%	13.3	25%	0.78	35.0%	33.69	0.66%
BATCH 1 (>6000)	13.2%	FRESH	100%	12.1	50%	12.3	4%	1.13	12.0%	33.69	0.03%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	14.4	50%	18.9	1%	1.41	5.0%	34.05	0.02%
BATCH 1 (>6000)	13.2%	FRESH	100%	14.4	50%	8.6	15%	0.37	23.5%	34.06	0.23%
BATCH 1 (>6000)	13.2%	FRESH	100%	12.1	50%	9.5	55%	0.76	63.0%	34.07	2.28%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	10.9	50%	7.9	10%	0.78	35.0%	34.11	1.11%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	14.4	50%	13.7	24%	0.78	35.0%	34.32	2.67%
BATCH 1 (>6000)	13.2%	FRESH	100%	14.4	50%	12.3	4%	0.76	63.0%	35.11	0.17%
BATCH 3 (<1000)	23.3%	SALINE	35%	14.4	50%	13.3	25%	1.41	5.0%	35.17	0.05%
BATCH 3 (<1000)	23.3%	FRESH	65%	10.9	50%	10.3	61%	1.41	5.0%	35.17	0.23%
BATCH 3 (<1000)	23.3%	SALINE	35%	10.9	50%	10.3	61%	1.41	5.0%	35.47	0.12%
BATCH 1 (>6000)	13.2%	FRESH	100%	12.1	50%	8.6	15%	0.76	63.0%	35.57	0.62%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	10.9	50%	9.7	65%	1.41	5.0%	35.98	1.03%

Flow Classification	Percent of Time Ambient Flow Occurs	Density Profile	Percent of Time Profile Occurs	Depth (m)	Percent of Time Depth Occurs	Effluent Flow (m^3/s)	Percent of Time Effluent Flow Occurs	Ambient Current Speed (m/s)	Percent of Time Current Speed Occurs	Flux-Averaged Initial Dilution	Probability of Occurrence
BATCH 1 (>6000)	13.2%	FRESH	100%	12.1	50%	10.4	26%	1.13	12.0%	36.08	0.21%
BATCH 3 (<1000)	23.3%	FRESH	65%	14.4	50%	16.2	10%	1.41	5.0%	36.27	0.04%
BATCH 3 (<1000)	23.3%	FRESH	65%	10.9	50%	8.8	4%	1.41	5.0%	37.46	0.02%
BATCH 1 (>6000)	13.2%	FRESH	100%	12.1	50%	9.5	55%	1.13	12.0%	37.50	0.43%
BATCH 1 (>6000)	13.2%	FRESH	100%	14.4	50%	10.4	26%	0.76	63.0%	37.63	1.08%
BATCH 3 (<1000)	23.3%	FRESH	65%	14.4	50%	10.3	61%	0.78	35.0%	38.02	1.62%
BATCH 1 (>6000)	13.2%	FRESH	100%	14.4	50%	12.3	4%	1.13	12.0%	38.53	0.03%
BATCH 3 (<1000)	23.3%	FRESH	65%	14.4	50%	13.3	25%	1.41	5.0%	38.57	0.09%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	14.4	50%	9.7	65%	0.78	35.0%	38.90	7.22%
BATCH 1 (>6000)	13.2%	FRESH	100%	12.1	50%	8.6	15%	1.13	12.0%	39.06	0.12%
BATCH 1 (>6000)	13.2%	FRESH	100%	14.4	50%	9.5	55%	0.76	63.0%	39.13	2.28%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	10.9	50%	7.9	10%	1.41	5.0%	39.20	0.16%
BATCH 3 (<1000)	23.3%	SALINE	35%	10.9	50%	8.8	4%	1.41	5.0%	39.29	0.01%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	14.4	50%	13.7	24%	1.41	5.0%	39.39	0.38%
BATCH 3 (<1000)	23.3%	FRESH	65%	14.4	50%	8.8	4%	0.78	35.0%	40.54	0.11%
BATCH 1 (>6000)	13.2%	FRESH	100%	14.4	50%	8.6	15%	0.76	63.0%	40.78	0.62%
BATCH 1 (>6000)	13.2%	FRESH	100%	14.4	50%	10.4	26%	1.13	12.0%	41.15	0.21%
BATCH 3 (<1000)	23.3%	SALINE	35%	14.4	50%	10.3	61%	1.41	5.0%	41.52	0.12%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	14.4	50%	7.9	10%	0.78	35.0%	42.45	1.11%
BATCH 1 (>6000)	13.2%	FRESH	100%	14.4	50%	9.5	55%	1.13	12.0%	42.71	0.43%
BATCH 3 (<1000)	23.3%	FRESH	65%	14.4	50%	10.3	61%	1.41	5.0%	43.20	0.23%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	14.4	50%	9.7	65%	1.41	5.0%	44.12	1.03%
BATCH 1 (>6000)	13.2%	FRESH	100%	14.4	50%	8.6	15%	1.13	12.0%	44.42	0.12%
BATCH 3 (<1000)	23.3%	FRESH	65%	14.4	50%	8.8	4%	1.41	5.0%	45.84	0.02%
BATCH 3 (<1000)	23.3%	SALINE	35%	14.4	50%	8.8	4%	1.41	5.0%	46.04	0.01%
BATCH 2 (6000>Q>1000)	63.5%	FRESH	100%	14.4	50%	7.9	10%	1.41	5.0%	47.84	0.16%

Appendix G

Performance of Tee Diffusers in Shallow Water with Crossflow, Seo, I.W.; Kim, H.S.; Yu, D.; and D.S. Kim, 2001.

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PERFORMANCE OF TEE DIFFUSERS IN SHALLOW WATER WITH CROSSFLOW

By Il Won Seo,[1] Hong Sik Kim,[2] Daeyoung Yu,[3] and Dong Soo Kim[4]

ABSTRACT: The dilution and plume trajectory of the tee diffuser has been investigated via the collection of experimental data for a wide range of ambient current conditions. A new dilution equation in which the stagnation effect between ambient current and diffuser discharge is assumed to be a function of the ratio of the ambient momentum to the discharge momentum, m_r, is proposed modifying the conventional theory of Adams that significantly underpredicts mixing for large m_r. A simple equation for the plume trajectory including the dependency of the momentum ratio is also derived by dimensional analysis. Experimental results on the near field dilution show that when $m_r < 1$ the dilution decreases with m_r, whereas when $m_r > 1$ it increases with increasing m_r, and approaches the stagnant water dilution for very large values of m_r. The equation is applied to aid the preliminary design of a diffuser discharging heated water from a power station in Korea.

INTRODUCTION

Submerged multiport diffusers are generally thought to be the most effective means for handling the rapid initial dilution of thermal discharges. A multiport diffuser is a linear diffusion structure that consists of a manifold containing many closely spaced ports through which heated water is discharged, at high velocity, in the form of a turbulent jet into the receiving water. By discharging the heated water through a large number of ports at a high velocity, the total area available for jet entrainment is increased, thus, rapidly diluting the discharged water. Submerged thermal diffusers are characterized by the low buoyancy of the discharge under shallow water conditions.

A number of basic diffuser types for a thermal discharge have been proposed (Jirka 1982; Miller and Brighouse 1984; Akar and Jirka 1991). As shown in Fig. 1, these diffusers are distinguished by an angle γ between the ambient current and the diffuser axis. A tee diffuser is a diffuser in which the diffuser alignment is parallel to the ambient cross flow ($\gamma = 0°$). Tee diffusers have the advantage of directing the thermal effluent away from the shoreline, and they perform equally well when the flow is in either direction. Because of certain advantages, tee diffusers have been used as the diffusion structure for heated water which is discharged from large steam electric generating stations in coastal environments (Miller and Brighouse 1984). The dilution characteristics and the plume trajectory of the tee diffusers have been studied by several investigators (Adams 1972, 1982; Lee et al. 1977; Lee and Jirka 1980; Jirka 1982; Lee 1984; Lee and Greenberg 1984) in order to provide basic information for the siting and design of the diffuser. Most of the prediction models for initial dilution of the tee diffusers in shallow water, except the semianalytic vortex model developed by Lee and Greenberg (1984), have been derived using energy and momentum equations in two dimensions. However, these models have not been rigorously tested against a wide range of field and experimental data. Most previous analyses of the dilution characteristics of tee diffusers have focused on conditions in which the ratio of the momentum of ambient current to the discharge momentum is small, usually less than 1. However, in some coastal areas where nuclear power plants are located, including Korean nuclear power plants, it is possible for combinations of strong tidal currents and relatively deep water depths to generate very large momentum ratios. For example, the current velocity in the coastal regions where some of the Korean nuclear power plants are located ranges from 40–80 cm/s, and the average water depth is from 10 to 20 m. Assuming that a typical tee diffuser with a length of 200 m, which has a discharge of 60 m^3/s with the discharging velocity of 3 m/s, has 100 ports with a diameter of 0.5 m, then the momentum of the ambient current in this coastal region becomes ten times as large as the momentum of the thermal discharge. This momentum ratio value is very large compared with typical values of the momentum ratio under which most of the previous studies on tee diffusers have been performed. It has been reported that the dilution equation for tee diffusers leads to inaccurate predictions, especially in strong ambient momentum conditions (Miller and Brighouse 1984; Seo and Kim 1998).

The objective of this study is to investigate the characteristics of the near field dilution and plume trajectory for tee diffusers over a wide range of momentum ratios. In this study, extensive experimental works have been carried out in order to collect mixing and dilution data for the tee diffuser. The measured data were used to test the existing dilution equations as well as to derive the new equation for the near field dilution and the plume trajectory over the complete range of momentum ratios.

EVALUATION OF PREVIOUS STUDIES

Dilution in Near Field

It has been reported that the near field dilution of the tee diffuser tends to decrease with increasing ambient current (Lee et al. 1977; Adams 1982; Li and Lee 1991). Adams (1982) presented two explanations for the reduction in dilution of tee diffusers when a cross flow exists. One is that the cross flow deflects the jets, causing interference between individual jets, thus reducing the effective jet cross-sectional area. A second explanation is that the ambient current and the effluent discharge from the diffuser collectively create a region of high pressure, which is represented by an increase in water surface elevation on the downstream side of the diffuser plume. This increased pressure is associated with partial stagnation of the ambient current, thus restricting the ambient water to entrain into the effluent plume boundary.

Adams (1972, 1982) first derived a dilution equation for a tee diffuser by applying Bernoulli equations for the approach

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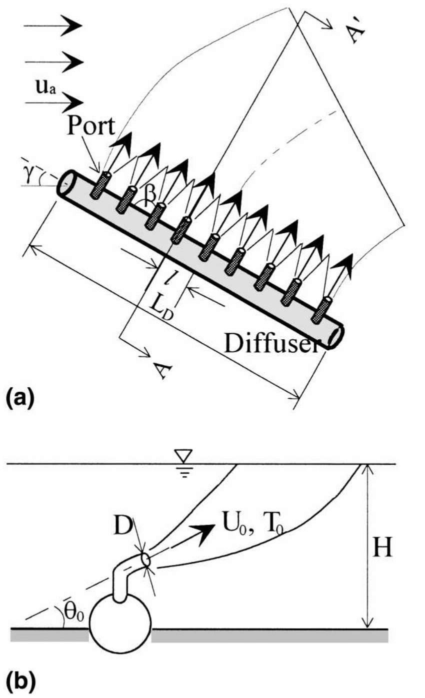

FIG. 1. Definition Sketch of Multiport Diffuser: (a) Alignment of Diffuser; (b) Diagram of A-A′ Section

and accelerating flows and a momentum equation for the pressure discontinuity across the diffuser axis. For the tee diffuser, he considered momentum loss caused by stagnation of the ambient current in a momentum equation for sections between the back and the front of the diffuser. The assumptions introduced are that the turbulent side entrainment in the near field region can be neglected, and the induced flow from behind the diffuser is separated from the ambient fluid at the ends of the diffuser. Combining energy and momentum equations, he derived the dilution equation for tee diffusers in the near field as

$$\frac{S_t}{S_0} = 1 - c_d m_r \tag{1}$$

where c_d = coefficient associated with the stagnation effect of the ambient current. m_r is the momentum ratio of the ambient current to the effluent discharge, which is expressed as

$$m_r = \frac{u_a^2 H}{U_0^2 B} \tag{2}$$

where u_a = ambient current; H = depth of the ambient water; and U_0 = velocity of the effluent discharge. B is the width of an equivalent slot diffuser, which is defined as

$$B = \frac{A_0}{l} \tag{3}$$

where A_0 = cross-sectional area of an individual port; and l = port spacing. S_0 is dilution in the case of stagnant ambient, which is given (Adams 1982) as

$$S_0 = \sqrt{\frac{H \cos \theta_0}{2B}} \tag{4}$$

where θ_0 = angle between the port and sea bed, which is usually taken to be $\theta_0 < 45°$.

In (1), the stagnation effect is incorporated into the coefficient c_d, which is treated as a constant by Adams (1972, 1982). Thus, if c_d is treated as a constant, predictions given by (1) show a monotonous decrease with increasing ambient momentum. Adams and Stolzenbach (1977), in order to obtain a better fit to the experimental data, proposed the following empirical equation

$$\frac{S_t}{S_0} = (1 + 5m_r)^{-1/2} \tag{5}$$

Lee et al. (1977) suggested a different empirical relation for the near field dilution for the tee diffuser, depending upon the m_r. In cases where $m_r < 0.1$, the authors postulated that the near field dilution is not affected by the ambient current, whereas in cases where $m_r > 0.1$, the near field dilution can be considerably lower than that of the stagnant water, and they suggested a linear relation between dilution and the momentum ratio.

Eqs. (1) and (5), and the relations suggested by Lee et al. (1977), are plotted against the available data in Fig. 2. Most of the data was collected from experiments involving a tee diffuser in which $\theta_0 = 0°$, except for the data reported by Seo and Kim (1998), in which the dilution data was collected from experiments involving tee diffusers with $\theta_0 = 22.5°$. For regions of weak to moderately strong currents, $m_r < 1$, (1) for various constant values of c_d gives a poor fit whereas (5) provides a better fit. This is natural, since (5) is empirically derived by fitting it to some of the data in the region of $m_r < 1$ shown in Fig. 2. The relation suggested by Lee et al. (1977) also provides a poor fit. This is because their relation was obtained by limited data sets, i.e., data by Acres (1974) and Lee et al. (1977). For regions involving significantly strong currents, $m_r > 1$, predictions by all of the existing equations are far off the actual measured data. The measured dilution for the tee diffuser shows that, when $m_r < 1$, the dilution decreases with m_r, whereas when $m_r > 1$, it increases back as m_r increases further. However, all existing equations provide predictions of monotonous decreasing dilution with increasing m_r. Moreover, Adams' theoretical equation with constant values of c_d gives a negative dilution when m_r is large, which is physically impossible.

It is generally thought that the discrepancies between predictions and measurements arise from the fact that the mixing process in the tee diffuser has not been correctly modeled, especially in the range where strong ambient momentum exists. The stagnation effect of the tee diffuser which results from

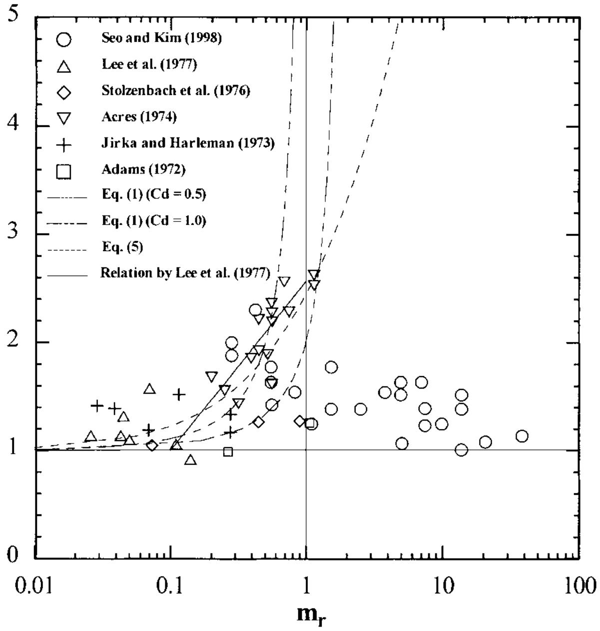

FIG. 2. Comparison of Existing Dilution Equations with Observed Dilution

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a 90° mismatch between the ambient current and diffuser effluent discharge is known to be dependent upon momentum ratio, m_r. However, existing equations, including Adams' theoretical equation, do not incorporate this changing nature of the stagnation effect into their model. Li and Lee (1991), based on the results of their numerical study using a two-dimensional model of the tee diffuser, maintained that when the cross current is strong, the momentum source representation in which they approximated the jets as a line source of momentum in a two-dimensional flow cannot account for the highly complicated three-dimensional nonlinear interaction between the jet group and the crossflow. For very strong crossflow, individual jets from each port are deflected and overlap significantly, so the control volume approach breaks down entirely.

Plume Trajectory

The prediction of the plume trajectory of the tee diffuser under various ambient current conditions is necessary in estimating the distance of the thermal plume from the shoreline. Lee et al. (1977) developed a theory calculating the plume trajectory of the tee diffuser in a crossflow based on a vertically fully mixed assumption. They integrated the continuity and momentum equations in both the axial and normal directions of the plume in which the bottom friction and the bending force due to ambient momentum are incorporated. They verified the predicted plume trajectory using the experimental data collected by Acres (1974) and Lee et al. (1977). Based on both theoretical prediction and experimental results, they postulated that the larger the value of m_r, the more the plume is deflected. They also found that a larger assumed value of blocking coefficient, which is associated with the bending force in the normal momentum equation, leads to a more pronounced plume deflection. Even though a satisfactory agreement between the computed plume trajectory and the observed data is obtained, their study was performed for conditions under weak to moderately strong momentum ratios, i.e., $m_r < 1$. Therefore, a comprehensive study for a wide range of momentum ratios is needed to properly predict the plume trajectory of the tee diffuser.

PROPOSED THEORY

In this paper, to correctly explain the dilution behavior of the tee diffuser for a complete range of momentum ratios, an improved model modified from Adams' (1972, 1982) theory is proposed. In the proposed model, unlike Adams' theory, the stagnation effect between ambient current and diffuser effluent discharge is assumed to be a decreasing function of the momentum ratio, m_r. Physically, these assumptions indicate that, when the momentum ratio is small, the blocking effect produced by the effluent discharge is dominant, and the reduction in dilution gradually increases. So, for this region, as modeled by Adams (1972, 1982), back entrainment behind the diffuser plays a major role in the mixing of the effluent discharge. However, when the cross flow momentum becomes stronger than the discharge momentum, i.e., $m_r > 1$, the cross flow begins to overcome the blocking effect of the effluent plume, tending to be entrained into the effluent plume, and as a result, direct entrainment from the cross flow now plays an important role in the dilution process. Therefore, when $m_r > 1$, as the ambient momentum increases, dilution begins to increase.

As a relation between c_d and the ratio of jet velocity to the ambient velocity, Subramanya and Porey (1984) suggested an exponential function based on the experimental data of the three-dimensional jet in crossflow. In this study, even though the mechanics of the two-dimensional plume in shallow water are quite different from the three-dimensional jet dealt with in Subramanya and Porey (1984), it is assumed that c_d is expressed as the following functional form:

$$c_d = a \exp(-b m_r^c) \tag{6}$$

Substituting (6) into (1) yields

$$\frac{S_0}{S_t} = \frac{1}{1 - [a \exp(-b m_r^c)] m_r} \tag{7}$$

In this study, constants in (7) are determined from the experimental data.

LABORATORY EXPERIMENTS

The laboratory model was constructed in a 20-m-long, 4.9-m-wide, and 0.6-m-deep flume in the Hydraulics Laboratory at Seoul National University, Seoul, Korea. A schematic diagram of the laboratory flume and the experimental setup is shown in Fig. 3. The model of the diffuser, analyzing the geometry of diffusers and the conditions of heated water discharged from power plants operating presently, is manufactured to indicate the representative characteristics (Jirka 1982). The principles of hydraulic similitude were used as guidelines in determining the appropriate scale of the model. Among the many similitude principles that are relevant to the modeling of thermal discharge, the similitude of the densimetric Froude number is used in this study, because Reynolds similarity is usually relaxed if the flow in the model is turbulent and the phenomenon of surface heat discharge is usually not of importance near the discharge, so that if the model covers mainly the nearfield area, it may be ignored (Fischer et al. 1979). Here, the densimetric Froude number is defined as $\mathsf{F}_j = (U_0/\sqrt{g_0' D})$, where $g_0' = (\Delta\rho/\rho)g$; $\Delta\rho$ = density difference between discharging fluid and ambient fluid; and g = gravitational acceleration. The total length of the model diffuser, L_D, is 120 cm. The inner diameter of the port is 0.43 cm with a variable spacing of 4.0–12.0 cm. The angle between the port and the channel bottom is selected to be 22.5°.

Flow rates were measured using an electromagnetic flow meter. Water temperature was measured using CC-type thermocouple sensors, installed on the instrument carriage. The thermocouple sensors were connected to a 40-channel data logger in which measured temperatures are stored in digital form. The thermal effluent was supplied from a specially manufactured hot water bath, which consisted of a preheating bath and a constant head tank, which provided hot water of constant temperature and flow rate. The discharge from the constant head tank to the diffuser pipe was measured using an electromagnetic flow meter.

Three sets of data were collected in connection with the experimental program. The ranges of experimental parameters

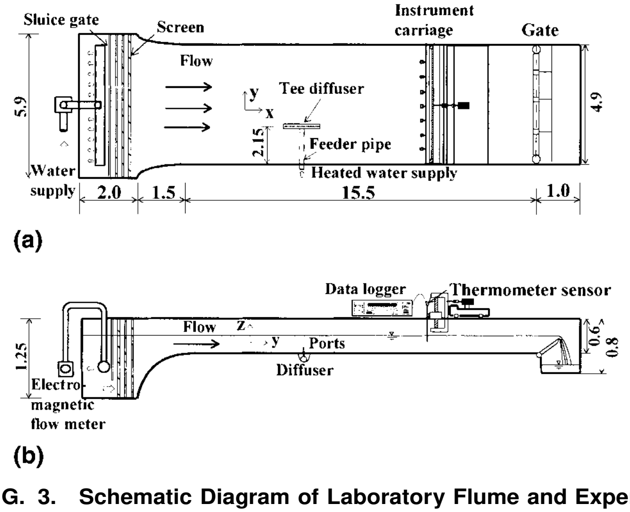

FIG. 3. Schematic Diagram of Laboratory Flume and Experimental Setup (Unit: m): (a) Plan View; (b) Side View

for series TS, TD, and TT are listed in Tables 1–3. These sets were arranged to study the effects of port spacing on the mixing of the tee diffuser. In this study, the experimental approach is focused on the conditions of strong ambient momentum, which is relevant to the oceanographic conditions of the Korean shoreline, where the existing nuclear power plants are located. Furthermore, whole experiments were conducted without distorting the physical mixing processes in real situations.

The assumption that the flow is vertically well mixed, and as a result, that buoyancy may be neglected, is considered using a criterion proposed by Jirka (1982), in which a densimetric Froude number based on water depth, mixed flow velocity, ambient velocity, and density difference at the diffuser is greater than unity. This criterion for a small slot width in an ambient current is given as follows:

$$\phi = \frac{m_0}{j_0^{2/3}H} + \frac{m_a + m_0 \cos \theta_0}{j_0^{2/3}H} \geq \phi_c \qquad (8)$$

in which m_a, m_0 = momentum fluxes per unit length of ambient and discharge fluid, respectively; and j_0 = buoyancy fluxes per unit length of discharge fluid. Jirka suggested that the value of ϕ_c is approximately 0.54.

TABLE 1. Experimental Parameters for TS Series (B = 0.0375)

Case (1)	H (cm) (2)	u_a (cm/s) (3)	U_0 (cm/s) (4)	m_r (5)	ϕ (6)	S_t (7)
TS301	10.0	18.8	56.8	30.2	86.3	9.5
TS302	10.0	15.3	57.3	19.6	59.9	9.5
TS303	11.0	11.8	63.6	10.5	37.9	8.7
TS304	19.0	1.6	95.9	0.14	9.78	11.1
TS305	15.0	3.9	80.2	0.99	10.2	10.5
TS306	12.0	8.6	71.8	4.77	19.7	9.1
TS307	13.0	7.8	74.4	3.93	17.7	10.0
TS308	13.0	6.8	74.7	2.94	15.3	10.5
TS309	14.0	5.5	77.7	1.93	12.3	11.8
TS310	14.0	5.0	76.2	1.69	11.6	9.5
TS311	15.0	4.5	84.4	1.16	11.1	9.5
TS312	15.0	3.9	82.0	0.96	12.6	10.0
TS313	16.0	3.5	82.9	0.80	11.6	10.0
TS314	16.0	3.1	81.7	0.65	13.1	10.0
TS315	17.0	2.5	88.3	0.36	12.7	9.5
TS316	18.0	2.2	92.0	0.28	8.21	10.5
TS317	20.0	1.3	97.0	0.10	9.57	10.5
TS601	15.8	6.3	34.7	14.3	15.3	12.5
TS602	17.2	6.4	35.4	15.5	15.3	13.3
TS603	17.0	6.9	35.4	18.0	17.6	14.3
TS604	17.4	7.3	35.4	20.2	19.0	13.3
TS605	17.5	7.7	35.7	22.7	21.1	13.3
TS606	17.0	7.9	51.5	11.0	19.4	11.1
TS607	13.9	9.2	53.7	11.1	25.2	10.5
TS608	14.2	9.4	51.1	13.4	26.5	10.0
TS609	14.2	9.8	50.6	14.5	27.9	9.1
TS610	14.2	10.2	47.5	18.0	30.5	12.5
TS611	14.3	10.4	55.4	14.0	30.8	11.8
TS612	11.3	15.0	46.0	33.2	63.7	10.0
TS613	11.2	15.7	46.2	35.7	68.6	9.5
TS614	11.3	16.0	46.5	37.0	70.7	10.5
TS615	11.0	17.0	44.7	43.5	81.4	9.5
TS616	10.5	15.1	46.1	31.2	65.2	9.1
TS617	9.0	16.0	35.7	49.8	83.4	8.7
TS618	9.0	16.4	35.9	52.0	87.0	8.7
TS619	9.0	17.2	35.0	60.0	96.2	8.7
TS620	9.3	19.4	32.1	92.9	126.1	9.5
TS621	9.2	20.5	35.8	83.3	132.0	9.5
TS622	15.1	0.8	104.1	0.03	13.5	10.5
TS623	15.8	0.9	51.5	0.12	5.11	10.5
TS624	16.1	1.0	51.3	0.16	5.05	9.5
TS625	16.3	1.2	50.4	0.23	4.94	8.7
TS626	16.3	1.3	49.8	0.31	4.96	10.5
TS627	16.0	1.7	54.5	0.41	5.91	11.1
TS628	16.0	1.0	55.2	0.14	5.44	8.0
TS629	16.0	0.9	54.7	0.13	5.41	9.5
TS630	16.0	0.8	54.6	0.09	5.30	9.1
TS631	15.8	0.7	55.5	0.07	5.45	8.7
TS632	9.0	21.4	33.2	103.1	150.6	8.7

TABLE 2. Experimental Parameters for TD Series (B = 0.0194)

Case (1)	H (cm) (2)	u_a (cm/s) (3)	U_0 (cm/s) (4)	m_r (5)	ϕ (6)	S_t (7)
TD401	15.0	11.3	59.0	30.0	49.5	16.7
TD402	14.8	0.5	58.8	0.05	5.19	14.3
TD403	15.8	0.7	62.4	0.10	5.31	14.3
TD404	17.0	1.8	65.7	0.69	8.46	12.5
TD405	18.0	2.1	70.2	0.86	8.87	12.5
TD406	18.0	2.2	69.9	0.95	8.84	14.3
TD407	19.0	2.4	73.2	1.17	10.2	16.7
TD408	18.8	2.8	73.7	1.54	11.1	14.3
TD409	19.9	3.1	74.6	1.91	11.3	20.0
TD410	20.1	9.8	74.3	19.2	46.5	18.2
TD411	21.0	3.8	75.0	2.99	13.5	13.3
TD412	21.2	4.4	78.8	3.68	15.8	13.3
TD413	22.1	5.1	80.6	4.89	18.1	16.7
TD414	22.0	5.5	80.1	5.74	19.6	18.2
TD415	23.3	6.0	84.9	6.32	21.7	22.2
TD416	23.3	6.3	79.9	8.10	23.4	16.7
TD417	24.2	6.8	85.1	8.54	25.3	20.0
TD418	25.0	7.4	86.7	9.95	27.8	16.7
TD419	18.2	1.6	65.1	0.64	8.25	13.3
TD420	18.2	1.3	69.0	0.38	8.30	13.3
TD421	18.9	1.0	70.4	0.20	7.75	12.5
TD422	18.8	0.6	70.2	0.07	7.36	16.7

TABLE 3. Experimental Parameters for TT Series (B = 0.0133)

Case (1)	H (cm) (2)	u_a (cm/s) (3)	U_0 (cm/s) (4)	m_r (5)	ϕ (6)	S_t (7)
TT501	15.2	10.0	63.8	30.8	70.0	20.0
TT502	15.5	0.4	64.7	0.05	7.06	14.3
TT503	16.0	0.6	67.4	0.11	7.28	14.3
TT504	16.0	1.1	69.0	0.33	7.77	15.4
TT505	17.0	1.4	71.4	0.51	7.96	16.7
TT506	17.0	1.6	71.9	0.69	8.27	16.7
TT507	18.1	1.8	76.3	0.85	9.36	18.2
TT508	18.0	1.7	73.0	0.85	8.71	14.3
TT509	19.0	2.2	75.7	1.35	9.59	20.0
TT510	18.9	2.6	76.4	1.75	10.5	15.4
TT511	20.0	2.8	77.9	2.10	11.2	18.2
TT512	20.1	8.8	76.5	21.8	48.7	22.2
TT513	20.9	3.5	81.5	3.13	13.3	22.2
TT514	21.2	3.8	81.7	3.88	14.5	22.2
TT515	22.2	4.5	84.7	5.06	16.8	20.0
TT516	21.8	4.9	81.4	6.65	19.8	20.0
TT517	23.0	5.4	89.6	6.84	21.5	20.0
TT518	23.3	5.7	88.1	8.10	23.2	22.2
TT519	24.5	6.1	90.7	9.04	24.7	22.2
TT520	26.0	6.3	90.8	10.4	25.6	33.3

ANALYSIS OF EXPERIMENT RESULTS

Near Field Dilution

The observed dilutions for series TS, TD, and TT are listed in Tables 1–3. Among a number of experimental cases, photographs of the plume behavior at the water surface from different typical groups of m_r are shown in Fig. 4. In this figure, the cross current is flowing from left to right. When m_r is smaller than 1, Fig. 4(a) shows that, as explained by Adams (1972, 1982) and Li and Lee (1991), the effluent discharge of the multiple jets restricts the ambient flow to be entrained into the plume boundary. Li and Lee (1991) maintained that the pressure hill is developed at the source line due to the imparted momentum, leading to the formation of the stagnation region near the windward end of the multiple jets. This blocking ef-

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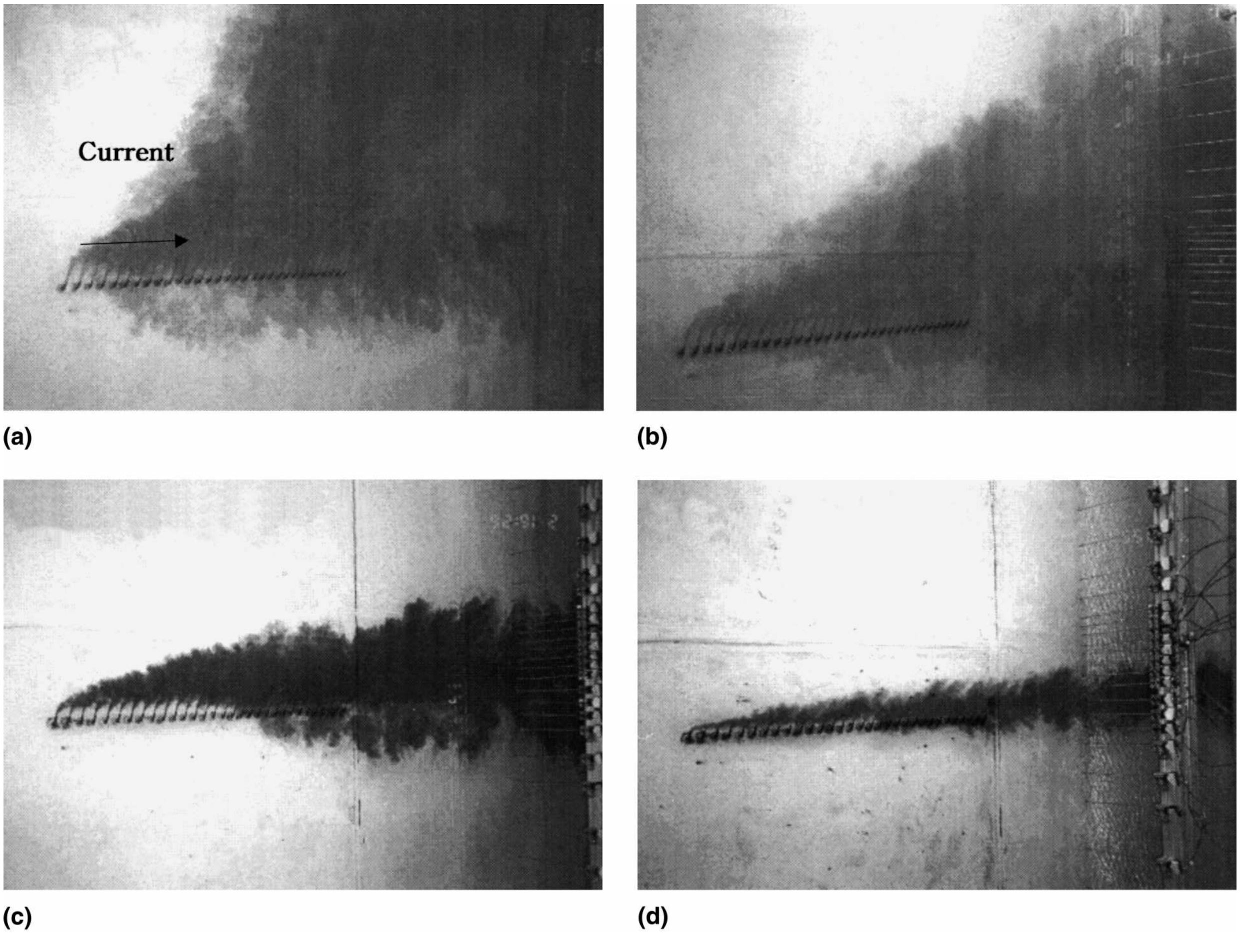

FIG. 4. Photographs of Plume Behavior at Water Surface: (a) Case TS316 ($m_r = 0.28$); (b) Case TS312 ($m_r = 0.96$); (c) Case TS607 ($m_r = 11.1$); (d) Case TS632 ($m_r = 103.1$)

fect remains dominant when m_r is less than 1. However, as shown in Figs. 4(c and d), when the cross flow momentum becomes stronger than the discharge momentum, i.e., $m_r > 1$, the cross flow begins to overcome the blocking effect of the effluent plume, tending to be entrained into the effluent plume. For very large m_r, as shown in Figs. 4(c and d), individual jets from each port are deflected and overlap significantly. For these cases, unlike the turbulent jets and plumes, the effluent discharge of the multiple jets loses most of its initial momentum. Thus, the effluent plume from the diffuser is transported by the ambient flow and, at the same time, it is spread by passive dispersion caused by the ambient current. The blocking effect of the effluent plume is now completely overcome, and the discharge momentum has no effect on the mixing of the plume.

The water surface isothermal contours from typical groups of m_r are shown in Fig. 5. In this figure, the isothermal contours are lines of $\Delta T/\Delta T_0$, in which $\Delta T = T - T_b$, and $\Delta T_0 = T_0 - T_b$. Here T = local temperature at the points of measurement; T_b = background temperature of the ambient water; and T_0 = initial temperature of the effluent discharge from each port of the diffuser. The plume trajectories are also drawn in this figure. The same arguments on the mechanics of plume for a various range of m_r can be drawn from this figure as Fig. 4.

Results of the experiments reveal that the effects of port spacing on the mechanics of the tee diffuser are not significant, provided the condition of vertically well-mixed flow is achieved. In this study, for most of the experimental cases, the criterion given by (8) was satisfied, as shown in Tables 1–3. Among a number of experimental cases, the vertical distributions of the excess temperature at the near field from different typical groups of m_r are shown in Fig. 6. These temperature data were collected at points of $x/L_D = 1.0–1.5$; $y/L_D = 0.1–1.7$. As shown in this figure, at the near field, the temperature distributions of the effluent plume under various cross flow conditions remain approximately uniform in the vertical direction.

The observed dilution, which is normalized by the stagnant water dilution, along with the existing experimental data are plotted in Fig. 7. The observed dilution is defined as the measured discharge temperature rise divided by the highest closed isotherm at the water surface of a scale greater than the port spacing to eliminate the consideration of local hot spots caused by single jets. As described earlier, it is clearly shown in Fig. 7 that when $m_r < 1$, dilution decreases with m_r. However, in the range where $m_r > 1$, it increases with increasing m_r and approaches stagnant water dilution, S_0, for a very large value of m_r. As shown in this figure and Fig. 2, predictions using existing equations by Adams (1982) and Adams and Stolzenbach (1977) are far off the actual measured data, especially for the region where $m_r > 1$.

In this study, constants in (7) were determined by fitting (7) to the available data to yield the following equation:

$$\frac{S_0}{S_t} = \frac{1}{1 - [60\ \exp(-5.0 m_r^{0.2})] m_r} \tag{9}$$

This equation has a functional form that is relevant to the distribution characteristics of the measured dilution. Eq. (9) is also plotted in Fig. 7. As shown in this figure, this equation is in excellent agreement with the measured dilution.

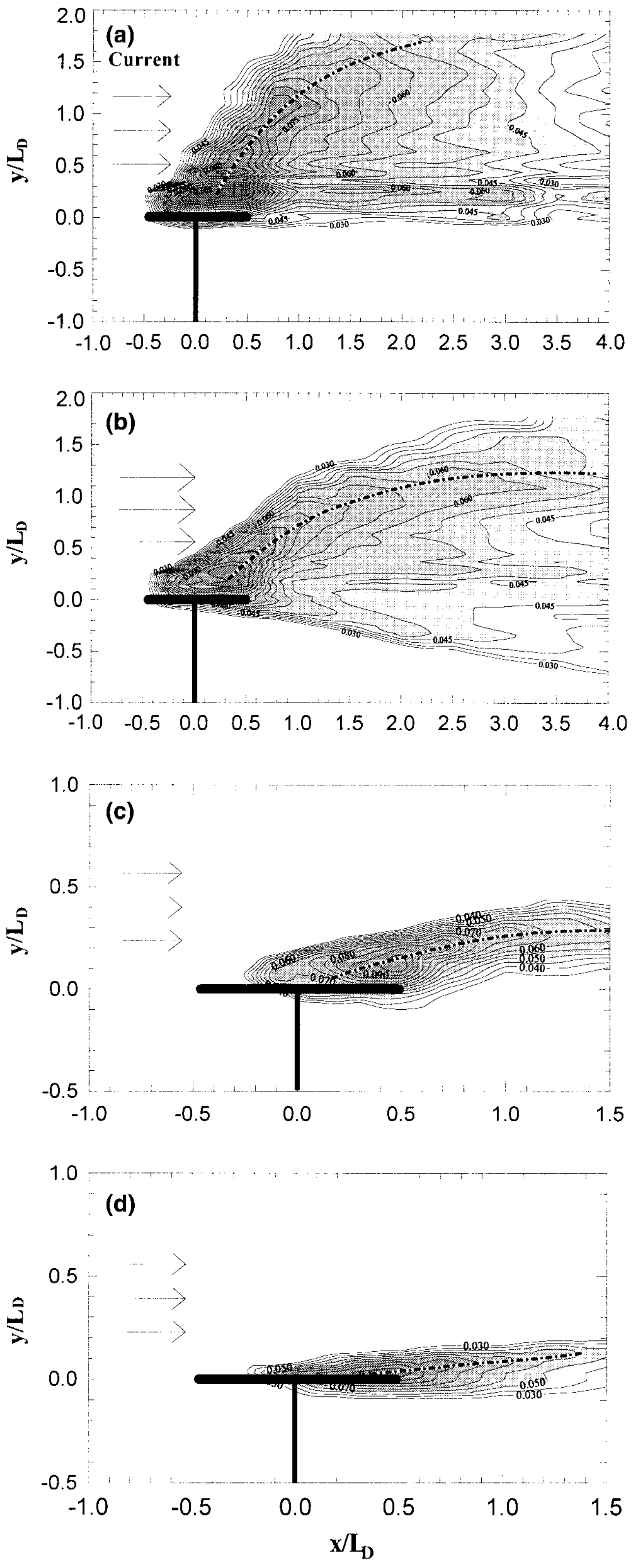

FIG. 5. Nondimensional Equitemperature Contours at Water Surface: (a) Case TS316 ($m_r = 0.28$); (b) Case TS312 ($m_r = 0.96$); (c) Case TS607 ($m_r = 11.1$); (d) Case TS632 ($m_r = 103.1$)

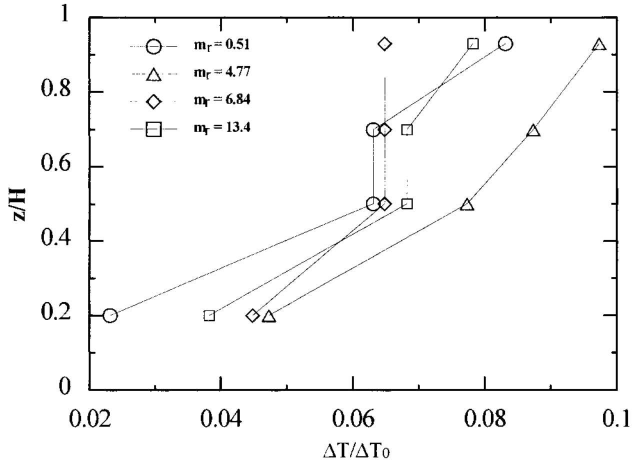

FIG. 6. Vertical Temperature Distributions at the Near Field

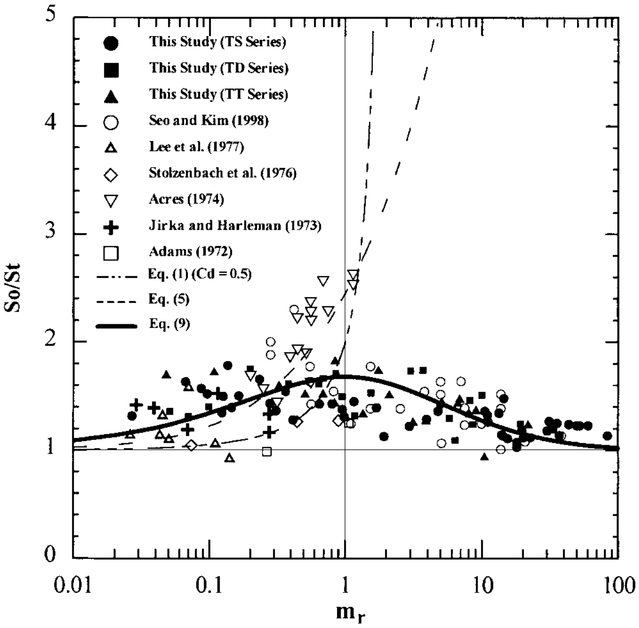

FIG. 7. Comparison of Observed Dilution with Predictions

As shown in Figs. 4(c and d), for very large m_r, effluent discharge of the multiple jets is advected by the ambient current after it loses most of its initial momentum, which is perpendicular to the ambient flow. Thus, the plume for very large m_r can be treated as those from a continuous line source with no momentum. The width of the plume spreading from a continuous source in two dimensions is proportional to $\sqrt{2\varepsilon_y(x/u_a)}$ (Fischer et al. 1979), where x is the longitudinal distance in the direction of the ambient current. If the ambient diffusion coefficient, ε_y, is expected to be proportional to u^*H, where u^* is the shear velocity, then the width of the plume at the end of the diffuser (near field) can be approximated as $k\sqrt{HL_D}$, where k is a coefficient related to the effects of the bottom friction and irregularities. Thus, the bulk flow rate at that section of the plume is given as

$$Q_N = kL_D^{1/2}H^{3/2}u_a \tag{10}$$

The near field dilution can be defined as

$$S_N = \frac{Q_N + Q_0}{Q_0} = \frac{kL_D^{1/2}H^{3/2}u_a}{L_DBU_0} + 1 \approx k\,\frac{u_aH^{3/2}}{U_0L_D^{1/2}B} \tag{11}$$

where Q_0 = total flow rate of the diffuser. Eq. (11) can be nondimensionalized by the stagnant dilution S_0 as

$$\frac{S_0}{S_N} = \frac{\sqrt{2}}{k}\left(\frac{H}{L_D}\right)^{-1/2} m_r^{-1/2} \tag{12}$$

Eq. (12) with $k = 0.5$ and $H/L_D = 0.075$ when $m_r = 100$ produces the same results as the experiments in which the dilution approaches the stagnant dilution when m_r is very large.

Excess Isotherm Areas

For environmental impact analysis, excess isotherm areas for different temperature rises should be investigated. In this study, for dimensional analysis, the excess isotherm area normalized by L_D^2 is related to various factors as follows:

$$\frac{A}{L_D^2} = f_1\left(\frac{\Delta T}{\Delta T_0}, U_0, B, u_a, H\right) \tag{13}$$

where A = area of the isothermal contour corresponding to $\Delta T/\Delta T_0$. Expressing (13) using nondimensional terms yields

$$\frac{A}{L_D^2} = f_2\left(\frac{\Delta T}{\Delta T_0}, S_t\right) \tag{14}$$

where, as shown earlier, S_t is expressed as

$$S_t = g(U_0, B, u_a, H) \tag{15}$$

Eq. (15) can be rearranged as

$$\frac{\Delta T}{\Delta T_0} S_t = f_3\left(\frac{A}{L_D^2}\right) \tag{16}$$

The relation between the normalized temperature rises and the normalized excess isotherm areas collected in this study, along with some data from previous studies (Acres 1974; Lee et al. 1977) are plotted in Fig. 8. Lee et al. (1977), based on the theoretical approaches in which a set of integral equations containing the bottom friction effect for the plume in the intermediate field was solved, maintained that solutions for the excess isotherm areas depend upon a frictional parameter $\Phi = f_0 L_D/6H$, in which f_0 is the Darcy-Weisbach friction factor for the bottom. The frictional parameter for data from Acres (1974) and Lee et al. (1977) ranges 0.01–0.03, whereas values of Φ for data collected in this study range 0.015–0.03. In Fig. 8, the data by Acres and Lee et al. were collected under stagnant ambient water. As shown in this figure, in general, observed data for different ranges of m_r show a similar trend. However, it indicates that the excess isotherm areas for cases where $m_r > 1$, corresponding to a particular temperature rise, are smaller than those for cases where $m_r < 1$. The regression equations that are best-fitted to the observed data are given as

$$\frac{\Delta T}{\Delta T_0} S_t = 0.67\left(\frac{A}{L_D^2}\right)^{-0.17}, \quad m_r < 1 \tag{17a}$$

$$\frac{\Delta T}{\Delta T_0} S_t = 0.57\left(\frac{A}{L_D^2}\right)^{-0.17}, \quad m_r > 1 \tag{17b}$$

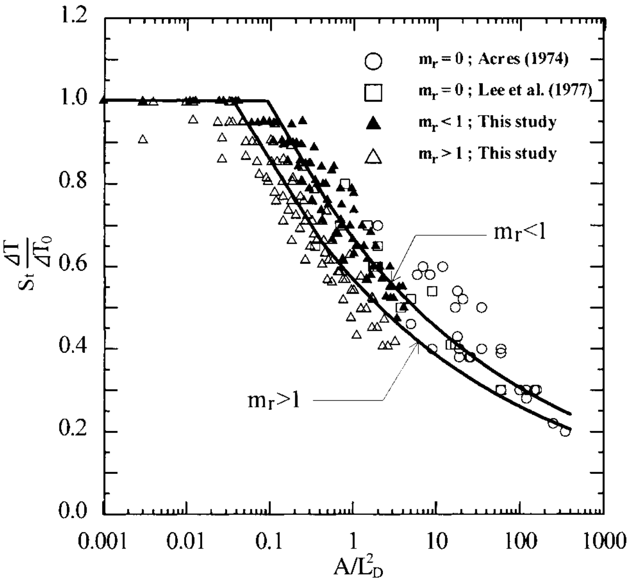

FIG. 8. Excess Isotherm Areas for Tee Diffuser

Plume Trajectory

For dimensional analysis, coordinates of the plume trajectory at the water surface are related to various factors as follows:

$$\phi_1(x, y, U_0, B, u_a, H, L_D) = 0 \tag{18}$$

in which x = coordinate parallel to the direction of the ambient current; and y = coordinate normal to the direction of the ambient current. By applying the Buckingham II theorem, this equation can be rearranged as

$$\frac{y}{L_D} m_r = \phi_2\left(\frac{x}{L_D} m_r\right) \tag{19}$$

In this study, the functional form in (19) is assumed as a power equation as

$$\frac{y}{L_D} m_r = d\left(\frac{x}{L_D} m_r\right)^e \tag{20}$$

The constants in (20) are determined from the experimental data.

The observed data for the plume trajectory collected in this study, along with the regression equation, are plotted in Fig. 9. The plume trajectory data shown in this figure are obtained from the isotherm contours such as those plotted in Fig. 5. In this figure, the data represent series TS from this study. As shown in this figure, the observed data of the plume trajectory plotted in a log-log scale indicate a linear relation. The regression equation can be obtained by best-fitting (20) to the observed data as

$$\frac{y}{L_D} m_r = 0.60\left(\frac{x}{L_D} m_r\right)^{0.55} \tag{21}$$

This equation of the plume trajectory explicitly contains the dependency upon the momentum ratio, m_r, as is also suggested by Akar and Jirka (1991). Based on the length scale analysis with momentum conservation, Akar and Jirka (1991) proposed the 2/3 exponent for the trajectory of the tee diffuser in the CORMIX2 model.

Practical Application

As stated earlier, this study focuses on the conditions of strong ambient momentum, which is relevant to the oceanographic conditions of some coastal areas where nuclear power plants are located, including Korean nuclear power plants. In

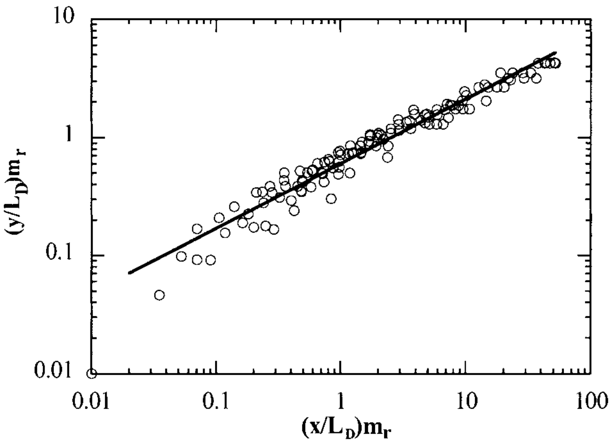

FIG. 9. Plume Trajectory for Tee Diffuser

this study, a nuclear power plant located on the Korean shoreline was selected as an example of a typical practical application of the performance of the tee diffuser. The power plant is the Kori nuclear power plant, located at the southeastern shoreline of Korean peninsula. At Kori nuclear power plant, in addition to the existing 4 units, 2–4 new units are planned to be constructed. Submerged multiport diffusers are considered to be the most viable option for discharging the heated water from the new units. Thus, in this study, as a preliminary design of the tee diffuser, the dimensions of the diffuser are decided, and dilution characteristics are calculated using the proposed equations.

The location map of the Kori nuclear power plant is given in Fig. 10. The current velocity of the ocean in front of the power plant ranges from 40–80 cm/s, and the water depths are shown in Fig. 10. Dimensions of the tee diffuser, decided in preliminary design considering the overall performance of the diffuser, are listed in Table 4. In this table, N is the number of ports. Dilution characteristics calculated using the equations proposed in this study for typical cases are summarized in Table 5. The centerlines of the plume and the isotherms of surface temperature rise corresponding to $\Delta T = 1°\text{C}$ are shown in Fig. 10. The isotherms in this figure are drawn following the typical shape of the plume observed in the experiment, such as that shown in Fig. 5(c). The values of the momentum ratio in this practical application example ($m_r = 2.72–10.9$) are very large compared with values of the momentum ratio under which most of the previous studies on tee diffusers have been performed. Thus, as stated earlier, for these conditions, the proposed equations give more accurate predictions for the dilution characteristics of tee diffusers than existing equations.

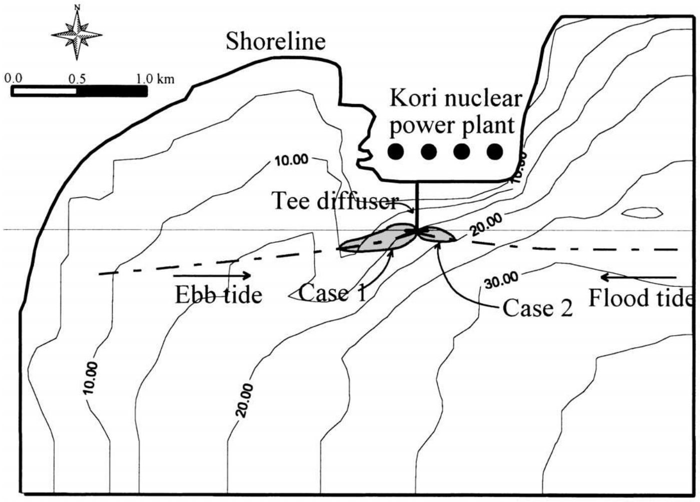

FIG. 10. Preliminary Design of Tee Diffuser for Kori Nuclear Power Plant

TABLE 4. Preliminary Design Example of Tee Diffuser for Kori Nuclear Power Plant

Q (m^3/s) (1)	U_0 (m/s) (2)	ΔT_0 (°C) (3)	L_D (m) (4)	N (5)	D (m) (6)	θ_0 (°) (7)
58.9	3	10	200	100	0.5	20

TABLE 5. Dilution Characteristics of Tee Diffuser for Kori Nuclear Power Plant

Case (1)	u_a (m/s) (2)	H (m) (3)	m_r (4)	S_0 (5)	S_t (6)	A [$\Delta T = 1°\text{C}$] (m^2) (7)
1	0.4 (flood tide)	15	2.72	8.47	5.40	55,000
2	0.8 (ebb tide)	15	10.9	8.47	6.72	15,000

CONCLUSIONS

A procedure for modifying Adams' theory on the dilution of the tee diffuser has been presented. The distinctive feature of the proposed equation is that the stagnation effect between ambient current and diffuser discharge is correctly incorporated into the momentum equation through the application of the exponential function of the ratio of the discharge momentum to ambient momentum, m_r. A simple equation for the plume trajectory including the dependency of the momentum ratio has been derived by applying dimensional analysis. Laboratory experiments involving the tee diffuser were conducted to verify the theoretical equations for a complete range of ambient current conditions.

The experimental results on the near field dilution show that when $m_r < 1$, dilution decreases with m_r, whereas when $m_r > 1$, it increases with increasing m_r, and that it approaches the stagnant water dilution for very large values of m_r. Existing equations provide a reasonable fit to the data in the region where $m_r < 1$; however, predictions by these equations are far off the actual measured data when m_r is larger than 1. A new equation derived in this study has good predictive values, especially when m_r is large.

The observed data for the excess isotherm areas indicate that the relation between the temperature rises and the normalized isotherm areas for different ranges of m_r show similar trends. However, the excess isotherm areas for cases where $m_r > 1$, corresponding to a particular temperature rise, are larger than those for cases where $m_r < 1$. The regression equations which are best-fitted to the observed data from this study can give accurate predictions for complete ranges of the momentum ratio. The observed data for the plume trajectory plotted in a log-log scale indicate a linear relation. The proposed equation for the plume trajectory explicitly contains the factor of the momentum ratio and can accurately predict the plume trajectories for wide ranges of m_r.

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APPENDIX II. NOTATION

The following symbols are used in this paper:

A = cross-sectional area of individual port;
a, b, c, d, e = constants;
B = width of equivalent slot diffuser;
c_d = coefficient associated with stagnation effect of ambient current;
D = port diameter;
F_j = densimetric Froude number;
g = gravitational acceleration;
g_0 = effective gravitational acceleration;
H = depth of ambient water;
j_0 = buoyancy flux per unit length;
k = coefficient related to effects of bottom friction and irregularities;
L_D = length of diffuser;
l = port spacing;
m_a = momentum flux per unit length of ambient fluid;
m_r = momentum ratio of ambient current to effluent discharge;
m_0 = momentum flux per unit length of discharge fluid;
N = number of ports;
Q_N = bulk flow rate at near field;
Q_0 = diffuser discharge;
S_N = dilution at near field;
S_t = dilution for tee diffuser in cross flow;
S_0 = dilution in stagnant water;
U_0 = velocity of effluent discharge;
u = local velocity;
u_a = velocity of ambient current;
u^* = shear velocity;
β = horizontal angle between diffuser port and diffuser axis;
γ = horizontal angle between diffuser axis and ambient current;
$\Delta\rho$ = density difference between discharging fluid and ambient fluid;
ε_y = ambient diffusion coefficient;
θ_0 = angle between port and sea bed;
ϕ = constant used in criteria for shallow water; and
ϕ_c = critical value of ϕ.

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APPENDIX B

Fraser River Ambient Water Quality Summary

Table B-1: Summary of Fraser River Ambient Water Quality for the Annacis Island WWTP Stage 1 EIS Study Area (2011-2014) During High Flows - Conventional Parameters[1]

Parameter	Units	Fraser River at Annacis Island - High Flow ≥ 6,000 m^3/s							
		Number of Samples	Number of Samples <MDL	Percent of Samples <MDL	Minimum[a]	Median[a]	Mean[b]	95th[c,d]	Maximum[a]
Conventional Parameters									
pH[e]	-	14	0	0	7.5	NC	7.8	7.9	7.9
Salinity	ppt	14	0	0	0.04	NC	0.044	0.05	0.05
Conductivity	µS/cm	0	-	-	-	-	-	-	-
Specific conductivity[e]	µS/cm	14	0	0	88	NC	96	108	113
Temperature	°C	14	0	0	10	NC	13	17	18
Dissolved oxygen	mg/L	6	0	0	10	NC	12	NC	12
Dissolved organic carbon	mg/L	14	0	0	2.1	NC	4.0	6.4	7.0
Hardness, as $CaCO_3$	mg/L	14	0	0	39	NC	44	50	52
Total alkalinity, as $CaCO_3$	mg/L	14	0	0	36	NC	42	48	51
Total dissolved solids	mg/L	0	-	-	-	-	-	-	-
Total organic carbon	mg/L	0	-	-	-	-	-	-	-
Total suspended solids	mg/L	14	0	0	21	NC	112	245	290
Turbidity	NTU	14	0	0	30	NC	68	134	143
Major Ions									
Bicarbonate	mg/L	0	-	-	-	-	-	-	-
Carbonate	mg/L	0	-	-	-	-	-	-	-
Chloride	mg/L	14	0	0	0.9	NC	1.4	1.9	2.1
Fluoride	mg/L	14	0	0	0.03	NC	0.038	0.048	0.06
Sulphate	mg/L	14	0	0	4.7	NC	5.5	6.2	6.4
Calcium	mg/L	14	0	0	12	NC	13	15	15
Magnesium	mg/L	14	0	0	2.1	NC	2.6	3.2	3.4
Potassium	mg/L	14	0	0	0.56	NC	0.65	0.80	0.86
Sodium	mg/L	14	0	0	1.5	NC	1.8	2.3	2.6
Nutrients									
Total ammonia	mg-N/L	14	0	0	0.014	NC	0.031	0.066	0.071
Un-ionized ammonia (calculated)	mg/L	NC	NC	NC	NC	NC	0.00047	NC	0.0018
Total phosphorus	mg-P/L	12	0	0	0.074	NC	0.19	0.34	0.35
Dissolved phosphorus	mg-P/L	13	0	0	0.005	NC	0.0086	0.016	0.021
Nitrate	mg-N/L	14	0	0	0.0018	NC	0.018	0.029	0.034
Nitrite	mg-N/L	14	0	0	0.002	NC	0.0096	0.022	0.033
Total nitrogen (calculated)	mg-N/L	13	0	0	0.18	NC	0.30	0.43	0.5
Total Phosphate - as P	mg-P/L	0	-	-	-	-	-	-	-
Total Metals									
Aluminum	µg/L	16	0	0	1030	NC	2464	5220	5670
Antimony	µg/L	16	0	0	0.055	NC	0.086	0.14	0.16
Arsenic	µg/L	16	0	0	0.67	NC	1.1	1.7	1.8
Barium	µg/L	16	0	0	25	NC	40	72	75
Beryllium	µg/L	16	0	0	0.034	NC	0.068	0.14	0.14
Bismuth	µg/L	16	0	0	0.01	NC	0.019	0.035	0.037
Boron	µg/L	16	0	0	1.5	NC	3.4	4.5	4.8
Cadmium	µg/L	16	0	0	0.032	NC	0.061	0.12	0.12
Calcium	mg/L	0	-	-	-	-	-	-	-
Chromium	µg/L	16	0	0	1.8	NC	4.4	9.3	9.8
Cobalt	µg/L	16	0	0	1.0	NC	2.2	4.3	4.4
Copper	µg/L	16	0	0	3.5	NC	6.5	13	13
Iron	µg/L	16	0	0	1630	NC	3644	7468	7820
Lead	µg/L	16	0	0	0.69	NC	1.5	2.9	3.3
Lithium	µg/L	16	0	0	1.4	NC	2.4	4.1	4.2
Magnesium	mg/L	0	-	-	-	-	-	-	-
Manganese	µg/L	16	0	0	51	NC	113	233	235
Mercury	µg/L	0	-	-	-	-	-	-	-
Molybdenum	µg/L	16	0	0	0.41	NC	0.54	0.67	0.69
Nickel	µg/L	16	0	0	3.6	NC	7.7	15	16
Potassium	mg/L	0	-	-	-	-	-	-	-
Platinum	µg/L	16	12	75	<0.001	<0.001	NC	0.001	0.001
Selenium	µg/L	16	0	0	0.06	NC	0.091	0.14	0.16
Silver	µg/L	16	0	0	0.008	NC	0.019	0.045	0.049
Sodium	mg/L	0	-	-	-	-	-	-	-
Strontium	µg/L	16	0	0	69	NC	82	99	107
Thallium	µg/L	16	0	0	0.013	NC	0.024	0.046	0.047
Tin	µg/L	16	1	6	<0.005	NC	0.010	0.018	0.019
Titanium	µg/L	0	-	-	-	-	-	-	-
Tungsten	µg/L	16	1	6	<0.001	NC	0.0071	0.01	0.011
Uranium	µg/L	16	0	0	0.2	NC	0.29	0.42	0.43
Vanadium	µg/L	16	0	0	2.8	NC	5.9	12	13
Zinc	µg/L	16	0	0	4.9	NC	10	21	22
Dissolved Metals									
Aluminum	µg/L	16	0	0	60	NC	138	213	244
Antimony	µg/L	16	0	0	0.031	NC	0.043	0.057	0.058
Arsenic	µg/L	16	0	0	0.26	NC	0.37	0.48	0.48
Barium	µg/L	16	0	0	11	NC	13	16	17
Beryllium	µg/L	16	0	0	0.004	NC	0.0071	0.012	0.014
Bismuth	µg/L	16	5	31	<0.001	NC	0.0014	0.003	0.003
Boron	µg/L	16	0	0	2.1	NC	3.2	4.0	4.2
Cadmium	µg/L	16	0	0	0.01	NC	0.015	0.022	0.031
Chromium	µg/L	16	0	0	0.11	NC	0.26	0.48	0.58
Cobalt	µg/L	16	0	0	0.054	NC	0.11	0.19	0.2
Copper	µg/L	5	0	0	0.84	NC	1.1	NC	1.6
Iron	µg/L	16	0	0	45	NC	146	262	313
Lead	µg/L	16	0	0	0.032	NC	0.090	0.15	0.15
Lithium	µg/L	16	0	0	0.64	NC	0.73	0.84	0.85
Manganese	µg/L	16	0	0	4.8	NC	9.1	15	18
Mercury	µg/L	0	-	-	-	-	-	-	-
Molybdenum	µg/L	16	0	0	0.63	NC	0.72	0.93	0.96
Nickel	µg/L	16	0	0	0.41	NC	0.84	1.5	1.7
Platinum	ug/L	16	15	94	<0.001	<0.001	NC	0.001	0.001
Selenium	µg/L	16	0	0	0.06	NC	0.076	0.1	0.11
Silver	µg/L	16	2	13	<0.001	NC	0.0017	0.0035	0.005
Strontium	µg/L	16	0	0	63	NC	70	74	76
Thallium	µg/L	16	0	0	0.003	NC	0.0044	0.007	0.007
Tin	µg/L	16	11	69	<0.005	<0.005	NC	0.022	0.044
Titanium	µg/L	0	-	-	-	-	-	-	-
Tungsten	µg/L	16	1	6	<0.001	NC	0.0063	0.0088	0.011
Uranium	µg/L	16	0	0	0.15	NC	0.18	0.21	0.22
Vanadium	µg/L	16	0	0	0.4	NC	0.69	1.1	1.1
Zinc	µg/L	16	0	0	0.2	NC	0.46	0.75	0.9
Bacteria									
Fecal Coliforms	MPN/100mL	NC	NC	NC	NC	NC	NC	NC	NC
Enterococus	MPN/100mL	NC	NC	NC	NC	NC	NC	NC	NC
Escherichia coli	MPN/100mL	NC	NC	NC	NC	NC	NC	NC	NC

Notes:

°C = degrees Celcius; µg/L = microgram per litre; µS/cm = microSiemen per centimetre; "<" = reported value is less than method detection limit (MDL); $CaCO_3$ = calcium carbonate; m^3/s = cubic metre per second; mg/L = milligram per litre; mL = millilitre; MPN = most probably number; N = nitrogen; NC = not calculated; P = phosphorus; ppt = parts per trillion; NTU = nephelometric turbidity unit.

1) Data sources were the Greater Vancouver Regional District Fraser River Ambient Monitoring Program, Metro Vancouver Annacis Wastewater Treatment Plant Initial Dilution Zone Boundary Monitoring Program and Environment Canada Pacific Water Quality Monitoring & Surveillance Program

a) Minimum, maximum, and median reported as the method detection limit when the summary statistic corresponded to a non-detect (ND) value in the dataset.
b) Mean was not calculated for parameters with greater than 50% non-detect values. A median was reported where a mean was not calculated.
c) 95th percentile was not calculated for parameters with fewer than 10 samples.
d) 95th percentile was not calculated for parameters with more than 95% non-detect values.
e) Specific Conductivity and pH data were supplimented with lab measured data.

Table B-2: Summary of Fraser River Ambient Water Quality for the Annacis Island WWTP Stage 1 EIS Study Area (2011-2014) During Moderate Flows - Conventional Parameters[1]

Parameter	Units	Fraser River at Annacis Island - Moderate Flow < 6,000 m^3/s and ≥ 1,000 m^3/s							
		Number of Samples	Number of Samples <MDL	Percent of Samples <MDL	Minimum[a]	Median[a]	Mean[b]	95th[c,d]	Maximum[a]
Conventional Parameters									
pH	-	37	0	0	6.5	NC	7.4	8.2	8.2
Salinity	ppt	61	0	0	0.03	NC	0.063	0.16	0.31
Conductivity	µS/cm	21	5	24	<1	NC	61	103	111
Specific conductivity	µS/cm	42	0	0	0.14	NC	96	180	197
Temperature	°C	71	0	0	2.7	NC	13	20	21
Dissolved oxygen	mg/L	39	0	0	8.3	NC	11	14	14
Dissolved organic carbon	mg/L	50	0	0	1.2	NC	2.6	6.4	8.2
Hardness, as $CaCO_3$	mg/L	61	0	0	31	NC	49	59	136
Total alkalinity, as $CaCO_3$	mg/L	32	0	0	28	NC	43	48	118
Total dissolved solids	mg/L	5	0	0	70	NC	86	NC	120
Total organic carbon	mg/L	19	0	0	1.6	NC	2.1	2.7	3.0
Total suspended solids	mg/L	60	0	0	4.9	NC	26	88	148
Turbidity	NTU	41	1	2	<0.1	NC	22	80	126
Major Ions									
Bicarbonate	mg/L	0	-	-	-	-	-	-	-
Carbonate	mg/L	0	-	-	-	-	-	-	-
Chloride	mg/L	61	0	0	0.53	NC	8.7	34	140
Fluoride	mg/L	32	0	0	0.021	NC	0.035	0.044	0.059
Sulphate	mg/L	32	0	0	3.4	NC	8.7	18	27
Calcium	mg/L	61	0	0	9.3	NC	14	16	22
Magnesium	mg/L	61	0	0	1.9	NC	3.5	5.4	19
Potassium	mg/L	61	0	0	0.58	NC	0.89	1.5	3.6
Sodium	mg/L	37	0	0	1.5	NC	9.0	25	80
Nutrients									
Total ammonia	mg-N/L	60	6	10	<0.005	NC	0.049	0.16	0.26
Un-ionized ammonia (calculated)	mg/L	NC	NC	NC	NC	NC	0.00028	NC	0.017
Total phosphorus	mg-P/L	38	0	0	0.009	NC	0.059	0.15	0.21
Dissolved phosphorus	mg-P/L	31	0	0	0.0056	NC	0.019	0.041	0.047
Nitrate	mg-N/L	60	0	0	0.0081	NC	0.068	0.21	0.69
Nitrite	mg-N/L	61	11	18	<0.001	NC	0.0042	0.011	0.024
Total nitrogen (calculated)	mg-N/L	57	0	0	0.11	NC	0.33	0.53	3.8
Total Phosphate - as P	mg-P/L	24	0	0	0.016	NC	0.031	0.052	0.057
Total Metals									
Aluminum	µg/L	67	0	0	56	NC	579	2084	3390
Antimony	µg/L	67	0	0	0.025	NC	0.053	0.097	0.11
Arsenic	µg/L	67	0	0	0.37	NC	0.55	1.0	1.5
Barium	µg/L	67	0	0	13	NC	20	40	51
Beryllium	µg/L	67	22	33	0.006	NC	0.019	0.066	0.097
Bismuth	µg/L	67	22	33	0.001	NC	0.0077	0.022	0.029
Boron	µg/L	67	29	43	<0.01	NC	12	50	<50
Cadmium	µg/L	67	0	0	0.0099	NC	0.027	0.081	0.21
Calcium	mg/L	29	0	0	11	NC	14	16	16
Chromium	µg/L	67	0	0	0.17	NC	1.1	4.3	6.5
Cobalt	µg/L	67	0	0	0.061	NC	0.54	2.0	2.8
Copper	µg/L	67	0	0	0.8	NC	2.3	7.0	9.9
Iron	µg/L	67	0	0	123	NC	868	3312	4690
Lead	µg/L	67	0	0	0.074	NC	0.42	1.4	2.0
Lithium	µg/L	67	2	3.0	<0.5	NC	1.3	2.5	3.0
Magnesium	mg/L	29	0	0	2.1	NC	3.1	4.1	5.3
Manganese	µg/L	67	0	0	9.8	NC	33	107	141
Mercury	µg/L	24	24	100	<0.01	<0.01	NC	NC	<0.01
Molybdenum	µg/L	67	0	0	0.39	NC	0.66	0.84	0.86
Nickel	µg/L	67	0	0	0.58	NC	2.4	8.4	29
Potassium	mg/L	29	0	0	0.64	NC	0.79	1.0	1.5
Platinum	µg/L	38	35	92	<0.001	<0.001	NC	0.001	0.002
Selenium	µg/L	67	0	0	0.06	NC	0.090	0.13	0.41
Silver	µg/L	67	24	36	0.001	NC	0.0066	0.021	0.032
Sodium	mg/L	5	0	0	4.9	NC	8.8	NC	20
Strontium	µg/L	67	1	1.5	<0.0755	NC	77	93	148
Thallium	µg/L	67	1	1.5	<0.002	NC	0.0090	0.025	0.032
Tin	µg/L	67	33	49	<0.005	NC	0.026	0.16	0.47
Titanium	µg/L	5	0	0	4.9	NC	6.4	NC	8.0
Tungsten	µg/L	38	1	3	<0.001	NC	0.009	0.012	0.013
Uranium	µg/L	67	0	0	0.05	NC	0.21	0.29	0.35
Vanadium	µg/L	67	0	0	0.36	NC	1.6	5.7	8.2
Zinc	µg/L	67	0	0	0.84	NC	3.0	10	14
Dissolved Metals									
Aluminum	µg/L	65	0	0	4.3	NC	45	161	267
Antimony	µg/L	65	1	1.5	<0.02	NC	0.043	0.060	0.07
Arsenic	µg/L	65	0	0	0.25	NC	0.34	0.47	0.58
Barium	µg/L	65	0	0	10.0	NC	13	16	36
Beryllium	µg/L	65	29	45	0.002	NC	0.007	0.011	0.015
Bismuth	µg/L	65	44	68	<0.001	0.003	NC	0.0094	0.094
Boron	µg/L	65	27	42	<0.01	NC	12	50	<50
Cadmium	µg/L	65	4	6.2	<0.005	NC	0.012	0.023	0.05
Chromium	µg/L	65	16	25	0.07	NC	0.15	0.41	0.66
Cobalt	µg/L	65	0	0	0.0077	NC	0.05	0.18	0.28
Copper	µg/L	47	0	0	0.53	NC	0.83	1.0	2.6
Iron	µg/L	65	0	0	3.8	NC	55	216	372
Lead	µg/L	65	7	11	<0.005	NC	0.033	0.11	0.18
Lithium	µg/L	65	9	14	<0.5	NC	0.86	1.6	2.7
Manganese	µg/L	65	0	0	0.11	NC	6.4	13	74
Mercury	µg/L	24	24	100	<0.01	<0.01	NC	NC	<0.023
Molybdenum	µg/L	65	0	0	0.54	NC	0.72	0.86	0.94
Nickel	µg/L	65	1	1.5	<0.005	NC	0.72	1.5	13
Platinum	ug/L	36	31	86	<0.001	<0.001	NC	0.001	0.001
Selenium	µg/L	65	0	0	0.05	NC	0.083	0.13	0.33
Silver	µg/L	65	47	72	<0.001	0.004	NC	0.005	<0.0052
Strontium	µg/L	65	0	0	0.069	NC	74	93	148
Thallium	µg/L	65	5	7.7	<0.002	NC	0.0046	0.0094	0.035
Tin	µg/L	65	55	85	<0.005	0.008	NC	0.012	<0.2
Titanium	µg/L	5	3	60	<0.5	<0.5	NC	NC	1.6
Tungsten	µg/L	36	1	3	<0.001	NC	0.0083	0.011	0.013
Uranium	µg/L	65	0	0	0.044	NC	0.17	0.22	0.24
Vanadium	µg/L	65	0	0	0.23	NC	0.39	0.82	1.2
Zinc	µg/L	65	24	37	<0.2	NC	0.53	0.9	1.8
Bacteria									
Fecal Coliforms	MPN/100mL	NC	NC	NC	NC	NC	NC	NC	NC
Enterococus	MPN/100mL	NC	NC	NC	NC	NC	NC	NC	NC
Escherichia coli	MPN/100mL	NC	NC	NC	NC	NC	NC	NC	NC

Notes:

°C = degrees Celcius; µg/L = microgram per litre; µS/cm = microSiemen per centimetre; "<" = reported value is less than method detection limit (MDL); $CaCO_3$ = calcium carbonate; m^3/s = cubic metre per second; mg/L = milligram per litre; mL = millilitre; MPN = most probably number; N = nitrogen; NC = not calculated; P = phosphorus; ppt = parts per trillion; NTU = nephelometric turbidity unit.

1) Data sources were the Greater Vancouver Regional District Fraser River Ambient Monitoring Program, Metro Vancouver Annacis Wastewater Treatment Plant Initial Dilution Zone Boundary Monitoring Program and Environment Canada Pacific Water Quality Monitoring & Surveillance Program.

a) Minimum, maximum, and median reported as the method detection limit when the summary statistic corresponded to a non-detect (ND) value in the dataset.

b) Mean was not calculated for parameters with greater than 50% non-detect values. A median was reported where a mean was not calculated.

c) 95th percentile was not calculated for parameters with fewer than 10 samples.

d) 95th percentile was not calculated for parameters with more than 95% non-detect values.

Table B-3: Summary of Fraser River Ambient Water Quality for the Annacis Island WWTP Stage 1 EIS Study Area (2011-2014) During Low Flows - Conventional Parameters[1]

Parameter	Units	Fraser River at Annacis Island - Low Flow < 1,000 m^3/s							
		Number of Samples	Number of Samples <MDL	Percent of Samples <MDL	Minimum[a]	Median[a]	Mean[b]	95th[c,d]	Maximum[a]
Conventional Parameters									
pH	-	32	0	0	7.4	NC	7.7	7.9	8.0
Salinity	ppt	33	0	0	0.04	NC	0.21	0.51	2.3
Conductivity	µS/cm	19	7	37	<1	NC	67	186	325
Specific conductivity	µS/cm	32	0	0	0.17	NC	111	417	736
Temperature	°C	40	0	0	0.43	NC	3.6	5.2	6.2
Dissolved oxygen	mg/L	32	0	0	12	NC	13	14	15
Dissolved organic carbon	mg/L	13	0	0	1.2	NC	2.2	2.8	3.0
Hardness, as $CaCO_3$	mg/L	33	0	0	31	NC	71	118	427
Total alkalinity, as $CaCO_3$	mg/L	1	0	0	50	NC	50	NC	50
Total dissolved solids	mg/L	15	0	0	64	NC	304	1034	2190
Total organic carbon	mg/L	12	0	0	1.8	NC	2.5	3.1	3.2
Total suspended solids	mg/L	33	0	0	3.5	NC	12	21	30
Turbidity	NTU	16	0	0	1.3	NC	5.6	12	12
Major Ions									
Bicarbonate	mg/L	0	-	-	-	-	-	-	-
Carbonate	mg/L	0	-	-	-	-	-	-	-
Chloride	mg/L	33	0	0	1.7	NC	71	204	1200
Fluoride	mg/L	1	0	0	0.042	NC	0.042	NC	0.042
Sulphate	mg/L	1	0	0	15	NC	15	NC	15
Calcium	mg/L	33	0	0	9.5	NC	16	20	39
Magnesium	mg/L	33	0	0	2.3	NC	7.9	17	82
Potassium	mg/L	33	0	0	0.67	NC	2.3	5.4	26
Sodium	mg/L	16	0	0	4.7	NC	72	275	661
Nutrients and Chlorophyll a									
Total ammonia	mg-N/L	33	0	0	0.017	NC	0.071	0.14	0.19
Un-ionized ammonia (calculated)	mg/L	NC	NC	NC	NC	NC	0.00040	NC	0.0023
Total phosphorus	mg-P/L	16	0	0	0.015	NC	0.03	0.053	0.053
Dissolved phosphorus	mg-P/L	1	0	0	0.02	NC	0.020	NC	0.02
Nitrate	mg-N/L	33	0	0	0.047	NC	0.19	0.25	0.27
Nitrite	mg-N/L	33	4	12	<0.001	NC	0.0028	0.0051	0.0065
Total nitrogen (calculated)	mg-N/L	33	0	0	0.25	NC	0.38	0.49	0.53
Total Phosphate - as P	mg-P/L	17	0	0	0.021	NC	0.027	0.035	0.037
Total Metals									
Aluminum	µg/L	33	0	0	50	NC	173	359	414
Antimony	µg/L	33	1	3.0	0.04	NC	0.067	0.084	<0.5
Arsenic	µg/L	33	0	0	0.42	NC	0.50	0.62	0.68
Barium	µg/L	33	0	0	9.6	NC	16	19	20
Beryllium	µg/L	33	29	88	0.0074	<0.01	NC	0.012	<1
Bismuth	µg/L	33	29	88	<0.005	<0.005	NC	0.05	<1
Boron	µg/L	33	22	67	<10	31	NC	58	296
Cadmium	µg/L	33	0	0	0.0086	NC	0.018	0.026	0.11
Calcium	mg/L	32	0	0	8.4	NC	16	19	40
Chromium	µg/L	33	1.0	3.0	0.13	NC	0.37	0.74	0.85
Cobalt	µg/L	33	0	0	0.049	NC	0.16	0.29	0.32
Copper	µg/L	33	0	0	0.81	NC	1.4	2.2	2.9
Iron	µg/L	33	0	0	128	NC	298	555	639
Lead	µg/L	33	0	0	0.046	NC	0.16	0.27	0.57
Lithium	µg/L	33	2	6.1	<0.51	NC	1.7	2.5	<20
Magnesium	mg/L	32	0	0	2.4	NC	8.0	17	79
Manganese	µg/L	33	0	0	8.8	NC	18	29	31
Mercury	µg/L	17	17	100	<0.01	<0.01	NC	NC	<0.01
Molybdenum	µg/L	33	0	0	0.52	NC	0.81	0.95	1.6
Nickel	µg/L	33	0	0	0.52	NC	1.1	1.7	2.6
Potassium	mg/L	32	0	0	0.68	NC	2.3	5.3	26
Platinum	µg/L	1	1	100	<0.001	<0.001	NC	NC	<0.001
Selenium	µg/L	33	4	12	0.073	NC	0.14	0.30	<0.5
Silver	µg/L	33	30	91	0.004	<0.005	NC	0.0064	<0.05
Sodium	mg/L	15	0	0	4.1	NC	73	285	627
Strontium	µg/L	33	0	0	47	NC	103	163	553
Thallium	µg/L	33	8	24	0.002	NC	0.0067	0.01	0.1
Tin	µg/L	33	27	82	<0.01	0.033	NC	0.28	<1
Titanium	µg/L	14	0	0	1.9	NC	4.2	6.4	7.6
Tungsten	µg/L	1	0	0	0.012	NC	0.012	NC	0.012
Uranium	µg/L	33	0	0	0.12	NC	0.22	0.27	0.4
Vanadium	µg/L	33	2	6.1	<0.2	NC	0.97	1.3	<10
Zinc	µg/L	33	3	9.1	0.73	NC	2.2	3.9	5.4
Dissolved Metals									
Aluminum	µg/L	33	0	0	9.1	NC	15	29	33
Antimony	µg/L	33	1	3.0	0.035	NC	0.061	0.068	<0.5
Arsenic	µg/L	33	0	0	0.32	NC	0.39	0.44	0.57
Barium	µg/L	33	0	0	10	NC	14	16	18
Beryllium	µg/L	33	32	97	0.003	<0.01	NC	NC	<1
Bismuth	µg/L	33	31	94	0.001	<0.005	NC	0.0061	<1
Boron	µg/L	33	21	64	<10	<32	NC	57	258
Cadmium	µg/L	33	1	3.0	0.006	NC	0.010	0.014	0.017
Chromium	µg/L	33	13	39	<0.1	NC	0.15	0.28	<0.5
Cobalt	µg/L	33	1.0	3.0	0.016	NC	0.038	0.055	<0.1
Copper	µg/L	32	0	0	0.64	NC	0.76	0.89	0.94
Iron	µg/L	33	0	0	18	NC	43	66	80
Lead	µg/L	33	1	3.0	0.0064	NC	0.020	0.040	0.056
Lithium	µg/L	33	7	21	<0.5	NC	1.6	2.6	<20
Manganese	µg/L	33	0	0	1.8	NC	8.5	15	18
Mercury	µg/L	17	17	100	<0.01	<0.01	NC	NC	<0.01
Molybdenum	µg/L	33	0	0	0.54	NC	0.84	0.98	1.5
Nickel	µg/L	33	2	6.1	<0.005	NC	0.53	0.68	0.8
Platinum	ug/L	1	1	100	<0.001	<0.001	NC	NC	<0.001
Selenium	µg/L	33	1	3.0	0.062	NC	0.12	0.23	<0.5
Silver	µg/L	33	31	94	0.002	<0.005	NC	0.005	<0.05
Strontium	µg/L	33	0	0	50	NC	103	167	559
Thallium	µg/L	33	19	58	<0.002	<0.002	NC	0.0064	<0.1
Tin	µg/L	33	31	94	<0.01	<0.011	NC	0.2	<1
Titanium	µg/L	14	9	64	<0.5	<0.5	NC	0.77	0.9
Tungsten	µg/L	1	0	0	0.006	NC	0.006	NC	0.006
Uranium	µg/L	33	0	0	0.11	NC	0.20	0.27	0.36
Vanadium	µg/L	33	3	9.1	<0.2	NC	0.62	0.52	<10
Zinc	µg/L	33	6	18	<0.56	NC	0.84	1.5	1.5
Bacteria									
Fecal Coliforms	MPN/100mL	NC	NC	NC	NC	NC	NC	NC	NC
Enterococcus	MPN/100mL	NC	NC	NC	NC	NC	NC	NC	NC
Escherichia coli	MPN/100mL	NC	NC	NC	NC	NC	NC	NC	NC

Notes:

°C = degrees Celcius; µg/L = microgram per litre; µS/cm = microSiemen per centimetre; "<" = reported value is less than method detection limit (MDL); $CaCO_3$ = calcium carbonate; m^3/s = cubic metre per second; mg/L = milligram per litre; mL = millilitre; MPN = most probably number; N = nitrogen; NC = not calculated; P = phosphorus; ppt = parts per trillion; NTU = nephelometric turbidity unit.

1) Data sources were the Greater Vancouver Regional District Fraser River Ambient Monitoring Program, Metro Vancouver Annacis Wastewater Treatment Plant Initial Dilution Zone Boundary Monitoring Program and Environment Canada Pacific Water Quality Monitoring & Surveillance Program.

a) Minimum, maximum, and median reported as the method detection limit when the summary statistic corresponded to a non-detect (ND) value in the dataset.

b) Mean was not calculated for parameters with greater than 50% non-detect values. A median was reported where a mean was not calculated.

c) 95th percentile was not calculated for parameters with fewer than 10 samples.

d) 95th percentile was not calculated for parameters with more than 95% non-detect values.

Table B-4: Summary of Fraser River Ambient Water Quality for the Annacis Island WWTP Stage 1 EIS Study Area (2011-2014) During Low Seasonal Flow - Conventional Parameters[1]

Parameter	Units	Fraser River at Annacis Island - Low Seasonal Flow (September to March)							
		Number of Samples	Number of Samples <MDL	Percent of Samples <MDL	Minimum[a]	Median[a]	Mean[b]	95th[c,d]	Maximum[a]
Conventional Parameters									
pH	-	65	0	0	6.5	NC	7.5	8.0	8.2
Salinity	ppt	78	0	0	0.03	NC	0.12	0.32	2.3
Conductivity	µS/cm	39	12	31	<1	NC	64	137	325
Specific conductivity	µS/cm	67	0	0	0.14	NC	102	225	736
Temperature	°C	95	0	0	0.43	NC	8.6	18	21
Dissolved oxygen	mg/L	66	0	0	8.3	NC	12	14	15
Dissolved organic carbon	mg/L	48	0	0	1.2	NC	2.1	3.0	4.0
Hardness, as $CaCO_3$	mg/L	78	0	0	31	NC	57	95	427
Total alkalinity, as $CaCO_3$	mg/L	18	0	0	28	NC	40	47	50
Total dissolved solids	mg/L	20	0	0	64	NC	249	621	2190
Total organic carbon	mg/L	31	0	0	1.6	NC	2.2	3.0	3.2
Total suspended solids	mg/L	78	0	0	3.5	NC	15	31	59
Turbidity	NTU	42	1	2	<0.1	NC	8.1	14	35
Major Ions									
Bicarbonate	mg/L	0	-	-	-	-	-	-	-
Carbonate	mg/L	0	-	-	-	-	-	-	-
Chloride	mg/L	78	0	0	0.69	NC	35	140	1200
Fluoride	mg/L	18	0	0	0.021	NC	0.033	0.04	0.042
Sulphate	mg/L	18	0	0	5.1	NC	9.7	17	27
Calcium	mg/L	78	0	0	9.3	NC	14	18	39
Magnesium	mg/L	78	0	0	1.9	NC	5.2	12	82
Potassium	mg/L	78	0	0	0.58	NC	1.5	3.5	26
Sodium	mg/L	38	0	0	1.8	NC	37	113	661
Nutrients									
Total ammonia	mg-N/L	77	6.0	7.8	<0.005	NC	0.057	0.15	0.23
Un-ionized ammonia (calculated)	mg/L	NC	NC	NC	NC	NC	0.00031	NC	0.015
Total phosphorus	mg-P/L	37	0	0	0.009	NC	0.031	0.053	0.064
Dissolved phosphorus	mg-P/L	17	0	0	0.007	NC	0.021	0.037	0.047
Nitrate	mg-N/L	77	0	0	0.0083	NC	0.12	0.24	0.27
Nitrite	mg-N/L	78	14	18	<0.001	NC	0.0027	0.0057	0.0065
Total nitrogen (calculated)	mg-N/L	64	0	0	0.11	NC	0.30	0.45	0.5
Total Phosphate - as P	mg-P/L	40	0	0	0.016	NC	0.029	0.046	0.053
Total Metals									
Aluminum	µg/L	81	0	0	50	NC	252	455	1220
Antimony	µg/L	81	1.0	1.2	0.025	NC	0.055	0.066	<0.5
Arsenic	µg/L	81	0	0	0.37	NC	0.47	0.59	0.71
Barium	µg/L	81	0	0	9.6	NC	16	20	26
Beryllium	µg/L	81	51	63	0.007	<0.01	NC	0.017	<1
Bismuth	µg/L	81	51	63	0.002	<0.005	NC	0.028	<1
Boron	µg/L	81	50	62	<0.01	<10	NC	50	296
Cadmium	µg/L	81	0	0	0.0086	NC	0.017	0.026	0.11
Calcium	mg/L	60	0	0	8.4	NC	15	18	40
Chromium	µg/L	81	1.0	1.2	0.13	NC	0.47	0.85	1.9
Cobalt	µg/L	81	0	0	0.049	NC	0.24	0.51	0.88
Copper	µg/L	81	0	0	0.8	NC	1.5	2.5	3.4
Iron	µg/L	81	0	0	123	NC	381	647	1630
Lead	µg/L	81	0	0	0.046	NC	0.22	0.49	0.76
Lithium	µg/L	81	4.0	4.9	<0.5	NC	1.3	2.3	<20
Magnesium	mg/L	60	0	0	2.1	NC	5.7	13	79
Manganese	µg/L	81	0	0	8.8	NC	19	31	51
Mercury	µg/L	40	40	100	<0.01	<0.01	NC	NC	<0.01
Molybdenum	µg/L	81	0	0	0.39	NC	0.74	0.91	1.6
Nickel	µg/L	81	0	0	0.52	NC	1.1	2.0	3.2
Potassium	mg/L	60	0	0	0.64	NC	1.6	3.9	26
Platinum	µg/L	21	21	100	<0.001	<0.001	NC	NC	<0.001
Selenium	µg/L	81	4.0	4.9	0.06	NC	0.11	0.2	<0.5
Silver	µg/L	81	54	67	0.001	<0.005	NC	0.007	<0.05
Sodium	mg/L	20	0	0	4.1	NC	57	162	627
Strontium	µg/L	81	1.0	1.2	<0.0755	NC	86	131	553
Thallium	µg/L	81	9.0	11	<0.002	NC	0.0066	0.010	<0.1
Tin	µg/L	81	58	72	<0.005	<0.01	NC	0.2	<1
Titanium	µg/L	19	0	0	1.9	NC	4.8	7.7	8.0
Tungsten	µg/L	21	0	0	0.008	NC	0.0097	0.012	0.013
Uranium	µg/L	81	0	0	0.12	NC	0.20	0.25	0.4
Vanadium	µg/L	81	2.0	2.5	<0.2	NC	0.95	1.4	<10
Zinc	µg/L	81	3.0	3.7	0.73	NC	2.0	3.4	5.4
Dissolved Metals									
Aluminum	µg/L	81	0	0	9.1	NC	22	41	169
Antimony	µg/L	81	2.0	2.5	<0.02	NC	0.049	0.058	<0.5
Arsenic	µg/L	81	0	0	0.26	NC	0.35	0.43	0.57
Barium	µg/L	81	0	0	10.0	NC	13	16	18
Beryllium	µg/L	81	60	74	0.002	<0.01	NC	0.01	<1
Bismuth	µg/L	81	69	85	<0.001	<0.005	NC	0.0073	<1
Boron	µg/L	81	47	58	<0.01	<11	NC	50	258
Cadmium	µg/L	81	5.0	6.2	<0.005	NC	0.011	0.015	0.021
Chromium	µg/L	81	28	35	0.07	NC	0.13	0.2	<0.5
Cobalt	µg/L	81	1.0	1.2	0.0077	NC	0.036	0.056	0.11
Copper	µg/L	70	0	0	0.53	NC	0.77	0.93	1.1
Iron	µg/L	81	0	0	3.8	NC	37	70	160
Lead	µg/L	81	8.0	9.9	<0.005	NC	0.021	0.043	0.09
Lithium	µg/L	81	16	20	<0.5	NC	1.1	2.1	<20
Manganese	µg/L	81	0	0	0.11	NC	6.3	12	18
Mercury	µg/L	40	40	100	<0.01	<0.01	NC	NC	<0.023
Molybdenum	µg/L	81	0	0	0.54	NC	0.77	0.93	1.5
Nickel	µg/L	81	3.0	3.7	<0.005	NC	0.49	0.69	0.9
Platinum	ug/L	21	18	86	<0.001	0.001	NC	0.001	0.001
Selenium	µg/L	81	1.0	1.2	0.05	NC	0.095	0.12	<0.5
Silver	µg/L	81	71	88	<0.001	<0.005	NC	0.005	<0.05
Strontium	µg/L	81	0	0	0.069	NC	85	129	559
Thallium	µg/L	81	23	28	<0.002	NC	0.0049	0.007	<0.1
Tin	µg/L	81	74	91	<0.005	<0.01	NC	0.2	<1
Titanium	µg/L	19	12	63	<0.5	<0.5	NC	0.97	1.6
Tungsten	µg/L	21	0	0	0.006	NC	0.0083	0.01	0.01
Uranium	µg/L	81	0	0	0.11	NC	0.19	0.23	0.36
Vanadium	µg/L	81	3.0	3.7	<0.2	NC	0.44	0.44	<10
Zinc	µg/L	81	27	33	0.2	NC	0.68	1.4	1.8
Bacteria[e]									
Fecal Coliforms	MPN/100mL	58	2	3	19	NC	120	912	1100
Enterococus	MPN/100mL	38	16	42	10	NC	23	90	220
Escherichia coli	MPN/100mL	38	1	3	19	NC	92	565	650

Notes:

°C = degrees Celcius; µg/L = microgram per litre; µS/cm = microSiemen per centimetre; "<" = reported value is less than method detection limit (MDL); $CaCO_3$ = calcium carbonate; mg/L = milligram per litre; mL = millilitre; MPN = most probably number; N = nitrogen; NC = not calculated; P = phosphorus; ppt = parts per trillion; NTU = nephelometric turbidity unit.

1) Data sources were the Greater Vancouver Regional District Fraser River Ambient Monitoring Program, Metro Vancouver Annacis Wastewater Treatment Plant Initial Dilution Zone Boundary Monitoring Program and Environment Canada Pacific Water Quality Monitoring & Surveillance Program.

a) Minimum, maximum, and median reported as the method detection limit when the summary statistic corresponded to a non-detect (ND) value in the dataset.
b) Mean was not calculated for parameters with greater than 50% non-detect values. A median was reported where a mean was not calculated.
c) 95th percentile was not calculated for parameters with fewer than 10 samples.
d) 95th percentile was not calculated for parameters with more than 95% non-detect values.
e) To align with Fraser River Water Quality Objectives, low flow was designated as November to March for bacterial parameters and geometric means were calculated in place of arithmetic means.

Table B-5: Summary of Fraser River Ambient Water Quality for the Annacis Island WWTP Stage 1 EIS Study Area (2011-2014) During High Seasonal Flow - Conventional Parameters[1]

Parameter	Units	Fraser River at Annacis Island - High Seasonal Flow (April to August)							
		Number of Samples	Number of Samples <MDL	Percent of Samples <MDL	Minimum[a]	Median[a]	Mean[b]	95th[c,d]	Maximum[a]
Conventional Parameters									
pH[e]	-	29	0	0	7.5	NC	7.7	7.9	8.1
Salinity	ppt	30	0	0	0.04	NC	0.055	0.12	0.19
Conductivity	µS/cm	1	0	0	69	NC	69	NC	69
Specific conductivity[e]	µS/cm	29	0	0	88	NC	119	260	404
Temperature	°C	30	0	0	6.0	NC	13	19	20
Dissolved oxygen	mg/L	11	0	0	9.4	NC	11	12	13
Dissolved organic carbon	mg/L	29	0	0	1.7	NC	3.9	7.3	8.2
Hardness, as $CaCO_3$	mg/L	30	0	0	39	NC	49	66	136
Total alkalinity, as $CaCO_3$	mg/L	29	0	0	36	NC	45	51	118
Total dissolved solids	mg/L	0	-	-	-	-	-	-	-
Total organic carbon	mg/L	0	-	-	-	-	-	-	-
Total suspended solids	mg/L	29	0	0	10	NC	81	201	290
Turbidity	NTU	29	0	0	8.4	NC	55	128	143
Major Ions									
Bicarbonate	mg/L	0	-	-	-	-	-	-	-
Carbonate	mg/L	0	-	-	-	-	-	-	-
Chloride	mg/L	30	0	0	0.53	NC	5.2	17	76
Fluoride	mg/L	29	0	0	0.03	NC	0.038	0.054	0.06
Sulphate	mg/L	29	0	0	3.4	NC	6.7	14	19
Calcium	mg/L	30	0	0	11	NC	14	16	22
Magnesium	mg/L	30	0	0	2.1	NC	3.5	6.3	19
Potassium	mg/L	30	0	0	0.56	NC	0.82	1.8	2.6
Sodium	mg/L	29	0	0	1.5	NC	4.2	11	43
Nutrients									
Total ammonia	mg-N/L	30	0	0	0.0063	NC	0.044	0.09	0.26
Un-ionized ammonia (calculated)	mg/L	NC	NC	NC	NC	NC	0.00053	NC	0.012
Total phosphorus	mg-P/L	29	0	0	0.023	NC	0.13	0.34	0.35
Dissolved phosphorus	mg-P/L	28	0	0	0.005	NC	0.013	0.031	0.047
Nitrate	mg-N/L	30	0	0	0.0018	NC	0.042	0.038	0.69
Nitrite	mg-N/L	30	1.0	3.3	<0.001	NC	0.0091	0.021	0.033
Total nitrogen (calculated)	mg-N/L	28	0	0	0.17	NC	0.44	0.57	3.84
Total Phosphate - as P	mg-P/L	1	0	0	0.057	NC	0.057	NC	0.057
Total Metals									
Aluminum	µg/L	35	0	0	155	NC	1814	4601	5670
Antimony	µg/L	35	0	0	0.05	NC	0.078	0.13	0.16
Arsenic	µg/L	35	0	0	0.45	NC	0.91	1.7	1.8
Barium	µg/L	35	0	0	18	NC	34	64	75
Beryllium	µg/L	35	0	0	0.006	NC	0.052	0.12	0.14
Bismuth	µg/L	35	0	0	0.001	NC	0.015	0.033	0.037
Boron	µg/L	35	1.0	2.9	1.5	NC	6.0	16	43
Cadmium	µg/L	35	0	0	0.013	NC	0.057	0.12	0.21
Calcium	mg/L	1	0	0	15	NC	15	NC	15
Chromium	µg/L	35	0	0	0.68	NC	3.4	8.2	9.8
Cobalt	µg/L	35	0	0	0.35	NC	1.6	4.1	4.4
Copper	µg/L	35	0	0	1.2	NC	5.2	12	13
Iron	µg/L	35	0	0	604	NC	2725	6587	7820
Lead	µg/L	35	0	0	0.21	NC	1.1	2.7	3.3
Lithium	µg/L	35	0	0	1.1	NC	2.1	3.8	4.2
Magnesium	mg/L	1	0	0	3.1	NC	3.1	NC	3.1
Manganese	µg/L	35	0	0	23	NC	87	217	235
Mercury	µg/L	1	1.0	100	<0.01	<0.01	NC	NC	<0.01
Molybdenum	µg/L	35	0	0	0.41	NC	0.57	0.71	0.86
Nickel	µg/L	35	0	0	1.3	NC	6.6	16	29
Potassium	mg/L	1	0	0	0.72	NC	0.72	NC	0.72
Platinum	µg/L	34	27	79	<0.001	<0.001	NC	0.001	0.002
Selenium	µg/L	35	0	0	0.06	NC	0.10	0.17	0.41
Silver	µg/L	35	0	0	0.002	NC	0.015	0.037	0.049
Sodium	mg/L	0	-	-	-	-	-	-	-
Strontium	µg/L	35	0	0	69	NC	83	113	148
Thallium	µg/L	35	0	0	0.004	NC	0.019	0.042	0.047
Tin	µg/L	35	3.0	8.6	<0.005	NC	0.025	0.036	0.47
Titanium	µg/L	0	-	-	-	-	-	-	-
Tungsten	µg/L	34	2	6	<0.001	NC	0.0078	0.011	0.013
Uranium	µg/L	35	0	0	0.05	NC	0.26	0.40	0.43
Vanadium	µg/L	35	0	0	1.1	NC	4.5	11	13
Zinc	µg/L	35	0	0	1.9	NC	7.9	19	22
Dissolved Metals									
Aluminum	µg/L	33	0	0	4.3	NC	116	233	267
Antimony	µg/L	33	0	0	0.031	NC	0.045	0.061	0.07
Arsenic	µg/L	33	0	0	0.25	NC	0.37	0.48	0.58
Barium	µg/L	33	0	0	11	NC	14	17	36
Beryllium	µg/L	33	1.0	3.0	0.002	NC	0.0069	0.014	0.015
Bismuth	µg/L	33	11.0	33.0	<0.001	NC	0.0021	0.0038	0.017
Boron	µg/L	33	1.0	3.0	2.1	NC	5.7	17	43
Cadmium	µg/L	33	0	0	0.006	NC	0.016	0.032	0.05
Chromium	µg/L	33	1.0	3.0	0.08	NC	0.24	0.54	0.66
Cobalt	µg/L	33	0	0	0.015	NC	0.10	0.20	0.28
Copper	µg/L	14	0	0	0.77	NC	1.1	1.9	2.6
Iron	µg/L	33	0	0	12	NC	130	279	372
Lead	µg/L	33	0	0	0.0067	NC	0.077	0.16	0.18
Lithium	µg/L	33	0	0	0.63	NC	0.87	1.6	2.7
Manganese	µg/L	33	0	0	0.38	NC	10	18	74
Mercury	µg/L	1	1.0	100	<0.01	<0.01	NC	NC	<0.01
Molybdenum	µg/L	33	0	0	0.54	NC	0.71	0.93	0.96
Nickel	µg/L	33	0	0	0.38	NC	1.2	1.7	13
Platinum	ug/L	32	29	91	<0.001	<0.001	NC	0.001	0.001
Selenium	µg/L	33	0	0	0.05	NC	0.088	0.15	0.33
Silver	µg/L	33	9.0	27.0	<0.001	NC	0.0020	0.005	0.005
Strontium	µg/L	33	0	0	60	NC	74	93	148
Thallium	µg/L	33	1.0	3.0	<0.0028	NC	0.0049	0.0082	0.01
Tin	µg/L	33	23.0	70.0	<0.005	<0.005	NC	0.013	0.044
Titanium	µg/L	0	-	-	-	-	-	-	-
Tungsten	µg/L	32	2	6	<0.001	NC	0.0073	0.011	0.013
Uranium	µg/L	33	0	0	0.044	NC	0.18	0.22	0.24
Vanadium	µg/L	33	0	0	0.33	NC	0.63	1.1	1.2
Zinc	µg/L	33	3.0	9.1	<0.2	NC	0.45	0.9	1.0
Bacteria[f]									
Fecal Coliforms	MPN/100mL	70	0	0	5.0	NC	41	163	670
Enterococcus	MPN/100mL	70	15	21	2.0	NC	23	116	370
Escherichia coli	MPN/100mL	50	0	0	5.0	NC	27	111	140

Notes:

°C = degrees Celcius; µg/L = microgram per litre; µS/cm = microSiemen per centimetre; "<" = reported value is less than method detection limit (MDL); $CaCO_3$ = calcium carbonate; mg/L = milligram per litre; mL = millilitre; MPN = most probably number; N = nitrogen; NC = not calculated; P = phosphorus; ppt = parts per trillion; NTU = nephelometric turbidity unit.

1) Data sources were the Greater Vancouver Regional District Fraser River Ambient Monitoring Program, Metro Vancouver Annacis Wastewater Treatment Plant Initial Dilution Zone Boundary Monitoring Program and Environment Canada Pacific Water Quality Monitoring & Surveillance Program.

a) Minimum, maximum, and median reported as the method detection limit when the summary statistic corresponded to a non-detect (ND) value in the dataset.

b) Mean was not calculated for parameters with greater than 50% non-detect values. A median was reported where a mean was not calculated.

c) 95th percentile was not calculated for parameters with fewer than 10 samples.

d) 95th percentile was not calculated for parameters with more than 95% non-detect values.

e) Specific Conductivity and pH data were supplimented with lab measured data.

f) To align with Fraser River Water Quality Objectives, high flow was designated as April to October for bacterial parameters and geometric means were calculated in place of arithmetic means.

Table B-6: Summary of Fraser River Ambient Water Quality for the Annacis Island WWTP Stage 1 EIS Study Area (2011-2014) - Organic Parameters[1]

Parameter	Units	Number of Samples	Number of Samples <MDL	Percent of Samples <MDL	Minimum[a]	Median[a]	Mean[b]	95th[c,d]	Maximum[a]
Polycyclic Aromatic Hydrocarbons									
Acenaphthene	µg/L	7	7	100	<0.01	<0.01	NC	NC	<0.04
Acenaphthylene	µg/L	7	7	100	<0.01	<0.01	NC	NC	<0.01
Acridine	µg/L	7	7	100	<0.01	<0.01	NC	NC	<0.01
Anthracene	µg/L	7	7	100	<0.01	<0.01	NC	NC	<0.01
Benz(a)anthracene	µg/L	7	7	100	<0.01	<0.01	NC	NC	<0.01
Benzo(a)pyrene	µg/L	7	7	100	<0.01	<0.01	NC	NC	<0.01
Benzo(b)fluoranthene	µg/L	7	7	100	<0.01	<0.01	NC	NC	<0.02
Benzo(g,h,i)perylene	µg/L	7	6	86	<0.01	<0.01	NC	NC	0.02
Benzo(k)fluoranthene	µg/L	7	7	100	<0.01	<0.01	NC	NC	<0.01
Chrysene	µg/L	7	7	100	<0.01	<0.01	NC	NC	<0.01
Dibenz(a,h)anthracene	µg/L	7	7	100	<0.01	<0.01	NC	NC	<0.01
Fluoranthene	µg/L	7	7	100	<0.01	<0.01	NC	NC	<0.03
Fluorene	µg/L	7	7	100	<0.01	<0.01	NC	NC	<0.03
Indeno(1,2,3-c,d)pyrene	µg/L	7	7	100	<0.01	<0.01	NC	NC	<0.01
1-Methylnaphthalene	µg/L	7	7	100	<0.01	<0.05	NC	NC	<0.05
2-Methylnaphthalene	µg/L	7	7	100	<0.01	<0.05	NC	NC	<0.07
Naphthalene	µg/L	7	7	100	<0.05	<0.05	NC	NC	<0.2
Phenanthrene	µg/L	7	7	100	<0.02	<0.02	NC	NC	<0.09
Pyrene	µg/L	7	7	100	<0.01	<0.01	NC	NC	<0.03
Quinoline	µg/L	7	7	100	<0.01	<0.01	NC	NC	<0.01
Alkylphenols									
4-Nonylphenols	ng/L	24	14	58	<3.1	8.4	NC	25	<28
4-Nonylphenol monoethoxylates	ng/L	24	24	100	<2.8	<8.4	NC	NC	<52
4-Nonylphenol diethoxylates	ng/L	24	24	100	<2.6	<12	NC	NC	<54
Octylphenol	ng/L	24	24	100	<0.34	<2.5	NC	NC	<8.4
Nonylphenol TEQ	ng/L	24	20	83	<11	<22	NC	60	<89
Sterols and Hormones									
Androsterone	ng/L	21	21	100	<1.1	<3.2	NC	NC	<6.6
Desogestrel	ng/L	21	21	100	<0.67	<3	NC	NC	<11
17 alpha-Estradiol	ng/L	21	21	100	<0.24	<0.44	NC	NC	<0.94
Estrone	ng/L	21	21	100	<0.72	<1.6	NC	NC	<4.2
Equilin	ng/L	21	20	95	<1.3	<2.2	NC	6.4	<7.6
Androstenedione	ng/L	21	20	95	<5.9	<12	NC	26	<111
17 alpha-Dihydroequilin	ng/L	21	21	100	<0.51	<1	NC	NC	<7.8
17 beta-Estradiol	ng/L	21	13	62	<0.28	0.49	NC	0.86	<0.87
Testosterone	ng/L	21	21	100	<2.1	<5.9	NC	NC	<14
Equilenin	ng/L	21	21	100	<0.51	<1.4	NC	NC	<2.9
Mestranol	ng/L	21	20	95	<0.69	<1.7	NC	4.4	<4.6
Norethindrone	ng/L	21	21	100	<1.4	<3.6	NC	NC	<8.4
17 alpha-Ethinyl-Estradiol	ng/L	21	16	76	<0.37	0.76	NC	1.9	<2.1
Progesterone	ng/L	21	21	100	<1.4	<3.4	NC	NC	<26
Norgestrel	ng/L	21	21	100	<1.8	<3.4	NC	NC	<8.2
Estriol	ng/L	21	21	100	<0.55	<1.2	NC	NC	<23
beta-Estradiol 3-benzoate	ng/L	21	21	100	<0.9	<2	NC	NC	<9.7
Coprostanol	ng/L	21	0	0	17	NC	119	210	240
Epicoprostanol	ng/L	21	0	0	2.4	NC	14	26	40
Cholesterol	ng/L	21	0	0	237	NC	509	684	1240
Cholestanol	ng/L	21	0	0	21	NC	44	79	89
Desmosterol	ng/L	21	0	0	22	NC	49	80	95
Ergosterol	ng/L	20	5	24	<0.8	NC	7.1	18	21
Campesterol	ng/L	21	0	0	95	NC	226	400	443
Stigmasterol	ng/L	21	0	0	83	NC	227	398	422
beta-Sitosterol	ng/L	21	0	0	530	NC	1282	2100	2410
beta Stigmastanol	ng/L	21	0	0	146	NC	378	683	738
Pyrethroid Pesticides									
Allethrin	ng/L	4	4	100	<5.3	<6.2	NC	NC	<23
Prallethrin	ng/L	4	4	100	<13	<15	NC	NC	<30
Cinerin I	ng/L	4	4	100	<0.92	<1.3	NC	NC	<2.8
Jasmolin I	ng/L	4	4	100	<2.9	<4.3	NC	NC	<10
Pyrethrin I	ng/L	4	4	100	<2.3	<3.4	NC	NC	<5.6
Cinerin II	ng/L	4	4	100	<1.1	<1.4	NC	NC	<4.7
Jasmolin II	ng/L	4	4	100	<4.7	<5.5	NC	NC	<20
Pyrethrin II	ng/L	4	4	100	<3.2	<3.6	NC	NC	<14
Resmethrin	ng/L	4	4	100	<1	<1.3	NC	NC	<11
Piperonyl butoxide	ng/L	4	4	100	<0.59	<1.7	NC	NC	<2.8
Tetramethrin	ng/L	4	4	100	<0.7	<2.8	NC	NC	<4.1
Bifenthrin	ng/L	4	4	100	<0.58	<1.1	NC	NC	<2.3
Fenpropathrin	ng/L	4	4	100	<4.2	<9.1	NC	NC	<10
Phenothrin	ng/L	4	4	100	<0.52	<0.57	NC	NC	<1.3
Permethrin	ng/L	4	4	100	<0.5	<0.51	NC	NC	<0.76
L-Cyhalothrin	ng/L	4	4	100	<0.5	<0.51	NC	NC	<1.4
Cyfluthrin	ng/L	4	4	100	<1.8	<2.1	NC	NC	<5.2
Cypermethrin	ng/L	4	4	100	<0.64	<0.9	NC	NC	<2.2
Flucythrinate	ng/L	4	4	100	<0.5	<0.51	NC	NC	<1.3
Fenvalerate	ng/L	4	4	100	<0.5	<0.51	NC	NC	<1.8
Deltamethrin/Tralomethrin	ng/L	4	4	100	<0.58	<0.82	NC	NC	<3.8
Polychlorinated Biphenyls (PCBs)									
PCB-1	pg/L	4	0	0	0.92	NC	1.5	NC	2.3
PCB-2	pg/L	4	0	0	0.53	NC	1.1	NC	1.6
PCB-3	pg/L	4	0	0	1.4	NC	2.2	NC	2.6
PCB-4	pg/L	4	1	25	1.5	NC	3.6	NC	6.1
PCB-5	pg/L	4	4	100	<1	<1.4	NC	NC	<2.6
PCB-6	pg/L	4	4	100	<0.92	<1.3	NC	NC	<2.4
PCB-7	pg/L	4	0	0	3.2	NC	25	NC	71
PCB-8	pg/L	4	1	25	<0.88	NC	3.1	NC	5.8
PCB-9	pg/L	4	4	100	<0.9	<1.3	NC	NC	<2.4
PCB-10	pg/L	4	4	100	<0.86	<1.3	NC	NC	<2.4
PCB-11	pg/L	4	0	0	6.3	NC	11	NC	16
PCB-12 + 13	pg/L	4	4	100	<1	<1.8	NC	NC	<2.6
PCB-14	pg/L	4	4	100	<0.94	<1.3	NC	NC	<2.5
PCB-15	pg/L	4	0	0	1.3	NC	1.9	NC	3.0
PCB-16	pg/L	4	0	0	1.3	NC	2.1	NC	3.3
PCB-17	pg/L	4	0	0	1.4	NC	2.1	NC	2.7

Table B-6: Summary of Fraser River Ambient Water Quality for the Annacis Island WWTP Stage 1 EIS Study Area (2011-2014) - Organic Parameters[1]

Parameter	Units	Number of Samples	Number of Samples <MDL	Percent of Samples <MDL	Minimum[a]	Median[a]	Mean[b]	95th[c,d]	Maximum[a]
PCB-18 + 30	pg/L	4	0	0	3.1	NC	4.1	NC	5.4
PCB-19	pg/L	4	0	0	0.42	NC	0.89	NC	1.5
PCB-20 + 28	pg/L	4	0	0	4.3	NC	5.3	NC	5.9
PCB-21 + 33	pg/L	4	0	0	1.6	NC	2.4	NC	3.2
PCB-22	pg/L	4	0	0	1.1	NC	1.7	NC	2.2
PCB-23	pg/L	4	4	100	<0.19	<0.42	NC	NC	<1.1
PCB-24	pg/L	4	4	100	<0.19	<0.36	NC	NC	<0.77
PCB-25	pg/L	4	1	25	0.34	NC	0.53	NC	<0.84
PCB-26 + 29	pg/L	4	0	0	0.67	NC	0.99	NC	1.5
PCB-27	pg/L	4	2	50	0.25	NC	0.43	NC	<0.7
PCB-31	pg/L	4	0	0	3.3	NC	4.1	NC	5.0
PCB-32	pg/L	4	0	0	0.99	NC	1.3	NC	1.6
PCB-34	pg/L	4	4	100	<0.19	<0.41	NC	NC	<0.98
PCB-35	pg/L	4	4	100	<0.19	<0.43	NC	NC	<1.1
PCB-36	pg/L	4	4	100	<0.19	<0.4	NC	NC	<0.95
PCB-37	pg/L	4	0	0	0.84	NC	1.2	NC	1.6
PCB-38	pg/L	4	4	100	<0.19	<0.4	NC	NC	<0.97
PCB-39	pg/L	4	4	100	<0.19	<0.41	NC	NC	<0.97
PCB-40 + 41 + 71	pg/L	4	0	0	1.7	NC	2.3	NC	3.0
PCB-42	pg/L	4	0	0	0.72	NC	0.92	NC	1.1
PCB-43	pg/L	4	4	100	<0.19	<0.58	NC	NC	<1.2
PCB-44 + 47 + 65	pg/L	4	0	0	9.0	NC	13	NC	16
PCB-45 + 51	pg/L	4	0	0	3.9	NC	5.4	NC	7.9
PCB-46	pg/L	4	2	50	0.21	NC	0.62	NC	<1.1
PCB-48	pg/L	4	0	0	0.75	NC	0.97	NC	1.2
PCB-49 + 69	pg/L	4	0	0	1.9	NC	2.5	NC	3.1
PCB-50 + 53	pg/L	4	1	25	0.62	NC	0.79	NC	0.93
PCB-52	pg/L	4	0	0	3.8	NC	4.8	NC	6.4
PCB-54	pg/L	4	4	100	<0.19	<0.4	NC	NC	<0.86
PCB-55	pg/L	4	4	100	<0.19	<0.51	NC	NC	<1.2
PCB-56	pg/L	4	0	0	0.96	NC	1.1	NC	1.4
PCB-57	pg/L	4	4	100	<0.19	<0.48	NC	NC	<1
PCB-58	pg/L	4	4	100	<0.19	<0.49	NC	NC	<1
PCB-59 + 62 + 75	pg/L	4	2	50	0.33	NC	0.49	NC	<0.69
PCB-60	pg/L	4	1	25	0.52	NC	0.8	NC	<1.1
PCB-61 + 70 + 74 + 76	pg/L	4	0	0	4.0	NC	5.4	NC	7.7
PCB-63	pg/L	4	4	100	<0.19	<0.46	NC	NC	<1
PCB-64	pg/L	4	0	0	1.3	NC	1.6	NC	1.9
PCB-66	pg/L	4	0	0	2.0	NC	2.5	NC	3.5
PCB-67	pg/L	4	4	100	<0.19	<0.44	NC	NC	<0.93
PCB-68	pg/L	4	0	0	1.6	NC	2.4	NC	2.9
PCB-72	pg/L	4	4	100	<0.19	<0.46	NC	NC	<0.98
PCB-73	pg/L	4	4	100	<0.19	<0.38	NC	NC	<0.67
PCB-77	pg/L	4	1	25	0.29	NC	0.62	NC	<1.1
PCB-78	pg/L	4	4	100	<0.19	<0.51	NC	NC	<1.2
PCB-79	pg/L	4	4	100	<0.19	<0.42	NC	NC	<0.87
PCB-80	pg/L	4	4	100	<0.19	<0.46	NC	NC	<0.99
PCB-81	pg/L	4	4	100	<0.19	<0.51	NC	NC	<1.1
PCB-82	pg/L	4	3	75	0.3	<0.77	NC	NC	<1.3
PCB-83 + 99	pg/L	4	0	0	1.6	NC	2.4	NC	3.4
PCB-84	pg/L	4	0	0	0.79	NC	1.3	NC	1.9
PCB-85 + 116 + 117	pg/L	4	1	25	0.64	NC	0.87	NC	1.3
PCB-86 + 87 + 97 + 108 + 119 + 125	pg/L	4	0	0	2.3	NC	3.3	NC	4.8
PCB-88 + 91	pg/L	4	2	50	0.36	NC	0.74	NC	<1.1
PCB-89	pg/L	4	4	100	<0.19	<0.71	NC	NC	<1.2
PCB-90 + 101 + 113	pg/L	4	0	0	3.0	NC	4.5	NC	6.4
PCB-92	pg/L	4	0	0	0.53	NC	0.86	NC	1.2
PCB-93 + 95 + 98 + 100 + 102	pg/L	4	0	0	2.4	NC	4.3	NC	6.9
PCB-94	pg/L	4	4	100	<0.19	<0.74	NC	NC	<1.2
PCB-96	pg/L	4	4	100	<0.19	<0.37	NC	NC	<0.7
PCB-103	pg/L	4	4	100	<0.19	<0.59	NC	NC	<0.98
PCB-104	pg/L	4	4	100	<0.19	<0.36	NC	NC	<0.81
PCB-105	pg/L	4	0	0	1.3	NC	2.1	NC	3.5
PCB-106	pg/L	4	4	100	<0.19	<0.61	NC	NC	<1.4
PCB-107 + 124	pg/L	4	4	100	<0.19	<0.94	NC	NC	<1.5
PCB-109	pg/L	4	3	75	0.34	<0.61	NC	NC	<1.3
PCB-110 + 115	pg/L	4	0	0	3.2	NC	5.5	NC	8.8
PCB-111	pg/L	4	4	100	<0.19	<0.52	NC	NC	<0.87
PCB-112	pg/L	4	4	100	<0.19	<0.52	NC	NC	<0.85
PCB-114	pg/L	4	4	100	<0.19	<0.64	NC	NC	<1.5
PCB-118	pg/L	4	0	0	2.4	NC	4.8	NC	8.6
PCB-120	pg/L	4	4	100	<0.19	<0.49	NC	NC	<0.8
PCB-121	pg/L	4	4	100	<0.19	<0.51	NC	NC	<0.87
PCB-122	pg/L	4	4	100	<0.19	<0.67	NC	NC	<1.6
PCB-123	pg/L	4	4	100	<0.19	<0.64	NC	NC	<1.5
PCB-126	pg/L	4	4	100	<0.19	<0.67	NC	NC	<1.5
PCB-127	pg/L	4	4	100	<0.19	<0.64	NC	NC	<1.5
PCB-128 + 166	pg/L	4	2	50	0.44	NC	1.0	NC	<1.5
PCB-129 + 138 + 160 + 163	pg/L	4	0	0	2.8	NC	5.2	NC	9.0
PCB-130	pg/L	4	4	100	<0.49	<1.1	NC	NC	<1.8
PCB-131	pg/L	4	4	100	<0.48	<1.1	NC	NC	<1.7
PCB-132	pg/L	4	1	25	0.9	NC	1.6	NC	2.3
PCB-133	pg/L	4	4	100	<0.46	<1	NC	NC	<1.6
PCB-134 + 143	pg/L	4	4	100	<0.92	<1.1	NC	NC	<1.7
PCB-135 + 151 + 154	pg/L	4	0	0	0.89	NC	1.2	NC	1.7
PCB-136	pg/L	4	2	50	0.34	NC	0.59	NC	<0.74
PCB-137	pg/L	4	4	100	<0.48	<1	NC	NC	<1.6
PCB-139 + 140	pg/L	4	4	100	<0.43	<1	NC	NC	<1.6
PCB-141	pg/L	4	2	50	0.62	NC	1.2	NC	1.7
PCB-142	pg/L	4	4	100	<0.47	<1	NC	NC	<1.7
PCB-144	pg/L	4	4	100	<0.41	<0.83	NC	NC	<1
PCB-145	pg/L	4	4	100	<0.33	<0.66	NC	NC	<0.79
PCB-146	pg/L	4	3	75	<0.39	<1.2	NC	NC	<1.5

Table B-6: Summary of Fraser River Ambient Water Quality for the Annacis Island WWTP Stage 1 EIS Study Area (2011-2014) - Organic Parameters[1]

Parameter	Units	Number of Samples	Number of Samples <MDL	Percent of Samples <MDL	Minimum[a]	Median[a]	Mean[b]	95th[c,d]	Maximum[a]
PCB-147 + 149	pg/L	4	0	0	1.8	NC	3.0	NC	4.2
PCB-148	pg/L	4	4	100	<0.41	<0.84	NC	NC	<1
PCB-150	pg/L	4	4	100	<0.31	<0.63	NC	NC	<0.77
PCB-152	pg/L	4	4	100	<0.3	<0.59	NC	NC	<0.72
PCB-153 + 168	pg/L	4	0	0	2.2	NC	3.9	NC	5.9
PCB-155	pg/L	4	4	100	<0.19	<0.43	NC	NC	<0.68
PCB-156 + 157	pg/L	4	2	50	0.33	NC	0.9	NC	<1.5
PCB-158	pg/L	4	3	75	<0.3	<0.78	NC	NC	1.1
PCB-159	pg/L	4	4	100	<0.32	<0.72	NC	NC	<1.2
PCB-161	pg/L	4	4	100	<0.33	<0.71	NC	NC	<1.2
PCB-162	pg/L	4	4	100	<0.32	<0.75	NC	NC	<1.2
PCB-164	pg/L	4	4	100	<0.33	<0.76	NC	NC	<1.3
PCB-165	pg/L	4	4	100	<0.36	<0.82	NC	NC	<1.4
PCB-167	pg/L	4	4	100	<0.19	<0.46	NC	NC	<1.1
PCB-169	pg/L	4	4	100	<0.33	<0.67	NC	NC	<1.2
PCB-170	pg/L	4	3	75	<0.41	<0.62	NC	NC	<1.3
PCB-171 + 173	pg/L	4	4	100	<0.19	<0.84	NC	NC	<1.2
PCB-172	pg/L	4	4	100	<0.19	<0.62	NC	NC	<1.3
PCB-174	pg/L	4	2	50	0.4	NC	0.72	NC	<1.2
PCB-175	pg/L	4	4	100	<0.19	<0.55	NC	NC	<1.1
PCB-176	pg/L	4	4	100	<0.19	<0.41	NC	NC	<0.82
PCB-177	pg/L	4	2	50	0.24	NC	0.67	NC	<1.2
PCB-178	pg/L	4	4	100	<0.19	<0.58	NC	NC	<1.2
PCB-179	pg/L	4	3	75	0.24	<0.4	NC	NC	<0.82
PCB-180 + 193	pg/L	4	0	0	1.1	NC	1.9	NC	2.9
PCB-181	pg/L	4	4	100	<0.19	<0.61	NC	NC	<1.2
PCB-182	pg/L	4	4	100	<0.19	<0.54	NC	NC	<1.2
PCB-183 + 185	pg/L	4	4	100	<0.19	<0.74	NC	NC	<1.1
PCB-184	pg/L	4	4	100	<0.19	<0.4	NC	NC	<0.8
PCB-186	pg/L	4	4	100	<0.19	<0.45	NC	NC	<0.9
PCB-187	pg/L	4	0	0	0.67	NC	1.3	NC	2.4
PCB-188	pg/L	4	4	100	<0.19	<0.41	NC	NC	<0.78
PCB-189	pg/L	4	4	100	<0.19	<0.53	NC	NC	<1.3
PCB-190	pg/L	4	4	100	<0.19	<0.47	NC	NC	<0.96
PCB-191	pg/L	4	4	100	<0.19	<0.47	NC	NC	<0.93
PCB-192	pg/L	4	4	100	<0.19	<0.5	NC	NC	<1
PCB-194	pg/L	4	4	100	<0.19	<0.59	NC	NC	<1.3
PCB-195	pg/L	4	4	100	<0.19	<0.64	NC	NC	<1.4
PCB-196	pg/L	4	4	100	<0.19	<0.48	NC	NC	<1.1
PCB-197 + 200	pg/L	4	4	100	<0.19	<0.5	NC	NC	<0.8
PCB-198 + 199	pg/L	4	4	100	<0.41	<0.91	NC	NC	<1.1
PCB-201	pg/L	4	4	100	<0.19	<0.42	NC	NC	<0.75
PCB-202	pg/L	4	4	100	<0.19	<0.42	NC	NC	<0.8
PCB-203	pg/L	4	3	75	0.28	<0.48	NC	NC	<1
PCB-204	pg/L	4	4	100	<0.19	<0.42	NC	NC	<0.8
PCB-205	pg/L	4	4	100	<0.19	<0.47	NC	NC	<1.1
PCB-206	pg/L	4	3	75	0.32	<1.3	NC	NC	<2.1
PCB-207	pg/L	4	4	100	<0.19	<0.99	NC	NC	<1.6
PCB-208	pg/L	4	3	75	<0.2	<1.6	NC	NC	<1.8
PCB-209	pg/L	4	0	0	0.4	NC	1.1	NC	1.6
Total Monochloro Biphenyls	pg/L	2	0	0	3.4	NC	4.7	NC	5.9
Total Dichloro Biphenyls	pg/L	2	0	0	30	NC	33	NC	36
Total Trichloro Biphenyls	pg/L	2	0	0	28	NC	30	NC	32
Total Tetrachloro Biphenyls	pg/L	2	0	0	47	NC	49	NC	52
Total Pentachloro Biphenyls	pg/L	2	0	0	29	NC	36	NC	44
Total Hexachloro Biphenyls	pg/L	2	0	0	7.6	NC	17	NC	26
Total Heptachloro Biphenyls	pg/L	2	0	0	2.3	NC	2.3	NC	2.4
TOTAL PCBs	pg/L	4	0	0	105	NC	155	NC	192
Polybrominated Diphenyl Ethers (BDE)									
Di-BDE-7	pg/L	4	4	100	<0.38	<0.72	NC	NC	<1.1
Di-BDE-8 + 11	pg/L	4	4	100	<0.38	<0.71	NC	NC	<1
Di-BDE-10	pg/L	4	4	100	<0.38	<0.72	NC	NC	<1.2
Di-BDE-12 + 13	pg/L	4	4	100	<0.38	<0.71	NC	NC	<1
Di-BDE-15	pg/L	4	3	75	<0.43	<0.72	NC	NC	<1
Tri-BDE-17 + 25	pg/L	4	0	0	0.74	NC	1.2	NC	2.1
Tri-BDE-28 + 33	pg/L	4	0	0	1.0	NC	1.5	NC	2.3
Tri-BDE-30	pg/L	4	4	100	<0.38	<0.71	NC	NC	<1
Tri-BDE-32	pg/L	4	4	100	<0.38	<0.71	NC	NC	<1
Tri-BDE-35	pg/L	4	4	100	<0.38	<0.71	NC	NC	<1
Tri-BDE-37	pg/L	4	0	0	0.92	NC	1.6	NC	2.9
Tetra-BDE-47	pg/L	4	0	0	35	NC	55	NC	98
Tetra-BDE-49	pg/L	4	0	0	1.4	NC	2.0	NC	3.0
Tetra-BDE-51	pg/L	4	4	100	<0.38	<0.71	NC	NC	<1
Tetra-BDE-66	pg/L	4	1	25	<1	NC	1.6	NC	2.4
Tetra-BDE-71	pg/L	4	4	100	<0.38	<0.71	NC	NC	<1
Tetra-BDE-75	pg/L	4	4	100	<0.38	<0.71	NC	NC	<1
Tetra-BDE-77	pg/L	4	4	100	<0.38	<0.71	NC	NC	<1
Tetra-BDE-79	pg/L	4	4	100	<0.38	<0.71	NC	NC	<1
Penta-BDE-85	pg/L	4	0	0	1.1	NC	2.4	NC	4.6
Penta-BDE-99	pg/L	4	0	0	29	NC	49	NC	87
Penta-BDE-100	pg/L	4	0	0	7.2	NC	11	NC	19
Penta-BDE-105	pg/L	4	4	100	<0.43	<0.83	NC	NC	<1
Penta-BDE-116	pg/L	4	1	25	<1	NC	1.4	NC	2.2
Penta-BDE-119 + 120	pg/L	4	4	100	<0.43	<0.74	NC	NC	<1
Penta-BDE-126	pg/L	4	4	100	<0.38	<0.71	NC	NC	<1
Hexa-BDE-128	pg/L	4	4	100	<0.43	<3.4	NC	NC	<7.6
Hexa-BDE-138 + 166	pg/L	4	2	50	0.81	NC	1.7	NC	2.5
Hexa-BDE-140	pg/L	4	4	100	<0.43	<1	NC	NC	<1.4
Hexa-BDE-153	pg/L	4	0	0	3.3	NC	7.4	NC	14
Hexa-BDE-154	pg/L	4	0	0	2.7	NC	4.4	NC	7.0
Hexa-BDE-155	pg/L	4	4	100	<0.43	<0.93	NC	NC	<1
Hepta-BDE-181	pg/L	4	3	75	<0.41	<0.71	NC	NC	4.5
Hepta-BDE-183	pg/L	4	1	25	<1	NC	7.4	NC	19

Table B-6: Summary of Fraser River Ambient Water Quality for the Annacis Island WWTP Stage 1 EIS Study Area (2011-2014) - Organic Parameters[1]

Parameter	Units	Number of Samples	Number of Samples <MDL	Percent of Samples <MDL	Minimum[a]	Median[a]	Mean[b]	95th[c,d]	Maximum[a]
Hepta-BDE-190	pg/L	4	2	50	<0.43	NC	2.7	NC	8.2
Octa-BDE-203	pg/L	4	1	25	<1	NC	17	NC	43
Nona-BDE-206	pg/L	4	0	0	7.0	NC	23	NC	36
Nona-BDE-207	pg/L	4	0	0	9.9	NC	28	NC	45
Nona-BDE-208	pg/L	4	0	0	6.8	NC	24	NC	45
Deca-BDE-209	pg/L	4	0	0	174	NC	231	NC	266
Total Tri-BDE (maximum)	pg/L	4	0	0	4.0	NC	6.5	NC	10
Total Tetra-BDE (maximum)	pg/L	4	0	0	39	NC	62	NC	109
Total Penta-BDE (maximum)	pg/L	4	0	0	40	NC	65	NC	115
Total Hexa-BDE (maximum)	pg/L	4	0	0	13	NC	19	NC	31
Total Hepta-BDE (maximum)	pg/L	4	0	0	3.3	NC	12	NC	32
Total Nona-BDE (maximum)	pg/L	4	0	0	24	NC	74	NC	125

Notes:

µg/L = microgram per litre; "<" = reported value is less than method detection limit (MDL); ng/L = nanogram per litre; pg/L = picogram per litre; NC = not calculated.

1) Data sources were the Greater Vancouver Regional District Fraser River Ambient Monitoring Program, Metro Vancouver Annacis Wastewater Treatment Plant Initial Dilution Zone Boundary Monitoring Program and Environment Canada Pacific Water Quality Monitoring & Surveillance Program.
a) Minimum, maximum, and median reported as the method detection limit when the summary statistic corresponded to a non-detect (ND) value in the dataset.
b) Mean was not calculated for parameters with greater than 50% non-detect values. A median was reported where a mean was not calculated.
c) 95th percentile was not calculated for parameters with fewer than 10 samples.
d) 95th percentile was not calculated for parameters with more than 95% non-detect values.

Table B-7: Screening of Fraser River Ambient Water Quality for the Annacis Island WWTP Stage 1 EIS Study Area (2011-2014) - Conventional Parameters

Parameter	Units	**Fraser River Water Quality Objectives - Long Term[1]**	Notes	Fraser River Water Quality Objectives - Short Term[1]	Notes	BC WQG Short Term Guideline[2]	Notes	*BC WQG Long Term Average Guideline[2]*	Notes	CCME Short Term Guideline[3]	Notes	CCME Long Term Guideline[3]	Notes	High Flow ≥ 6,000 m^3/s	Moderate Flow < 6,000 m^3/s and ≥ 1,000 m^3/s	Low Flow < 1000 m^3/s	High Seasonal Flow - April to August	Low Seasonal Flow - September to March
														Mean/Median Concentration[4,5]	Mean/Median Concentration[4,5]	Mean/Median Concentration[4,5]	Mean/Median Concentration[4,5]	Mean/Median Concentration[4,5]
Conventional Parameters																		
pH	-	**6.5-8.5**				7-8.7	M/ES	*7-8.7*	M/ES			7 - 8.7	M/ES	7.8	7.4	7.7	7.7	7.5
Salinity	ppt											Less than 10% of baseline	I, M/ES	0.044	0.063	0.21	0.055	0.12
Conductivity	µS/cm													-	61	67	69	64
Specific conductivity	µS/cm													96	96	111	119	102
Temperature	°C					±1°C change from background (receiving environment temperature) with an hourly rate of change no greater than 0.5						Less than 1°C change due to human activities and less than 0.5°C/hour	FS, M/ES	13	13	3.6	13	8.6
Dissolved oxygen	mg/L	**80% saturation or 8 mg/L**	min	All areas: 5 mg/L (min); Fish spawning areas: 9 mg/L (min)	min	5-9	LS, min	*8-11*	LS, min			9.5	min, FS, LS	12	11	13	11	12
Dissolved organic carbon	mg/L							*± 20% median background*	FS					4.0	2.6	2.2	3.9	2.1
Hardness, as $CaCO_3$	mg/L													44	49	71	49	57
Total alkalinity, as $CaCO_3$	mg/L							*20*	Ca					*42*	*43*	*50*	*45*	*40*
Total dissolved solids	mg/L													-	86	304	-	249
Total organic carbon	mg/L													-	2.1	2.5	-	2.2
Total suspended solids	mg/L	**+10mg/L from background (<100mg/L); 10% of background (>100mg/L)**				+10 mg/L from background or +10% when background is >100 mg/L	LV	*See Table in 2015 BCWG Summary Document[8]*	FS			>5 mg/L from background (30-d) in clear waters; >10 mg/L from background in waters between 25-100 mg/L or >10% when background is >100 mg/L	FS, M/ES	112	26	12	81	15
Turbidity	NTU					+5 NTU if background <50 NTU; ± 10% if >50 NTU	LV	*See table in 2015 BC WQG Summary Document[8]*	FS			>2 NTUs for clear water (30-d period); >8 NTUs when background is between 8 & 80 NTUs, >10% of background when background >80 NTUs	FS, M/ES	68	22	5.6	55	8.1
Major Ions																		
Bicarbonate	mg/L													-	-	-	-	-
Carbonate	mg/L													-	-	-	-	-
Chloride	mg/L					100	IR	*150*	FS	640	FS	120	FS	1.4	8.7	71	5.2	35
Fluoride	mg/L					1 - 1.2	H, FS [a]					120	FS	0.038	0.035	0.042	0.038	0.033
Sulphate	mg/L							*218*	H, FS [a]					5.5	8.7	15	6.7	9.7
Calcium	mg/L													13	14	16	14	14
Magnesium	mg/L													2.6	3.5	7.9	3.5	5.2
Potassium	mg/L													0.65	0.89	2.3	0.82	1.5
Sodium	mg/L													1.8	9.0	72	4.2	37
Nutrients																		
Total ammonia	mg-N/L	**1.54 - 1.98**	FS, M/ES, T, pH [a]	8.02 - 14	FS, M/ES, T, pH [a]	8.02 - 14	FS, T, pH [b]	*1.54 - 1.98*	FS, T, pH [b]			1.033 - 2.855	FS, T, pH [a]	0.031	0.049	0.071	0.044	0.057
Un-ionized ammonia	mg/L											0.019	FS	0.00047	0.00028	0.0004	0.00053	0.00031
Total phosphorus	mg-P/L													0.19	0.059	0.03	0.13	0.031
Dissolved phosphorus	mg-P/L													0.0086	0.019	0.02	0.013	0.021
Nitrate	mg-N/L					32.8	FS	*3*	FS	124	FS	3	FS	0.018	0.068	0.19	0.042	0.12
Nitrate + nitrite	mg-N/L													0.09	0.19	0.2	0.2	0.16
Nitrite	mg-N/L	**0.02 - 0.2**	Cl [b]	0.06 - 0.6	Cl [b]	0.06 - 0.6	Cl [c]	*0.02 - 0.2*	Cl [c]			0.06	FS	0.0096	0.0042	0.0028	0.0091	0.0027
Total nitrogen (calculated)	mg-N/L													0.3	0.33	0.38	0.44	0.3
Total Phosphate - as P	mg-P/L													-	0.031	0.027	0.057	0.029
Total Metals																		
Aluminum	µg/L											100	pH, FS [b]	2464	579	173	1814	252
Antimony	µg/L							*9*	W, FS					0.086	0.053	0.067	0.078	0.055
Arsenic	µg/L							*5*	FS			5	FS	1.1	0.55	0.5	0.91	0.47
Barium	µg/L													40	20	16	34	16
Beryllium	µg/L							*0.13*	W, FS					0.068	0.019	<0.01	0.052	<0.01
Bismuth	µg/L													0.019	0.0077	<0.005	0.015	<0.005
Boron	µg/L							*500-1200*	IR, FS, M/ES	29000	FS	1500	FS	3.4	12	31	6.0	<10[9]
Cadmium	µg/L					0.12	W, M			0.91 - 1.48	H, FS [a]	*0.08 - 0.119*	H, FS [c]	0.061	0.027	0.018	0.057	0.017
Calcium	mg/L													-	14	16	15	15
Chromium	µg/L							*1*	W, V, FS [d]			1 [Cr(III)] 8.9 [Cr(VI)]	V, FS	*4.4*	*1.1*	0.37	*3.4*	0.47
Cobalt	µg/L					110	FS	*4*	FS					2.2	0.54	0.16	1.6	0.24

Parameter	Units	**Fraser River Water Quality Objectives - Long Term[1]**	Notes	Fraser River Water Quality Objectives - Short Term[1]	Notes	BC WQG Short Term Guideline[2]	Notes	*BC WQG Long Term Average Guideline[2]*	Notes	CCME Short Term Guideline[3]	Notes	CCME Long Term Guideline[3]	Notes	High Flow ≥ 6,000 m^3/s	Moderate Flow < 6,000 m^3/s and ≥ 1,000 m^3/s	Low Flow < 1000 m^3/s	High Seasonal Flow - April to August	Low Seasonal Flow - September to March
														Mean/Median Concentration[4,5]	Mean/Median Concentration[4,5]	Mean/Median Concentration[4,5]	Mean/Median Concentration[4,5]	Mean/Median Concentration[4,5]
Copper	µg/L	**2**	FS, M/ES, H [c]	2.1 - 3	FS, M/ES, H [c]	6 - 9	M/ES	*2 - 2.8*	M/ES; FS at hardness < 50 mg/L $CaCO_3$ [e]			2	H, FS [d]	***6.5***	*2.3*	1.4	***5.2***	1.5
Iron	µg/L					1000	FS					300	FS	3644	868	298	2725	381
Lead	µg/L	**2**	M/ES	28.6 - 40	FS, H [d]	28.6 - 52.7	H, FS [d]	*4.4 - 5.4*	H, FS [f]			1 - 2.05	H, FS [e]	1.5	0.42	0.16	1.1	0.22
Lithium	µg/L													2.4	1.3	1.7	2.1	1.3
Magnesium	mg/L													-	3.1	8.0	3.1	5.7
Manganese	µg/L			100		1023 - 1322	H, FS [e]	*798 - 948*	H, FS [l]					113	33	18	87	19
Mercury	µg/L					2	Ir	*0.00125-0.002*	MeHg, FS, M/ES [g]			0.016	I, M/ES	-	<0.01[9]	<0.01[9]	<0.01[9]	<0.01[9]
Molybdenum	µg/L					50	LV, IR, WI	*10*	IR			73	I, FS	0.54	0.66	0.81	0.57	0.74
Nickel	µg/L							*25*	W, FS			25 - 73.6	H, FS [f]	7.7	2.4	1.1	6.6	1.1
Potassium	mg/L													-	0.79	2.3	0.72	1.6
Platinum	ug/L													<0.001	<0.001	<0.001	<0.001	<0.001
Selenium	µg/L							*2*	FS, M/ES, WI			1	FS	0.091	0.09	0.14	0.1	0.11
Silver	µg/L					0.1	H, FS [f]	*0.05*	H, FS [h]			0.25	FS	0.019	0.0066	<0.005	0.015	<0.005
Sodium	mg/L													-	8.8	73	-	57
Strontium	µg/L													82	77	103	83	86
Sulphur	mg/L													-	<10	12	-	11
Thallium	µg/L							*0.8*	FS			0.8	FS	0.024	0.009	0.0067	0.019	0.0066
Tin	µg/L													0.01	0.026	0.033	0.025	<0.01
Titanium	µg/L													-	6.4	4.2	-	4.8
Tungsten	µg/L													0.0071	0.009	0.012	0.0078	0.0097
Uranium	µg/L							*8.5*	W, FS	33	FS	15	FS	0.29	0.21	0.22	0.26	0.2
Vanadium	µg/L							*50*	W, M/ES					5.9	1.6	0.97	4.5	0.95
Zinc	µg/L	**14**		30		33	H, FS [g]	*7.5*	H, FS [i]			30	FS	*10*	3.0	2.2	*7.9*	2.0
Dissolved Metals																		
Aluminum	µg/L					100	pH, FS [h]	*50*	pH, FS [j]					*138*	45	15	*116*	22
Antimony	µg/L													0.043	0.043	0.061	0.045	0.049
Arsenic	µg/L													0.37	0.34	0.39	0.37	0.35
Barium	µg/L													13	13	14	14	13
Beryllium	µg/L													0.0071	0.007	<0.01	0.0069	<0.01
Bismuth	µg/L													0.0014	0.003	<0.005	0.0021	<0.005
Boron	µg/L													3.2	12	<32	5.7	<11
Cadmium	µg/L					0.25 - 0.41	H, FS [i]	*0.12 - 0.16*	H, FS [k]					0.015	0.012	0.01	0.016	0.011
Chromium	µg/L													0.26	0.15	0.15	0.24	0.13
Cobalt	µg/L													0.11	0.05	0.038	0.1	0.036
Copper	µg/L													1.1	0.83	0.76	1.1	0.77
Iron	µg/L					350	FS							146	55	43	130	37
Lead	µg/L													0.09	0.033	0.02	0.077	0.021
Lithium	µg/L													0.73	0.86	1.6	0.87	1.1
Manganese	µg/L													9.1	6.4	8.5	10	6.3
Mercury	µg/L													-	<0.01	<0.01	<0.01	<0.01
Molybdenum	µg/L													0.72	0.72	0.84	0.71	0.77
Nickel	µg/L													0.84	0.72	0.53	1.2	0.49
Platinum	ug/L													<0.001	<0.001	<0.001	<0.001	0.001
Selenium	µg/L													0.076	0.083	0.12	0.088	0.095
Silver	µg/L													0.0017	0.004	<0.005	0.002	<0.005
Strontium	µg/L													70	74	103	74	85
Sulphur	mg/L													-	<10	12	-	<10
Thallium	µg/L													0.0044	0.0046	<0.002	0.0049	0.0049
Tin	µg/L													<0.005	0.008	<0.011	<0.005	<0.01
Titanium	µg/L													-	<0.5	<0.5	-	<0.5
Tungsten	µg/L													0.0063	0.0083	0.006	0.0073	0.0083
Uranium	µg/L													0.18	0.17	0.2	0.18	0.19
Vanadium	µg/L													0.69	0.39	0.62	0.63	0.44
Zinc	µg/L													0.46	0.53	0.84	0.45	0.68
Bacteria[10]																		
Fecal Coliforms	MPN/100mL	**200**	geo mean, Apr-Oct, CFU			0	LV							NC	NC	NC	41	120
Enterococus	MPN/100mL	**20**	geo mean, Apr-Oct, CFU			0	LV							NC	NC	NC	**23**	**23**
Escherichia coli	MPN/100mL	**77**	geo mean, Apr-Oct, CFU			0	LV							NC	NC	NC	27	**92**

Notes:
min = minimum objective; LS = Lifestage dependant guideline; LV = guideline for lifestock; M/ES = marine/estuarine guideline aquatic life guideline; IR = guideline for irrigation; FS = freshwater aquatic life guideline; T = temperature dependant guideline; W = working guideline; pH = pH dependant guideline; Cl = chloride dependant guideline; WI = wildlife guideline; NC = not calculated; < = reported value is less than method detection limit (MDL); MeHg = methyl mercury (MeHg) dependent guideline; I = interim guideline; V = valence dependant guideline; µg/L = micrograms per liter; mg/L = milligrams per liter; MPN/100mL = most probable number of colony forming units per one hundred milliliters of water; µS/cm = microseimens per centimeter; Ca = calcium dependant guideline; Apr-Oct = guideline only
Where freshwater and marine/estuarine guidelines were available, the most conservative values were used for screening.

Un-ionized ammonia values are calculated using the equation: un-ionized ammonia = total ammonia x 1/(1 + $10^{(pKa-pH)}$) where pKa is: 0.09018+2729.92/temperature, mean temperatures and pHs are used for the mean un-ionized ammonia calculation and maximum temperature and pH are used for the maximun un-ionized ammonia calculation.

[1] Water Quality Assessment and Objectives for the Fraser River From Hope to Sturgeon and Roberts Banks First Update, Freshwater, Estuarine or Marine Water Quality Criteria for the Fraser River Main Arm from the New Westminister Triurcation to the Banks. Accessed May 2016. Available online at http://www.dfo-mpo.gc.ca/Library/272539.pdf

[2] British Columbia Ministry of Environment Approved Water Quality Guidelines (2016) for freshwater/estuarine/marine aquatic life. Accessed May 2016. Available online at: http://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/waterquality/waterqualityguidesobjs/approved-wat-qual-guides/final_approved_wqg_summary_march_2016.pdf where approved guidelines were not available working guidelines were used for screening.Accessed May 2016. Available at http://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/waterquality/waterqualityguidesobjs/final_2015_wwqgs_26_nov_2015.pdf

[3] Canadian Council of Ministers of the Environment (CCME) Surface Water Guidelines for the Protection of Aquatic Life freshwater and marine guidelines. Accessed May 2016. Available online at: http://st-ts.ccme.ca/en/index.html?chems=all&chapters=1

[4] Median reported as the method detection limit when the summary statistic corresponded to a non-detect (ND) value in the dataset.

[5] Mean was not calculated for parameters with greater than 50% non-detect values. A median was reported where a mean was not calculated.

[6] 95th percentile was not calculated for parameters with fewer than 10 samples.

[7] 95th percentile was not calculated for parameters with more than 95% non-detect values.

[8] Guidelines are dependant on water bed substrate size, substrate size is not available for data so guidelines are not presented.

[9] Screening value was less than method detection limit.

[10] Due to the temporal restrictions of the Fraser River Objectives for bacteria, ambient water quality data was sorted to align with these parameters. Ambient data were divided by season; high flow season consisted of April to October and low flow season consisted of November to March. To align with screening values, instead of arithmetic means, geometric means were calculated.

Number	Exceeds the Most Conservative Freshwater/Marine/EstuarineFraser River Long Term Water Quality Objectives
Number	Exceeds the Most Conservative Freshwater/Marine/EstuarineFraser River Short Term Water Quality Objectives
Number	Exceeds the Most Conservative Freshwater/Marine/Estuarine BC WQG Short Term Guidelines
Number	Exceeds the Most Conservative Freshwater/Marine/Estuarine BC WQG Short Term Guidelines
Number	Exceeds the Most Conservative Freshwater/Marine/Estuarine CCME Short Term Guidelines
Number	Exceeds the Most Conservative Freshwater/Marine/Estuarine CCME Long Term Guidelines

Equation Notes for Fraser River Long Term Water Quality Objectives
a) pH and temperature dependent ammonia WQO values selected from Table 11 in BC WQO document based on mean temperature and pH of the flow scenario.
b) Chloride dependent nitrite WQO (mg/L) = 0.02 mg/L at Cl <2 mg/L; at Cl 2-4 mg/l = 0.04; at Cl 4-6 mg/L = 0.06; at Cl 6-8 mg/L = 0.08; at Cl 8-10 mg/L = 0.1; at Cl >10 = 0.2
c) Hardness dependent Cu WQO (µg/L) = minimum value of (0.04*hardness)+2) and 2.

Equation Notes for Fraser River Short Term Water Quality Objectives
a) pH and temperature dependent ammonia WQO values selected from Table 12 in BC WQO document based on based on mean temperature and pH of the flow scenario.
b) Chloride dependent nitrite guideline: WQO (mg/L) = 0.06 at Cl <2 mg/L; at Cl 2-4 mg/L = 0.12; at Cl 4-6 mg/L = 0.18; at Cl 6-8 mg/L = 0.24; at Cl 8-10 = 0.30; at Cl >10 = 0.6.
c) Hardness dependent Cu WQO (µg/L) = minimum value of [(0.094*hardness)+2] and 3.
d) Hardness dependent Pb WQO (µg/L) = EXP((1.273*(ln(hardness))-1.46).

Equation Notes for BC WQG Short Term Guideline
a) Hardness dependent fluoride guideline: BC max WQG (mg/L) =-51.73+(92.57*log(hardness))*0.01 at hardness ≥ 10; 0.4 mg/L at hardness <10.
b) pH and temperature dependent ammonia guideline: values selected from Table 3 in BC WQG based on mean temperature and pH of the flow scenario.
c) Chloride dependent nitrite guideline: BC max WQG (mg/L) = 0.06 at Cl <2 mg/L; at Cl 2-4 mg/L = 0.12; at Cl 4-6 mg/L = 0.18; at Cl 6-8 mg/L = 0.24; at Cl 8-10 = 0.30; at Cl >10 = 0.6.
d) Hardness dependent Pb guideline: BC max WQG (µg/L) = exp(1.273*ln(hardness)-1.46) at hardness ≥ 8; 3 at hardness < 8.
e) Hardness dependent Mn guideline: BC max WQG (µg/L) = (0.01102*(hardness)+0.54)*1000.
f) Hardness dependent Ag guideline: BC max WQG (µg/L) = 0.1 at hardness ≤100 mg/L; at hardness >100 mg/L = 3.
g) Hardness dependent Zn guideline: BC max WQG (µg/L) = 33+0.75(hardness-90).
h) pH dependent dissolved Al guideline: BC max WQG (µg/L) = (exp(1.209-2.426*(pH)+0.286*(pH2)))*1000 at pH <6.5; 100 at pH ≥6.5 .
i) Hardness dependent dissolved Cd guideline: max BC WQG (µg/L) = exp(1.03*ln(hardness)-5.274).

Equation Notes for BC WQG Long Term Average Guideline
a) Hardness dependent sulphate guideline: BC 30-d WQG (mg/L) = 128 at hardness <30 mg/L; at hardness 31-75 mg/L = 218; at hardness 76-180 mg/L = 309; at hardness 181-250 mg/L = 429; at hardness >250 mg/L determine base on site water.
b) pH and temperature dependent ammonia guideline: values selected from Table 4 in BC WQG based on maximum temperature and corresponding pH.
c) Chloride dependent nitrite guideline: BC 30-d WQG (mg/L) = 0.02 mg/L at Cl <2 mg/L; at Cl 2-4 mg/l = 0.04; at Cl 4-6 mg/L = 0.06; at Cl 6-8 mg/L = 0.08; at Cl 8-10 mg/L = 0.1; at Cl >10 = 0.2.
d) Guideline is for Cr(VI).
e) Hardness dependent Cu guideline for FS: BC 30-d WQG (µg/L) = 2 at hardness ≤50 mg/L; at hardness >50 mg/L = 0.04*hardness.
f) Hardness dependent Pb guideline: BC 30-d WQG (µg/L) = 3.31 + exp(1.273*ln(hardness) - 4.704) at hardness > 8 mg/L.
g) Hg BC 30-d WQG (µg/L) = 0.0001/(MeHg/THg), where MeHg is mass (or concentration) of methyl mercury and THg is total mass (or concentration) of mercury in a given water volume. Range is 0.02 µg/L for 0.5% and 0.00125 µg/L for 8% MeHg.
h) Hardness dependent Ag guideline: BC 30-d WQG (µg/L) = 0.05 at hardness ≤100 mg/L; at hardness > 100 mg/L = 1.5.
i) Hardness dependent Zn guideline: BC 30-d WQG (µg/L) = 7.5+0.75(hardness-90).
j) pH dependent dissolved Al guideline: BC 30-d WQG (µg/L) = (exp(1.6-3.327*(median pH)+0.402*(median pH2)))*1000 at pH <6.5; 50 at pH ≥6.5.
k) Hardness dependent dissolved Cd guideline: BC 30-d WQG (µg/L) = exp(0.736*ln(hardness)-4.943).
l) Hardness dependent Mn guideline: BC 30-d WQG (µg/L) = (0.0044*hardness+0.605)*1000.

Equation Notes for CCME Short Term Guideline
a) Hardness dependent Cd guideline: CCME WQG (µg/L) = 10^((1.016*(log(hardness)))-1.71) at hardness ≥ 5.3 to ≤ 360 mg/L; 0.11 at hardness < 5.3 mg/L; 7.7 at hardness > 360 mg/L.

Equation Notes for CCME Long Term Guideline
a) pH and temperature dependent ammonia guideline: values calculated from an equation based on Table 2 in the CCME WQG document where WQG (NH3-N) = (0.019*(1/(1/(1+(10^((0.0901821+(2729.92/(273.15+temperature)))-pH))))))*0.8224 where mean pH and temperature of the flow scenario were used for the calculation.
b) pH dependent Al guideline: CCME WQG (µg/L) = 5 at at pH < 6.5; 100 at pH ≥ 6.5.
c) Hardness dependent Cd guideline: CCME WQG (µg/L) = 10^((0.83*(LOG(hardness))-2.46) at hardness ≥ 17 to ≤ 280 mg/L; 0.04 at hardness < 17 mg/L; 0.37 at hardness > 280 mg/L.
d) Hardness dependent Cu guideline: CCME WQG (µg/L) = 0.2*(EXP((0.8545*(LN(hardness)))-1.465) at hardness ≥ 82 to ≤ 180 mg/L; 2 at hardness < 82 mg/L; 4 at hardness > 180 mg/L.
e) Hardness dependent Pb guideline: CCME WQG (µg/L) = EXP((1.273*(LN(hardness)))-4.705 at hardness > 60 to ≤ 180 mg/L; 1 mg/L at hardness ≤ 60 mg/L; 7 at hardness > 180 mg/L.
f) Hardness dependent Ni guideline: CCME WQG (µg/L) = EXP((0.76*(LN(hardness)))+1.06) at hardness > 60 to ≤ 180 mg/L; 25 mg/L at hardness ≤ 60 mg/L; 150 at hardness > 180 mg/L.

Table B-8: Screening of Fraser River Ambient Water Quality for the Annacis Island WWTP Stage 1 EIS Study Area (2011-2014) - Organic Parameters

Parameter	Units	Fraser River Water Quality Objectives[1]	Notes	BC WQG Short Term Guideline[2]	Notes	*BC WQG Long Term Average Guideline*[2]	Notes	CCME Short Term Guideline[3]	Notes	CCME Long Term Guideline[3]	Notes	Lower Fraser River Ambient Water Quality (2011-2014) Mean/Median Concentration[4,6]
Polycyclic Aromatic Hydrocarbons												
Acenaphthene	µg/L			6	M/ES	*6*	FS			5.8	FS	<0.01
Acenaphthylene	µg/L											<0.01
Acridine	µg/L					*0.05*	p, FS			4.4	I, FS	<0.01
Anthracene	µg/L					*0.1*	p, FS			0.012	I, FS	<0.01
Benzo(a)anthracene	µg/L					*0.1*	p, FS			0.018	I, FS	<0.01
Benzo(a)pyrene	µg/L			0.01	M/ES	*0.01*	FS			0.015	I, FS	<0.01
Benzo(b)fluoranthene	µg/L											<0.01
Benzo(g,h,i)perylene	µg/L											<0.01
Benzo(k)fluoranthene	µg/L											<0.01
Chrysene	µg/L			0.1	M/ES							<0.01
Dibenz(a,h)anthracene	µg/L											<0.01
Fluoranthene	µg/L					*0.2*	p, FS			0.04	I, FS	<0.01
Fluorene	µg/L			12	M/ES	*12*	FS			3	I, FS	<0.01
Indeno(1,2,3-c,d)pyrene	µg/L											<0.01
1-Methylnaphthalene	µg/L			1	M/ES							<0.05
2-Methylnaphthalene	µg/L			1	M/ES							<0.05
Naphthalene	µg/L			1	M/ES	*1*	FS			1.1	I, FS	<0.05
Phenanthrene	µg/L					*0.3*	FS			0.4	I, FS	<0.02
Pyrene	µg/L					*0.02*	p, FS			0.025	I, FS	<0.01
Quinoline	µg/L					*3.4*	W, FS			3.4	I, FS	<0.01
Alkylphenols												
4-Nonylphenols	ng/L											8.4
4-Nonylphenol monoethoxylates	ng/L											<8.4
4-Nonylphenol diethoxylates	ng/L											<12
Octylphenol	ng/L											<2.5
Nonylphenol TEQ	ng/L					*700*				700	I, M/ES	<22
Sterols and Hormones												
17 α-Ethinyl-Estradiol	ng/L			0.75	FS	*0.5*	FS					*0.76*
Campesterol	ng/L											226
β-Sitosterol	ng/L											1282
β-Stigmastanol	ng/L											378
Pyrethroid Pesticides												
Permethrin	ng/L									1	I, M/ES	<0.51
Deltamethrin/Tralomethrin	ng/L					*0.4*	W, FS			0.4	FS	<0.82
Polychlorinated Biphenyls												
PCB-77	pg/L			40	FS, M/ES							0.62
PCB-105	pg/L			90	FS, M/ES							2.1
PCB-126	pg/L			0.25	FS, M/ES							<0.67
PCB-169	pg/L			60	FS, M/ES							<0.67
Total PCBs	pg/L			100	FS, M/ES							155
Polybrominated Diphenyl Ethers												
Penta-BDE-99	pg/L									3900	[5]	49
Penta-BDE-100	pg/L									230	[5]	11
Tri BDE (total)	pg/L									46,000	[5]	6.5
Tetra BDE (total)	pg/L									24,000	[5]	62
Penta BDE (total)	pg/L									3900	[5]	65
Hexa BDE (total)	pg/L									120,000	[5]	19
Hepta BDE (total)	pg/L									170,000	[5]	12
Octa BDE (total)	pg/L									170,000	[5]	17

Notes:

< = reported value is less than method detection limit (MDL); ng/L = microgram per litre; FS = freshwater guideline; I = interim guideline; M/ES = marine or estuarine guideline; p = guideline is for phototoxicity; pg/L = picogram per litre; TWQ = toxic equivalency; W = working guideline.

Where freshwater and marine/estuarine guidelines were available, the most conservative values were used for screening.

[1] Water Quality Assessment and Objectives for the Fraser River From Hope to Sturgeon and Roberts Banks First Update, Freshwater, Estuarine or Marine Water Quality Criteria for the Fraser River Main Arm from the New Westminister Triurcation to the Banks. Accessed May 2016. Available online at http://www.dfo-mpo.gc.ca/Library/272539.pdf

[2] British Columbia Ministry of Environment Approved Water Quality Guidelines (2015) for freshwater/estuarine/marine aquatic life. Accessed May 2016. Available at: http://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/waterquality/waterqualityguidesobjs/approved-wat-qual-guides/final_approved_wqg_summary_march_2016.pdf. Where approved guidelines were not available, working guidelines were used for screening. Accessed May 2016. Available at http://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/waterquality/waterqualityguidesobjs/final_2015_wwqgs_26_nov_2015.pdf.

[3] Canadian Council of Ministers of the Environment (CCME) SedGuidelines for the Protection of Aquatic Life freshwater and marine sediment quality guidelines. Accessed May 2016. Available online at: http://st-ts.ccme.ca/en/index.html?chems=all&chapters=3.

[4] Mean was not calculated for parameters with greater than 50% non-detect values. A median was reported where a mean was not calculated.

[5] Guidelines obtained from Environment Canada. 2013. Canadian Environmental Protection Act, 1999. Federal Environmental Quality Guidelines: Polybrominated Diphenyl Ethers (PBDEs). February 2013. Accessed July 2016. Available at https://www.ec.gc.ca/ese-ees/default.asp?lang=En&n=05DF7A37-1

[6] Median reported as the method detection limit when the summary statistic corresponded to a non-detect (ND) value in the dataset.

Number	Exceeds Fraser River Water Quality Objectives
Number	Exceeds the Most Conservative Freshwater/Marine/Estuarine BC WQG Short Term Guidelines
Number	Exceeds the Most Conservative Freshwater/Marine/Estuarine BC WQG Short Term Guidelines
Number	Exceeds the Most Conservative Freshwater/Marine/Estuarine CCME Short Term Guidelines
Number	Exceeds the Most Conservative Freshwater/Marine/Estuarine CCME Long Term Guidelines

Table B-9: Screening of Fraser River Ambient Water Quality for the Annacis Island WWTP Stage 1 EIS Study Area (2011-2014) - Human Health (Conventional Parameters)

Parameter	Units	Selected Recreational Screening Criterion[1]	Notes		Instantaneous Concentrations			Average 30-day Concentrations	
					High Flow ≥ 6,000 m^3/s	Moderate Flow < 6,000 m^3/s and ≥ 1,000	Low Flow < 1000 m^3/s	High Seasonal Flow - April to August	Low Seasonal Flow - September to March
Conventional Parameters									
pH	-	**5.0 to 9.0**	R	BC, HC	7.8	7.4	7.7	7.7	7.5
Salinity	ppt				0.044	0.063	0.21	0.055	0.12
Conductivity	µS/cm				-	61	67	69	64
Specific conductivity	µS/cm				96	96	111	119	102
Temperature	°C	**30**	R	BC	13	13	3.6	13	8.6
Dissolved oxygen	mg/L				12	11	13	11	12
Dissolved organic carbon	mg/L				4.0	2.6	2.2	3.9	2.1
Hardness, as $CaCO_3$	mg/L				44	49	71	49	57
Total alkalinity, as $CaCO_3$	mg/L				42	43	50	45	40
Total dissolved solids	mg/L				-	86	304	-	249
Total organic carbon	mg/L				-	2.1	2.5	-	2.2
Total suspended solids	mg/L				112	26	12	81	15
Turbidity	NTU	**± 5 if background <50 NTU; ± 10% if >50**	R	BC	68	22	5.6	55	8.1
Major Ions									
Chloride	mg/L	**250**	DW	BC[2]	1.4	8.7	71	5.2	35
Fluoride	mg/L	**15**	DW	BC, HC	0.038	0.035	0.042	0.038	0.033
Sulphate	mg/L				5.5	8.7	15	6.7	9.7
Calcium	mg/L				13	14	16	14	14
Magnesium	mg/L				2.6	3.5	7.9	3.5	5.2
Potassium	mg/L				0.65	0.89	2.3	0.82	1.5
Nutrients									
Ammonia (un-ionized)	mg-N/L				0.00047	0.00028	0.00040	0.00053	0.00031
Total ammonia	mg-N/L				0.031	0.049	0.071	0.044	0.057
Total phosphorus	mg-P/L				0.19	0.059	0.03	0.13	0.031
Dissolved phosphorus	mg-P/L				0.0086	0.019	0.02	0.013	0.021
Nitrate	mg-N/L	**100**	DW	BC, HC	0.018	0.068	0.19	0.042	0.12
Nitrate + nitrite	mg-N/L	**10**	R	BC	0.090	0.19	0.20	0.20	0.16
Nitrite	mg-N/L	**1**	R	BC	0.0096	0.0042	0.0028	0.0091	0.0027
Total nitrogen (calculated)	mg-N/L				0.30	0.33	0.38	0.44	0.30
Total Phosphate - as P	mg-P/L				-	0.031	0.027	0.057	0.029
Total Metals									
Aluminum	µg/L	**40000**	DW	EPA	2464	579	173	1814	252
Antimony	µg/L	**60**	DW	HC	0.086	0.053	0.067	0.078	0.055
Arsenic	µg/L	**100**	DW	HC	1.1	0.55	0.5	0.91	0.47
Barium	µg/L	**10000**	DW	HC	40	20	16	34	16
Beryllium	µg/L	**50**	DW	EPA	0.068	0.019	<0.01	0.052	<0.01
Bismuth	µg/L				0.019	0.0077	<0.005	0.015	<0.005
Boron	µg/L	**50000**	DW	BC, HC	3.4	12	31	6.0	<10
Cadmium	µg/L	**50**	DW	HC	0.061	0.027	0.018	0.057	0.017
Chromium	µg/L	**500**	DW	HC	4.4	1.1	0.37	3.4	0.47
Cobalt	µg/L	**12**	DW	EPA	2.2	0.54	0.16	1.6	0.24
Copper	µg/L	**1000**	R	BC	6.5	2.3	1.4	5.2	1.5
Iron	µg/L	**28000**	DW	EPA	3644	868	298	2725	381
Lead	µg/L	**50**	R	BC	1.5	0.42	0.16	1.1	0.22
Lithium	µg/L	**80**	DW	EPA	2.4	1.3	1.7	2.1	1.3
Manganese	µg/L	**860**	DW	EPA	113	33	18	87	19
Mercury	µg/L	**10**	DW	BC, HC	-	<0.01	<0.01	<0.01	<0.01
Molybdenum	µg/L	**2500**	DW	BC	0.54	0.66	0.81	0.57	0.74
Nickel	µg/L	**780**	DW	EPA	7.7	2.4	1.1	6.6	1.1
Platinum	µg/L				<0.001	<0.001	<0.001	<0.001	<0.001
Selenium	µg/L	**100**	DW	BC	0.091	0.09	0.14	0.10	0.11
Silver	µg/L	**188**	DW	EPA	0.019	0.0066	<0.005	0.015	<0.005
Strontium	µg/L	**24000**	DW	EPA	82	77	103	83	86
Thallium	µg/L	**0.4**	DW	EPA	0.024	0.009	0.0067	0.019	0.0066
Tin	µg/L	**24000**	DW	EPA	0.010	0.026	0.033	0.025	<0.01
Titanium	µg/L				-	6.4	4.2	-	4.8
Tungsten	µg/L	**32**	DW	EPA	0.0071	0.009	0.012	0.0078	0.0097
Uranium	µg/L	**200**	DW	HC	0.29	0.21	0.22	0.26	0.20
Vanadium	µg/L	**172**	DW	EPA	5.9	1.6	0.97	4.5	0.95
Zinc	µg/L	**5000**	R	BC	10	3.0	2.2	7.9	2.0
Dissolved Metals									
Aluminum	µg/L	**200**	R	BC	138	45	15	116	22
Antimony	µg/L				0.043	0.043	0.061	0.045	0.049
Arsenic	µg/L				0.37	0.34	0.39	0.37	0.35
Barium	µg/L				13	13	14	14	13
Beryllium	µg/L				0.0071	0.0070	<0.01	0.0069	<0.01
Bismuth	µg/L				0.0014	0.0030	<0.005	0.0021	<0.005
Boron	µg/L				3.2	12	<32	5.7	<11
Cadmium	µg/L				0.015	0.012	0.010	0.016	0.011
Chromium	µg/L				0.26	0.15	0.15	0.24	0.13
Cobalt	µg/L				0.11	0.05	0.038	0.10	0.036
Copper	µg/L				1.1	0.83	0.76	1.1	0.77
Iron	µg/L				146	55	43	130	37
Lead	µg/L				0.090	0.033	0.020	0.077	0.021
Lithium	µg/L				0.73	0.86	1.6	0.87	1.1
Manganese	µg/L				9.1	6.4	8.5	10	6.3
Mercury	µg/L				-	<0.01	<0.01	<0.01	<0.01
Molybdenum	µg/L				0.72	0.72	0.84	0.71	0.77
Nickel	µg/L				0.84	0.72	0.53	1.2	0.49
Platinum	µg/L				<0.001	<0.001	<0.001	<0.001	0.0010
Selenium	µg/L				0.076	0.083	0.12	0.088	0.095
Silver	µg/L				0.0017	0.0040	<0.005	0.0020	<0.005
Strontium	µg/L				70	74	103	74	85
Thallium	µg/L				0.0044	0.0046	<0.002	0.0049	0.0049
Tin	µg/L				<0.005	0.008	<0.011	<0.005	<0.01
Titanium	µg/L				-	<0.5	<0.5	-	<0.5
Tungsten	µg/L				0.0063	0.0083	0.006	0.0073	0.0083
Uranium	µg/L				0.18	0.17	0.20	0.18	0.19
Vanadium	µg/L				0.69	0.39	0.62	0.63	0.44
Zinc	µg/L				0.46	0.53	0.84	0.45	0.68
Bacteria[3]									
Fecal Coliforms	MPN/100mL	200	R	BC	-	-	-	35	-
Enterococus	MPN/100mL	100	R	BC	-	-	-	15	-
Escherichia Coli	MPN/100mL	385	R	BC	-	-	-	27	-

Notes:

Bold	Exceeds the most conservative recreational guideline protective of human health

µg/L = micrograms per liter; mg/L = milligrams per liter; µS/cm = microseimens per centimeter; ppt = parts per trillion; mg N/L = milligrams Nitrogen per liter; mg P/L = milligrams Phosphorus per liter;°C = degrees Celsius; NTU = Nephelometric Turbidity Unit; < = reported value is less than method detection limit (MDL); $CaCO_3$ = Calcium Carbonate; P = Phosphorus; MPN/100mL = most probable number of colony forming units per one hundred milliliters of water; R = Recreational Guideline; DW = Drinking Water Guideline (x10); BC = British Columbia Approved Water Quality Guidelines; HC = Guidelines for Canadian Drinking Water Quality (Health Canada); EPA = Environmental Protection Agency; NC = not calculated

(1) Values were preferentially selected from the BC Approved Water Quality Guidelines (WQG) Summary Report (March 2016) for secondary recreational contact. If no recreational value was available, the drinking water guideline multiplied by 10 was used. Health-based drinking water guidelines were obtained from the BC Approved WQGs (2016) and Guidelines for Canadian Drinking Water Quality (Health Canada 2014), with the most conservative value selected preferentially. The US EPA (2016) tapwater RSLs were used when a BC or Health Canada value was not available. The RSLs were adjusted to reflect an HQ of 0.2 and ILCR of 10^{-5} (target risk levels for Canada). The BC Approved WQG Summary Report [accessed July 2016] available at: http://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-quality/water-quality-guidelines/approved-water-quality-guidelines. Guidelines for Canadian Drinking Water Quality [accessed July 2016] available at: http://www.hc-sc.gc.ca/ewh-semt/water-eau/drink-potab/guide/index-eng.php. US EPA tapwater RSLs [accessed July 2016] available at: https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables-may-2016.

(2) An aesthetic guideline for drinking water was used in the absence of a health-based guideline.
(3) Due to the temporal restrictions of the Fraser River Objectives for bacteria, ambient water quality data was sorted to align with these parameters. Ambient data were divided by season; high flow season consisted of April to October and low flow season consisted of November to March. To align with screening values, instead of arithmetic means, geometric means were calculated.

Table B-10: Screening of Fraser River Ambient Water Quality for the Annacis Island WWTP Stage 1 EIS Study Area (2011-2014) - Human Health (Organic Parameters)

Parameter	Units	Selected Recreational Screening Criterion[1]	Notes	Instantaneous Concentrations			Average 30-day Concentrations	
				High Flow ≥ 6,000 m^3/s	Moderate Flow < 6,000 m^3/s and ≥ 1,000 m^3/s	Low Flow < 1000 m^3/s	High Seasonal Flow - April to August	Low Seasonal Flow - September to March
Polycyclic Aromatic Hydrocarbons								
Acenaphthene	µg/L	**1060**	DW EPA	<0.01	<0.01	<0.01	<0.01	<0.01
Acenaphthylene	µg/L			<0.01	<0.01	<0.01	<0.01	<0.01
Acridine	µg/L			<0.01	<0.01	<0.01	<0.01	<0.01
Anthracene	µg/L	**3600**	DW EPA	<0.01	<0.01	<0.01	<0.01	<0.01
Benz(a)anthracene	µg/L	**1.2**	DW EPA	<0.01	<0.01	<0.01	<0.01	<0.01
Benzo(a)pyrene	µg/L	**0.1**	DW BC, HC	<0.01	<0.01	<0.01	<0.01	<0.01
Benzo(b)fluoranthene	µg/L	**3.4**	DW EPA	<0.01	<0.01	<0.01	<0.01	<0.01
Benzo(g,h,i)perylene	µg/L			<0.01	<0.01	<0.01	<0.01	<0.01
Benzo(k)fluoranthene	µg/L	**34**	DW EPA	<0.01	<0.01	<0.01	<0.01	<0.01
Chrysene	µg/L	**340**	DW EPA	<0.01	<0.01	<0.01	<0.01	<0.01
Dibenz(a,h)anthracene	µg/L	**0.34**	DW EPA	<0.01	<0.01	<0.01	<0.01	<0.01
Fluoranthene	µg/L	**1600**	DW EPA	<0.01	<0.01	<0.01	<0.01	<0.01
Fluorene	µg/L	**580**	DW EPA	<0.01	<0.01	<0.01	<0.01	<0.01
Indeno(1,2,3-c,d)pyrene	µg/L	**3.4**	DW EPA	<0.01	<0.01	<0.01	<0.01	<0.01
1-Methylnaphthalene	µg/L	**110**	DW EPA	<0.05	<0.05	<0.05	<0.05	<0.05
2-Methylnaphthalene	µg/L	**72**	DW EPA	<0.05	<0.05	<0.05	<0.05	<0.05
Naphthalene	µg/L	**12.2**	DW EPA	<0.05	<0.05	<0.05	<0.05	<0.05
Phenanthrene	µg/L			<0.02	<0.02	<0.02	<0.02	<0.02
Pyrene	µg/L	**240**	DW EPA	<0.01	<0.01	<0.01	<0.01	<0.01
Quinoline	µg/L	**2.4**	DW EPA	<0.01	<0.01	<0.01	<0.01	<0.01
Alkylphenols								
4-Nonylphenols	ng/L			8.4	8.4	8.4	8.4	8.4
4-Nonylphenol monoethoxylates	ng/L			<8.4	<8.4	<8.4	<8.4	<8.4
4-Nonylphenol diethoxylates	ng/L			<12.1	<12.1	<12.1	<12.1	<12.1
Octylphenol	ng/L			<2.5	<2.5	<2.5	<2.5	<2.5
Nonylphenol TEQ	ng/L			<22	<22	<22	<22	<22
Sterols and Hormones								
17 α-Ethinyl-Estradiol	ng/L			0.76	0.76	0.76	0.76	0.76
Campesterol	ng/L			226	226	226	226	226
β-Sitosterol	ng/L			1282	1282	1282	1282	1282
β-Stigmastanol	ng/L			378	378	378	378	378
Polychlorinated Biphenyls								
PCB-77	pg/L	**280000**	DW EPA	0.62	0.62	0.62	0.62	0.62
PCB-105	pg/L	**400000**	DW EPA	2.1	2.1	2.1	2.1	2.1
PCB-126	pg/L	**120**	DW EPA	<0.67	<0.67	<0.67	<0.67	<0.67
PCB-169	pg/L	**400**	DW EPA	<0.67	<0.67	<0.67	<0.67	<0.67
Total PCBs	pg/L			155	155	155	155	155
Polybrominated Diphenyl Ethers								
Penta-BDE-99	pg/L			49	49	49	49	49
Penta-BDE-100	pg/L			11	11	11	11	11
Tri BDE (total)	pg/L			6.5	6.5	6.5	6.5	6.5
Tetra BDE (total)	pg/L			62	62	62	62	62
Penta BDE (total)	pg/L			65	65	65	65	65
Hexa BDE (total)	pg/L			19	19	19	19	19
Hepta BDE (total)	pg/L			12	12	12	12	12
Octa-BDE-203	pg/L			17	17	17	17	17

Notes:

Bold	Exceeds the most conservative recreational guideline protective of human health

µg/L = micrograms per liter; mg/L = milligrams per liter; ng/L - nanograms per liter; pg/L = picograms per liter; µS/cm = microseimens per centimeter; TEQ = Toxic Equivalent Quantity < = reported value is less than method detection limit (MDL); DW = Drinking Water Guideline; BC = British Columbia Approved Water Quality Guidelines; HC = Guidelines for Canadian Drinking Water Quality (Health Canada); EPA = Environmental Protection Agency.

(1) Values were preferentially selected from the BC Approved Water Quality Guidelines (WQG) Summary Report (March 2016) for secondary recreational contact. If no recreational value was available, the drinking water guideline multiplied by 10 was used. Health-based drinking water guidelines were obtained from the BC Approved WQGs (2016) and Guidelines for Canadian Drinking Water Quality (Health Canada 2014), with the most conservative value selected preferentially. The US EPA (2016) tapwater RSLs were used when a BC or Health Canada value was not available. The RSLs were adjusted to reflect an HQ of 0.2 and ILCR of 10-5 (target risk levels for Canada). The BC Approved WQG Summary Report [accessed July 2016] available at: http://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-quality/water-quality-guidelines/approved-water-quality-guidelines. Guidelines for Canadian Drinking Water Quality [accessed July 2016] available at: http://www.hc-sc.gc.ca/ewh-semt/water-eau/drink-potab/guide/index-eng.php. US EPA tapwater RSLs [accessed July 2016] available at: https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables-may-2016.

APPENDIX C

Fish and Fish Habitat and Species of Management Concern Assessment (Envirowest 2016)

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604-944-0502

August 3, 2016

Ms. Elaine Irving, Ph.D., R.P.Bio., P.Biol.
Golder Associates Ltd.
Suite 200, 2920 Virtual Way
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Dear Ms. Irving,

RE: ANNACIS ISLAND WASTEWATER TREATMENT PLANT OUTFALL UPGRADE

FISH AND FISH HABITAT AND SPECIES OF MANAGEMENT CONCERN ASSESSMENT FOR STAGE 1 OF THE ENVIRONMENTAL IMPACT STUDY TECHNICAL MEMORANDUM

The Greater Vancouver Sewerage and Drainage District proposes construction of a transient mitigation and outfall system at the Annacis Island Wastewater Treatment Plant (AIWWTP) at 1299 Derwent Way, Delta, British Columbia (Property). Envirowest Consultants Inc. (Envirowest) was retained to conduct a habitat and species-at-risk assessment for the project location.

This correspondence comprises the species-at-risk assessment and habitat assessment of the terrestrial, intertidal and aquatic habitat within the project location in accordance with the information requirements outlined in the Terms of Reference (TOR) submitted to the British Columbia Ministry of Environment for Stage 1 of the Environmental Impact Study (EIS). The EIS is being prepared by your office pursuant with regulatory requirements of the British Columbia *Environmental Management Act* and the Municipal Wastewater Regulation (MWR).

Envirowest conducted reconnaissance level assessments of existing terrestrial and intertidal attributes at and near the proposed outfall in November 2015, February 2016, and June 2016

SITE DESCRIPTION

AIWWTP is located on an approximately 50.97 hectare (ha) property at 1299 Derwent Way, Delta (PID 023-319-160, legal description LT 1 DL 351 GP 1 NWD PL LMP25806) on Annacis Island, located within the south arm of the lower Fraser River immediately downstream of the trifurcation at New Westminster. AIWWTP receives wastewater via the New Westminster Interceptor and South Surrey Interceptor, and provides secondary treatment of wastewater for fourteen (14) municipalities. The existing outfall for AIWWTP extends into the City Reach of the Annieville Channel immediately downstream of the Alex Fraser Bridge. The existing outfall extends approximately 150 metres (m) off of the north bank of the channel and extends parallel to the South Surrey Interceptor influent conduit.

Adjacent land uses to the north, south and west are characterized by industrial properties. Transportation corridors including Highway 91 / Alex Fraser Bridge, railway tracks, and local roads are located in proximity to the proposed outfall.

The new outfall will extend generally from the AIWWTP to the edge of the north boundary of the navigation channel within the Fraser River south arm. The outfall will comprise a 4.2 metre inside diameter pipe extending from the AIWWTP at an approximate depth of 30 metres below ground surface to a riser shaft located in the river. A pair of diffuser pipes would extend approximately 150 metres upstream and downstream from the riser shaft, aligned parallel with and immediately north (landward) of the north edge of the navigation channel. The diffuser pipes would be buried at a shallow depth, as multiple vertical diffuser ports would extend from the diffuser pipes into the river flows.

ENVIRONMENTAL CONDITIONS

The following environmental conditions are a compilation of previous environmental reports on the project area and surrounding area as well as the results of the Envirowest reconnaissance level site assessments.

Biogeoclimatic Zone

Annacis Island is located within the Coastal Western Hemlock biogeoclimatic zone, Very Dry Maritime subzone, Eastern variant (CWHxm1), as described by the Biogeoclimatic Ecosystem Classification system developed for the Province of British Columbia. A narrow band of CWHxm1 passes through Metro Vancouver from West Vancouver in the northwest to the Fraser Valley in the southeast. The Coastal Douglas-fir Moist Maritime subzone (CDFmm) characterizes areas immediately to the south and west of Annacis Island. The Coastal Western Hemlock Dry Maritime subzone (CWHdm) characterizes areas to the north and northeast (Province of British Columbia 2015[1]).

The CWH zone is present at low to middle elevations from Alaska to Oregon, mostly west of the coastal mountains. It receives, on average, more rain than all other biogeoclimatic zones in British Columbia, and is characterized by a cool mesothermal climate, with typically cool summers (which can be punctuated by hot dry periods) and mild winters (Pojar *et al.* 1991[2]).

Within the CWH, the CWHxm subzone occurs from sea level to approximately 700 metre (m) elevations (Green & Klinka 1994[3]). The CWHxm1 (Eastern variant) occurs on the British Columbia mainland primarily along the south side of Fraser River from Chilliwack west to Vancouver, on the Sunshine Coast north to Desolation Sound, on the eastern part and inland portions of Vancouver Island from Campbell River south to Sooke, and on several of the Gulf Islands.[1] Historical mean annual precipitation within the CWHxm is 1570 millimetres (mm), and mean annual temperature is 8.7 °C (ibid.).

Climax or near-climax zonal forest canopy species within the CWHxm1 are characterized by Douglas-fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*), with less prevalent western redcedar (*Thuja plicata*). The shrub layer is characterized by salal (*Gaultheria shallon*), dull Oregon-grape (*Mahonia nervosa*), and red huckleberry (*Vaccinium parvifolium*), with less prevalent trailing blackberry (*Rubus ursinus*), baldhip rose (*Rosa gymnocarpa*), oceanspray (*Holodiscus discolor*), and prince's pine (*Chimaphila umbellata* ssp. *umbellata*).

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[1] **Province of British Columbia. 2015.** iMapBC. Retrieved November 12, 2015 Available at http://maps.gov.bc.ca/ess/sv/imapbc/.

[2] **Pojar, J., K. Klinka, and D.A. Demarchi. 1991.** Chapter 6: Coastal Western Hemlock Zone. *In* Meidinger, D., and J. Pojar. 1991. Ecosystems of British Columbia. Special Report Series 6. Research Branch, BC Ministry of Forests, Victoria, BC.

[3] **Green, R.N., and K. Klinka. 1994.** A Field Guide to Site Identification and Interpretation for the Vancouver Forest Region. Land Management Handbook Number 28. Research Branch, BC Ministry of Forests, Victoria, BC.

The herb layer is characterized by bracken fern (*Pteridium aquilinum*), sword fern (*Polystichum munitum*), twinflower (*Linnaea borealis*), and vanilla-leaf (*Achlys triphylla*). The moss layer is characterized by Oregon beaked moss (*Kindbergia oregana*) and step moss (*Hylocomium splendens*), with less prevalent flat moss (*Plagiothecium undulatum*) and lanky moss (*Rhytidiadelphus loreus*) (ibid.).

Shoreline Features

The lower Fraser River has been extensively modified since the arrival of Europeans. The modifications were initially based on resource extraction (e.g. logging), followed closely by land reclamation and farming. The latter activities involved the construction of flood protection dikes along the river, entraining flows except during catastrophic flood events of 1894 and 1948. More recent modifications in the delta include commercial, industrial, agricultural, and residential developments, as well as major transportation infrastructure projects.

The south shore of Annacis Island extending downstream from the Alex Fraser Bridge pier to the south terminus of Fraserview Place includes shoreline protection (i.e rip rap and other assorted materials including concrete rubble) and unprotected shoreline. Unprotected shoreline is characterized by a narrow band of vegetation extending along most of the Island’s perimeter. Conversely, armoured shoreline is generally located where vegetation is absent (i.e. at the southern terminus of Fraserview Place) or associated with recent anthropogenic structures (i.e. Alex Fraser Bridge, Southern Rail Annacis Island Barge Rail Terminal). Armoured shoreline is most prevalent along the upstream extent of the island at the bifurcation of Annieville and Annacis channels, and along the ship docks along the south shoreline upstream of the Alex Fraser Bridge.

Vegetation established along unprotected shoreline in proximity to this project is confined to a narrow corridor generally not exceeding a width of 15 metres., a function of railway tracks extending along and immediately landward of the shoreline. Canopy species associated with the unprotected shoreline are predominated by red alder (*Alnus rubra*), black cottonwood (*Populus balsamifera* ssp. *trichocarpa*); western redcedar (*Thuja plicata*) and ornamental cherry (*Prunus* sp.) are occasional. Understorey species include Himalayan blackberry (*Rubus armeniacus*), common snowberry (*Symphoricarpos albus*), Nootka rose (*Rosa nutkana*), Pacific ninebark (*Physocarpus capitatus*), red elderberry (*Sambucus racemosa*), cut-leaf evergreen blackberry (*Rubus laciniatus*), and willow (*Salix* spp.). Ground cover is poorly represented, a function of shading by understorey species.

Intermittent intertidal fringe marsh is established along and immediately riverward of the shoreline. Marsh species are subjected to grazing pressures by water fowl (in particular Canada geese) and impact damage by river-borne debris. Marsh species include dwarf spikerush (*Eleocharis parvula*), Family *Asteraceae*, Family *Poaceae*, Lyngby sedge (*Carex lyngbyei*), American bugleweed (*Lycopus americanus*), reed canary grass (*Phalaris arundinacea*), creeping buttercup (*Ranunculus repens*) and sporadic creeping bentgrass (*Agrostis stolonifera*).

An intertidal marsh bench was constructed in 2009 as part of the Southern Railway of BC barge loading facility. The constructed marsh is founded on a rectangular platform that extended over mudflat into the river. Vegetation established on the constructed marsh includes Baltic rush (*Juncus balticus*), jointed rush (*Juncus articulata*), and Lyngby sedge.

Intertidal mudflat extends riverward from the shoreline. Construction of the north sand island protecting the north tower of the Alex Fraser Bridge created an embayment that has over subsequent years developed into an extensive intertidal mudflat. Narrower intertidal mudflat continues downstream along the shoreline.

The former Fraser River Estuary Management Program (FREMP) classified the shorelines of the Fraser River based on the relative value of the habitat features (Fraser River Estuary Management Program 2006a[4]). FREMP was a cooperative agreement amongst member agencies, including Environment Canada, Fisheries and Oceans Canada, Transport Canada, Fraser River Port Authority, North Fraser Port Authority, BC Ministry of Environment, and the Greater Vancouver Regional District (Anonymous 2007[5]). FREMP's Estuary Management Plan (Water and Land Use Committee 2003[6]) integrates habitat management and recreational activities with strategies for water and sediment quality, log management, navigation and dredging, and urban and water related industrial development.

The classification of habitats within the Fraser River estuary during the mid-1980s was one of the first management initiatives of the newly fledged FREMP. The FREMP colour-coded system classified the overall habitat value of the estuarine shoreline and identified development constraints associated with each classification (ibid.). The definition of habitat was limited to functional habitat values provided by estuarine environments for fish and wildlife. Development constraints applied to all components of development, including design, construction and operation.

The FREMP classification system comprised a three tiered colour-coded system: habitats were colour-coded red, yellow or green (ibid.). The FREMP classification system applied only to intertidal habitat and riparian habitat extending up to 30 metres landward of the shoreline. Habitats below local low water, hence below the intertidal zone, were not addressed by the system. This is particularly relevant, as the new outfall does not engage habitats above local low water (i.e. within the intertidal or upland zones). Red-coded shorelines sustained highly productive fish and wildlife habitats. Yellow-coded shorelines sustained moderately productive habitats, while green-coded shorelines were characterized by habitats of low productivity.

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[4] **Fraser River Estuary Management Program. 2006a**. Habitat Inventory. Available at http://cmnmaps.ca/FREMP/map.php?agree=0.

[5] **Anonymous. 2007.** Memorandum of Understanding – Respecting the Coordinated Management of the Burrard Inlet Environmental Action Program (BIEAP) and the Fraser River Estuary Management Program (FREMP). http:www.bieapfremp.org/faq.html (06/17/2015)

[6] **Water and Land Use Committee. 2003.** A Living Working River Updated 2003. The Estuary Management Plan for the Fraser River. Fraser River Estuary Management Program, New Westminster, BC. 88p + appendices.

Development constraints were greatest within red-coded habitats, while development within green-coded habitats were constrained the least. Constraints within yellow-coded habitats were intermediate between those for red-coded and green-coded habitats.

FREMP ceased to exist in March 2013. Despite this, the three tiered colour-coded system is occasionally applied as a tool by municipalities (i.e. Richmond and Delta) to assess impacts to fish and wildlife associated with proposed upland developments and related activities within the Fraser River estuary.

The FREMP habitat classifications of the south shoreline of Annacis Island are predominantly high (red) productivity or moderate (yellow) productivity habitats. The high and moderate productivity classifications are largely a function of riparian vegetation and intermittent fringe marsh establishment along the shoreline. Low (green) productivity habitat is reserved for the footing protection structure of the Alex Fraser Bridge north support structure immediately upstream of the Project, and the ship docks at the upstream extent of the Island.

The south shoreline of the South Arm (i.e. Corporation of Delta shoreline) includes all three habitat classifications. Moderate productivity shoreline is generally more prevalent, interspersed with Low productivity shoreline and occasional High productivity habitat. High productivity habitat is more prevalent along the Tilbury Island shoreline.

Wildlife

Wildlife observed during the site assessments included eight (8) bird species: mallard (*Anas platyrhynchos*), great blue heron (*Ardea herodias*), red-tailed hawk (*Buteo jamaicensis*), bald eagle (*Haliaeetus leucocephalus*), downy woodpecker (*Picoides pubescens*), northwestern crow (*Corvus caurinus*), common raven (*Corvus corax*), and rock pigeon (*Columba livia*). Northern flicker (*Colaptes auratus*) nest cavity holes were present in snags or dead portions of several trees.

Indirect sign of one (1) mammal species was detected: coast mole (*Scapanus orarius*) molehills were present within the railway corridor.

Potential wildlife use of terrestrial and intertidal areas of the project area includes burrowing and foraging by coast mole, foraging and denning by urban generalist mammal species such as striped skunk (*Mephitis mephitis*) or raccoon (*Procyon lotor*), and foraging, nesting, and perching by birds. Ducks, double-crested cormorant (*Phalacrocorax auratus*), rock pigeon, downy woodpecker and great blue heron may forage in and around the project area. Vegetation and manmade structures within the area are suitable for red-tailed hawk and bald eagle perching. Nesting habitat for common raven, northwestern crow and downy woodpecker is also present. Rock pigeon may nest or roost on nearby buildings and other structures.

Aquatic Environment

The Fraser River is one of the largest unregulated rivers in North America and one of the most important salmonid-producing rivers in the world (Northcote & Burwash 1991[7]; Northcote & Larkin 1989[8]). The Fraser River catchment area encompasses approximately 232,000 square kilometres, the majority of which is located east of the Lower Mainland.

The lower Fraser River extends from Hope, BC to the Strait of Georgia. The lower Fraser River includes several channels influenced by marine tides downstream of the City of New Westminster. The tidal influence on river water levels is generally considered to extend from the delta front upstream to the Highway 11 bridge connecting the cities of Mission and Abbotsford.

The Project is located in the South Arm Meso-Tidal segment of the river (Fraser River Estuary Management Program 2006b[9]). This segment extends generally the upstream tip of Kirkland Island to the trifurcation of the river at the upstream extent of the Annieville channel. At New Westminster flows are divided into the North Arm taking approximately 15 percent of flow and the South Arm taking approximately 85 percent of flow (Swain *et al.* 1998[10]). The South Arm is initially comprised of Annacis Channel extending along the north perimeter of Annacis Island taking approximately 7 percent of South Arm flow and the Annieville Channel extending along the south perimeter of Annacis Island taking approximately 93 percent of south arm flow (ibid.). These channels join downstream of Annacis Island.

Flow

Flow within the Fraser River varies seasonally. Snow melt dominated flows discharged by the river generally peak in June during the freshet, with lowest flows in December to March during interior freezing. From 1965 to 1992 monthly flows in the Fraser River at the Port Mann Pump Station average flows ranged from 1,030 cubic metres per second (m^3/s) in winter and 11,900 m^3/s in early summer (Water Office 2015[11]). Within Annieville Channel maximum water velocities range from 0.2 metres per second (m/s) at the north and south banks to 1.6 m/s at the

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[7] **Northcote, T.G., and M. D. Burwash. 1991.** Fish and fish habitats of the Fraser River basin. Pp 117 – 141. In A.H.J. Dorcey and J.R. Griggs (eds.), Water in sustainable development: exploring our common future in the Frasr River basin. Westwater Research Centre, University of British Columbia, BC.

[8] **Northcote, T.G., and P.A. Larking. 1989.** The Fraser River: A major salmonine production system. In Proceedings of the Large River Symposium. Edited by D.P. Dodge. Can. Spec. Publ. Fish. Aqaut. Sci. 106: 172 – 204.

[9] **Fraser River Estuary Management Program. 2006b.** Environmental Management Strategy for Dredging in the Fraser River Estuary. Final Report approved January 2006. 31 p. + appendices..

[10] **Swain, L.G., Walton, D.G., Phippen, B., Lewis, H., Brown, S. Bamford, G., Newsom, D., and I. Lundman. 1998.** Water Quality Assessment and Objectives for the Fraser River from Hope to Sturgeon and Roberts Banks. First Update. Prepared for British Columbia Ministry of Environment, Lands and Parks. 532 p. + Appendix.

[11] **Water Office. 2015.** Daily Discharge Statistics Graph for Fraser River at Port Mann Pumping Station (08MH126). Available at http://wateroffice.ec.gc.ca/report/report_e.html?type=stat&stn=08MH126.

scour hole immediately downstream of the Alex Fraser Bridge (Newby & Pathirage 2015[12]). Maximum water velocity in the majority of the channel ranges from 0.8 m/s to 1.2 m/s (ibid.).

Substrates

The lower Fraser River is divided into two reaches based on dominant substrate type; 'Gravel Reach' extends from Hope to Mission and 'Sand Reach' extends downstream from Mission to the marine environment (Rempel *et al.* 2012 [13]). The dominant substrate in Annieville Channel and surrounding area is sand. Nearby sloughs sustain a mud bottom (Newby & Pathirage 2015). Areas within the lower Fraser River, including around Annacis Island, are frequently dredged for maintenance of in-water facilities and navigation channels.

Substantial flows combined with rock armouring of the South Surrey Interceptor and channel restrictions associated with the Alex Fraser Bridge have resulted in a diverse bathymetry in proximity to the Project. The most notable bathymetric feature includes a deep scour hole extending downstream of the South Surrey Interceptor and past the Project. Other notable bathymetric features include sand waves established within the downstream extent of the scour hole, becoming increasingly mobile during freshet flows.

Salt Wedge

Characteristics of the lower Fraser River are influenced marine tides and by the occurrence of a salt wedge that forms during flood tides. A salt wedge forms when saltwater moves upstream along the bottom of the river during a large flood tide and recedes during ebb tide. The distance upstream that the salt wedge extends is dependent on river discharge. In the Fraser River, during high discharge the salt wedge extends only a short distance into the river whereas during low discharge the salt wedge may extend to Annacis Island (Ages 1979[14]).

Fish

112 fish species that have been reported to occur in the lower Fraser River downstream of Douglas Island are included in Table 1, Attachment A.

Several species occurring in the Fraser River are managed by federal and provincial governments in the context of commercial, recreational, and First Nation fisheries. Salmonines and eulachon

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[12] **Newby, J. and K. Pathirage. 2015.** Outfall Systems Kick-off Annacis Island Wastewater Treatment Plant Transient Mitigation and Outfall – Consulting Engineering Services Presentation. August 17, 2015. Prepared by CDM Smith.

[13] **Rempel, L.L, Healy, K. and F.J.A. Lewis. 2012.** Lower Fraser River Juvenile Fish Habitat Suitability Criteria. Canadian Technical Report of Fisheries and Aquatic Sciences 2911. Prepared by Fisheries and Oceans Canada. 56p. + Appendices.

[14] **Ages, A. 1979.** The salinity intrusion in the Fraser River: Salinity, temperature and current observations, 1976, 1977. Pacific Marine Science Report 79-1A. Institute of Ocean Sciences. Sidney, BC. 193p.

stocks are intensively managed by the Government of Canada, whereas white sturgeon stocks are managed by the Government of British Columbia.

- Salmonines

Seven (7) species of salmonines (*Oncorhynchus* spp.) occur within the lower Fraser River. Anadromous species include chinook salmon (*O. tshawytscha*); chum salmon (*O. keta*); coho salmon (*O. kisutch*); pink salmon (*O. gorbuscha*);; and sockeye salmon (*O. nerka*); trout species include cutthroat trout, *clarkii* subspecies (*O. clarkii clarkii*) and rainbow trout (*O. mykiss*) (Fraser River Estuary Management Program 2006b).

Salmonid utilization of the City Reach of the Annieville Channel consists primarily of upstream and downstream migration by adult and juvenile fish, respectively. Salmon spawning habitat does not occur within this reach, although salmon spawning is well documented within numerous tributary streams in the Lower Mainland.

Upstream migration by adult salmon generally commences shortly after freshet flows peak in June, and continues into early December. Early Stuart Sockeye enter the river in early July whereas Cultus Lake Sockeye migrate through the river to the lake generally between September to December. Summer run Sockeye peaks in this section of the river in mid-August. Early run Pink salmon enter the river in mid-September, followed in early October by late run Pinks. Coho salmon generally enter the Fraser River in early fall (end of September and early October), although late runs can enter the river in December or January (i.e. Elk Creek, Chilliwack) (McPhail 2007[15]). Chinook salmon enter the Fraser River in July, and again in September and October (ibid.). Chum salmon generally spawn in the lower Fraser River tributaries between September and early January (ibid.).

Downstream migration by juvenile salmon is associated with commencement of the freshet, which brings flow, sediment, and nutrients to peripheral areas of the active channel (Rempel *et al.* 2012). Downstream migration by smolts appears to be dependent upon adequate river current (Bjornn & Reiser 1991[16]). Migration occurs rapidly on time scales of days to weeks, with interspecific variability in time required to reach the river mouth (Melnychuk *et al.* 2010[17]). Migration rates also vary with run type, distance from the ocean, date, and fish size (Carter *et al.* 2009[18]). Downstream migration by juveniles of all anadromous salmonines extends generally from mid-March to mid-May.

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[15] **McPhail, J.D. 2007.** The Freshwater Fishes of British Columbia. University of Alberta Press. 535p.

[16] **Bjornn, T.C., and D.W. Reiser. 1991.** Habitat requirements of salmonids in streams. Chapter 4 in Influences of forest and rangeland management on salmonid fishes and their habitats. Am. Fish. Soc. Special Publication 19:83-138.

[17] **Melnychuk, M.C., D.W. Welch, and C.J. Waters. 2010.** Spatio-temporal migration patterns of Pacific salmon smolts in rivers and coastal marine waters. PLoS ONE 5:e12916.

[18] **Carter, J.A., G.A. McMichael, I.D. Welch, R.A. Harnish, and B.J. Bellgraph. 2009.** Seasonal juvenile salmonid presence and migratory behavior in the lower Columbia River. PNNL-18246, Pacific Northwest National Laboratory, Richmond, WA.

Juvenile migration is considered a sensitive life stage in the context of downstream pressures, as localized impacts to juvenile migratory survival may disproportionately affect particular runs during mass downstream migrations. Juvenile salmon generally move along the shoreline at depths between 0.1 m and 2.0 m (Southard *et al.* 2006[19]). Nearshore juvenile salmon habitats are largely untouched by the proposed outfall construction activities, as the installation of the outfall and associated diffusers is to occur below local low water.

Limited empirical sampling data exists for juvenile salmon utilization along the south shoreline of Annacis Island. Extensive sampling for juvenile white sturgeon was undertaken within the Fraser River, including around Annacis Island (Glova *et al.* 2008[20]). The sampling program extended from September 2007 to March 2008, with the bulk of the sampling completed between September and November 2007. The sampling would have preceded the out-migration by juvenile salmonines. Juvenile salmon are, however, expected to out-migrate along the south shoreline Annacis Island, and to utilize the downstream ‘shadow’ of the Alex Fraser Bridge headland as a refuge from higher flows encountered in the channel centre.

Salmon have been and continue to be important to First Nations for food, social and ceremonial purposes (Fisheries and Oceans Canada 2015a[21]). Kwikwetlem First Nation (Pattullo Bridge to Douglas Island), Musqueam First Nation (below Port Mann Bridge), Tsawwassen First Nation (below Port Mann Bridge), Tsleil-Wautututh First Nation (below Port Mann Bridge) and New Westminster First Nation (Douglas Island to Queensborough/Alex Fraser) have been granted fishing licenses between 2011 and 2014 downstream of the Port Mann Bridge (Fisheries and Oceans Canada 2015b[22]). The majority of First Nations fisheries openings downstream of the Port Mann Bridge were for salmon, however, eulachon openings have also occurred each year since 2011 (ibid.).

Tens of thousands of recreational fishers engage in catch and release and retention fisheries throughout British Columbia, a large part of which occur within the Fraser River. Fraser River stocks support several commercial fisheries. Commercial and aboriginal fishing occurs near this project location (ibid.). Fraser River stocks support several commercial marine fisheries.

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[19] **Southard, S.L., and R.M. Thom, G.D. Williams, J.D. Toft, C.W. May, G.A. McMichael, J.A. Vucelick, J.T. Newell, and J.A. Southard. 2006.** Impacts of Ferry Terminals on Juvenile Salmon Movement along Puget Sound Shorelines. Report No. WA-RD 648.1. Prepared for: Washington State Department of Transportation, Olympia, WA. Prepared by: Battelle Memorial Institute, Sequim, WA. 84p.

[20] **Glova, G., T. Nelson, K. English, and T. Mochizuki. 2008**. A preliminary report on juvenile White Sturgeon habitat use in the Lower Fraser River, 2007 – 2008. LGL Limited Environmental Research Associates, Sidney, BC and Fraser River Sturgeon Conservation Society, Vancouver, BC.

[21] **Fisheries and Oceans Canada. 2015a.** Salmon Fisheries in the Pacific Region. http://www.pac.dfo-mpo.gc.ca/fm-gp/speices-especes/salmon-saumon/fisheries-peches/index-eng.html (07/02/2015).

[22] **Fisheries and Oceans Canada. 2015b.** Fraser River Fisheries Archived Reports. Archived First Nations Fishery Reports – Lower Fraser River. . Available at http://www.pac.dfo-mpo.gc.ca/fm-gp/fraser/archives-a-eng.html.

- Eulachon

Spawning by the semelparous Eulachon occurs in April and May in the lower Fraser River (Hay *et al.* 2002[23]). Most spawning occurs between Mission and Chilliwack (approximately 60 to 120 kilometres upstream), where the substrate changes from silt and sand to gravel (McPhail 2007). Additional spawning locations were found to be generally located within the lower 50 kilometres of the river, more specifically in the North and South Arms of the River (Hay *et al.* 2002; Fisheries and Oceans Canada 2015c[24]). Potential Eulachon spawning sites have also been more recently identified in the main stem of the Fraser River at the Port Mann bridge crossing, along the north shoreline of Douglas Island opposite the confluence with the Pitt River, and along the north shoreline of the river at the confluence of the Coquitlam River (Plate 2009[25]). Occurences of Eulachon within the Annieville channel, and more specifically along the north shoreline of this channel, have not been documented, but can be expected. Juvenile eulachon appear to disperse into marine waters within their first year of life. The juvenile migration portion of the eulachon life cycle is poorly understood (McPhail 2007).

- White Sturgeon

White sturgeon spawn in June and July in the Fraser River between Hope and Chilliwack. Sturgeon do not spawn every year, and spawning migrations are not conspicuous due to the length of the spawning season and small number of spawners (McPhail 2007).

Late juvenile (over two years) and adult white sturgeon habitat is typically located in large rivers, large natural lakes, and large reservoirs (COSEWIC 2012[26]). River habitat is typically characterized by deep waters with backwater and eddy flow characteristics, adjacent to heavy flows, with a sand and fine gravel substrate (Fisheries and Oceans Canada 2014a[27]). Within the Fraser River, adult white sturgeon are present in the main channel for much of the year, moving upstream to spawn and downstream to exploit seasonal food availability. Downstream of Mission, the substrate is characterized by sandy silt, with water depths of 10 metres (m) to 20 m and turbid water. Adult sturgeon spend the winter (October to March) in a low-activity state in deep, low-velocity locations. Adults also at least occasionally use brackish estuary waters and occasionally spend extended periods in the marine environment (McPhail 2007).

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[23] **Hay, D.E., P.B. McCarter, R. Joy, M. Thompson, and K. West. 2002.** Fraser River Eulachon Biomass Assessments and Spawning Distribution: 1995 – 2002. Canadian Science Advisory Secretariat, research Document 2002/117. Fisheries and Oceans Canada, Nanaimo, BC.

[24] **Fisheries and Oceans Canada. 2015c**. Recovery Potential Assessment for Eulachon – Fraser River Designatable Unit. Canadian Science Advisory Secretariat, Science Advisory Report 2015/002.

[25] **Plate, E.M. 2009.** Fraser River, Port Mann Bridge – Douglas Island Eulachon Study, 2009. LGL Limited Environmental Research Associates, Sidney BC, and Terra Remote Sensing Incorporated, Sidney, BC.

[26] **COSEWIC. 2012.** COSEWIC assessment and status report on the White Sturgeon *Acipenser transmontanus* in Canada. Committee on the Status of Endangered Wildlife in Canada, Ottawa. xxvii + 75p.

[27] **Fisheries and Oceans Canada. 2014a.** Recovery Strategy for White Sturgeon (*Acipenser transmontanus*) in Canada [Final]. In Species at Risk Act Recovery Strategy Series. Fisheries and Oceans Canada, Ottawa. 252p.

Little is known about juvenile (less than two years) white sturgeon habitat in British Columbia, but evidence suggests that juveniles are typically associated with areas of slow to moderate water velocities, in areas such as tributaries' lower reaches or confluence points, large backwaters, side channels, and sloughs (ibid.). Water depth and substrate are varied (ibid.). Juveniles leave these areas, most likely for the main channel, once water temperatures fall below 13 degrees Celsius (°C) to 15 °C (ibid.).

Occurrences of juvenile White Sturgeon along the south shoreline of Annacis Island are well documented by recent sampling (Glova *et al.* 2008 and 2009[28]). Captures of juvenile White Sturgeon occurred in the deeper reaches of the Annieville Channel as well as within shallow waters along the north and south shorelines of Annacis Island. Juvenile White Sturgeon were also captured during the same sampling events in the deeper channel sections of the river where flows are more pronounced. Utilization of the south shoreline of Annacis Island by juvenile White Sturgeon is anticipated. The proposed works have the potential to engage juvenile White Sturgeon.

- Dolly Varden Char

Dolly Varden were previously Blue-listed (species of special concern) in British Columbia (BC), however, they have been moved to the Yellow list, indicating BC populations are secure (BC Ministry of Environment 2016[29]). Little is known about Dolly Varden populations in the lower Fraser River, therefore information from other BC populations has been extrapolated to the lower Fraser River for this description. Dolly Varden is often mistakenly identified as bull trout (*S. confluentus*) and hybridization has been documented between these two species (McPhail 2007).

Three life history strategies are utilized by Dolly Varden in BC, including in the lower Fraser River (ibid.) These strategies include anadromous, stream-resident and, and adfluvial life histories. Anadromous individuals migrate between freshwater and ocean conditions, spending much time in estuaries, stream-residents reside in rivers and streams for their entire life and adfluvial individuals reside in lakes for most of their life and spawn in streams (ibid., Fisheries and Oceans Canada 2010,[30]). Both mature and immature anadromous Dolly Varden have been recorded migrating between freshwater and ocean conditions (McPhail 2007) therefore, migration may not be strictly related to reproductive processes but may also be related to feeding opportunities (BC Ministry of Fisheries 1999[31]).

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[28] **Glova, G., T. Nelson, K. English, and T. Mochizuki. 2009**. A further report on juvenile White Sturgeon habitat use in the Lower Fraser River, 2008 – 2009. LGL Limited Environmental Research Associates, Sidney, BC and Fraser River Sturgeon Conservation Society, Vancouver, BC.

[29] **British Columbia Ministry of Environment. 2016**. Ministry of Environment Glossary. Available: http://www.env.gov.bc.ca/atrisk/glossary.html.

[30] **Fisheries and Oceans Canada (DFO). 2010.** Aquatic Species – Details for Dolly Varden Char. Available: http://www.dfo-mpo.gc.ca/species-especes/aquatic-aquatique/dolly-varden-char-omble-dolly-varden-eng.html.

[31] **British Columbia Ministry of Fisheries. 1999.** B.C. Fish Facts – Dolly Varden. Available: http://www.gofishbc.com/docs/default-source/freshwater-fish-of-bc/dolly_varden.pdf?sfvrsn=2.

Dolly Varden are present in freshwater tributaries of the Fraser River year round (Logan *et al.* 2015[32]). Stream-residents typically spawn locally whereas anadromous and adfluvial populations migrate prior to spawning (McPhail 2007). Although adfluvial populations have not been directly studied, observations suggest these individuals migrate short distances to spawn (i.e. less than 1 kilometre) (ibid.). Anadromous populations migrate to spawning streams between May and December (Hoos and Packman 1974[33], BC Conservation Data Centre 2016[34]).

Dolly Varden occurrences have been documented in the South Arm downstream of the Project near Steveston, as well as upstream of the Project at the confluences of the Coquitlam and Pitt rivers.

Benthic Invertebrates

Aquatic ecosystems are comprised of complex matrices that connect several tiers of consumers to each other. Epifaunal and infaunal benthic invertebrates form a critical link between organic debris and detritus and fish, including species of management and/or conservation concern, such as white sturgeon, eulachon and salmon. Benthic invertebrates have been used in biomonitoring programs worldwide (Rosenberg *et al.* 1999[35]).

Benthic invertebrates are sensitive to short-term environmental impacts as they are sessile or have limited mobility and are not typically able to escape such impacts (Beatty *et al.* 2006[36]). Benthic invertebrates collected in grab samples from three stations in the south arm of the Fraser River in 1972 and 1973 were composed of pollution tolerant species (Swain *et al.* 1998) and included ctenophores, nemerteans, nematodes, annelids, molluscs, crustaceans and insects. Of the 41 taxa collected, two (2) sensitive species were collected over the course of sampling (ibid.).

Benthic invertebrates that inhabit the area in the area of influence of the existing outfall are adapted to the conditions created by effluent discharge from the outfall. However, under current conditions substrate movement within the project area is high. Therefore, conditions are not favourable for the establishment of extensive benthic invertebrate communities in the immediate area of the existing and proposed outfalls.

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[32] **Logan, K.A., Scott, D., Rosenberger, A. and M. MacDuffee. 2015.** Potential Effects on Fraser River Salmon from an Oil Spill by the Trans Mountain Expansion Project. Prepared by: Raincoast Conservation Foundation. Prepared for: National Energy Board hearings. 120p. + appendices.

[33] **Hoos, L.M. and G.A. Packman. 1974.** The Fraser River Estuary Status of Environmental Knowledge to 1974. Report of the Estuary Working Group. Special Estuary Series No. 1. 237p. + appendices.

[34] **British Columbia Conservation Data Centre. 2016.** BC Species and Ecosystems Explorer. Available: http://a100.gov.bc.ca/pub/eswp/.

[35] **Rosenberg, D.M., Reynoldson, T.B., and V.H. Resh. 1999.** Establishing reference conditions for benthic invertebrate monitoring in the Fraser River catchment, British Columbia, Canada. DOE-FRAP 1998-32. 116p + appendices.

[36] **Beatty, J.M., L.E. McDonald, F.M. Westcott, and C.J. Perrin. 2006.** Guidelines for sampling benthic invertebrates in British Columbia streams. BC Ministry of Environment, Victoria. 28p + appendix.

The majority of benthic invertebrates present in the south arm are pollution-tolerant, however, changes to the discharge would likely impact the benthic invertebrate community by altering the benthic habitats and nutrient availability. The magnitude of effects on invertebrates, and upon fish that prey on such invertebrates, is dependent upon effects upon the riverine benthic community as a whole, and upon the tenure of such effects on the abundance, structure and membership of the assemblage within the immediate zone of impact and upon overall riverine community.

SPECIES OF MANAGEMENT CONCERN

Regulatory Context

Definition

Species of management concern are identified in the context of the provincial and national ranking systems. The provincial ranking system applies to species and ecological communities that have been assessed by the British Columbia Conservation Data Centre (CDC). The national ranking system applies to species that have been assessed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). The CDC and COSEWIC publish lists of species-at-risk in order to prioritize species for conservation. The CDC also publishes a list of ecological communities-at-risk in order to prioritize ecological communities for conservation.

Conservation Data Centre

In British Columbia, the BC Ministry of Environment supports the CDC. The CDC maintains dynamic tracking lists of rare plant and animal species and rare ecological communities that occur within BC. The CDC utilizes three ranked criteria for species and ecological communities of management concern and presents them as lists, specifically the Red, Blue, and Yellow lists. The definitions of these designations are as follows (BC Ministry of Environment 2015[37]):

Red List:	List of ecological communities, and indigenous species and subspecies that are extirpated, endangered or threatened in British Columbia. Red-listed species and sub-species may be legally designated as, or may be considered candidates for legal designations as Extirpated, Endangered or Threatened under the Wildlife Act. Not all Red-listed taxa will necessarily become formally designated. Placing taxa on these lists flags them as being at risk and requiring investigation.
Blue List:	List of ecological communities, and indigenous species and subspecies of special concern (formerly vulnerable) in British Columbia.
Yellow List:	List of ecological communities and indigenous species that are not at risk in British Columbia.

The CDC listings serve two purposes: first, they provide a list of species for consideration for formal designation as Endangered or Threatened, either provincially under the *Wildlife Act*, which currently designates one (1) species as Threatened, and three (3) species as Endangered, or nationally by COSEWIC, as described below. Second, the listings assist in the setting of conservation priorities for species and ecological communities considered at risk in BC.

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[37] **BC Ministry of Environment. 2015.** Ministry of Environment Glossary. Retrieved September 11, 2015 from http://www.env.gov.bc.ca/atrisk/glossary.html.

Committee on the Status of Endangered Wildlife in Canada

The Canada *Species At Risk Act* (SARA) was proclaimed with the specific intent of protecting wildlife species-at-risk in Canada. Within SARA, COSEWIC was established as an independent body of experts responsible for identifying and assessing species considered to be at risk. COSEWIC currently addresses all native mammals, birds, reptiles, amphibians, fish, arthropods, molluscs, vascular plants, mosses and lichens (COSEWIC 2009[38]).

The identification and assessment of species considered to be at risk is the first step towards protecting species of management concern. Species that have been designated by COSEWIC may qualify for legal protection and recovery under SARA. It is the responsibility of the Canadian Minister of Environment (the Minister responsible for SARA) to assign legal protection of species designated by COSEWIC. This involves listing the species in Schedule 1 of SARA. Species included in Schedules 2 and 3 are candidates for inclusion in Schedule 1, following further assessment.

COSEWIC (2014[39]) defines "wildlife species" as:

> A species, subspecies, variety or geographically or genetically distinct population of animal, plant or other organism, other than a bacterium or virus, that is wild by nature and is either native to Canada or has extended its range into Canada without human intervention and has been present in Canada for at least 50 years.

Wildlife status categories utilized by COSEWIC (ibid.) consist of:

Extinct	A wildlife species that no longer exists.
Extirpated	A wildlife species that no longer exists in the wild in Canada, but exists elsewhere.
Endangered	A wildlife species facing imminent extirpation or extinction.
Threatened	A wildlife species that is likely to become endangered if nothing is done to reverse the factors leading to its extirpation or extinction.
Special Concern	A wildlife species that may become threatened or endangered because of a combination of biological characteristics and identified threats.
Not at Risk	A wildlife species that has been evaluated and found to be not at risk of extinction given the current circumstances.
Data Deficient	A category that applies when the available information is insufficient (a) to resolve a wildlife species' eligibility for assessment or (b) to permit an assessment of the wildlife species' risk of extinction.

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[38] **COSEWIC. 2009.** About COSEWIC. Updated February 2009. Retrieved September 11, 2015 from http://www.cosewic.gc.ca/eng/sct6/sct6_1_e.cfm.

[39] **COSEWIC. 2014.** Status Reports: Definitions and Abbreviations. Approved by COSEWIC in November 2013. Retrieved September 15, 2015 from http://www.cosewic.gc.ca/eng/sct2/sct2_6_e.cfm.

Species At Risk Act

Schedule 1 of SARA formally designates species as being Extirpated, Endangered, Threatened, or of Special Concern. Schedule 2 and Schedule 3 include species that have been tracked by COSEWIC prior to the proclamation of SARA, yet require reassessment using the latest assessment criteria before being listed on Schedule 1.

Under Section 2 of SARA, an "individual" means:

> an individual of a wildlife species, whether living or dead, at any developmental stage and includes larvae, embryos, eggs, sperm, seeds, pollen, spores and asexual propagules.

As specified in Section 34 of SARA, Section 32 of SARA protects individuals of listed wildlife species that are aquatic species; that are migratory birds protected by the *Migratory Birds Convention Act*, 1994; that are on federal lands; or that have been subject to an order made by the Governor in Council; as follows:

> (1) No person shall kill, harm, harass, capture or take an individual of a wildlife species that is listed as an extirpated species, an endangered species or a threatened species.
> (2) No person shall possess, collect, buy, sell or trade an individual of a wildlife species that is listed as an extirpated species, an endangered species or a threatened species, or any part or derivative of such an individual.
> (3) For the purposes of subsection (2), any animal, plant or thing that is represented to be an individual, or a part or derivative of an individual, of a wildlife species that is listed as an extirpated species, an endangered species or a threatened species is deemed, in the absence of evidence to the contrary, to be such an individual or a part or derivative of such an individual.

Section 2 of SARA defines a "residence" as:

> a dwelling-place, such as a den, nest or other similar area or place, that is occupied or habitually occupied by one or more individuals during all or part of their life cycles, including breeding, rearing, staging, wintering, feeding or hibernating.

As specified in Section 34 of SARA, Section 33 of SARA protects the residences of listed wildlife species that are aquatic species; that are migratory birds protected by the *Migratory Birds Convention Act,* 1994; that are on federal lands; or that have been subject to an order made by the Governor in Council; as follows:

> No person shall damage or destroy the residence of one or more individuals of a wildlife species that is listed as an endangered species or a threatened species, or that is listed as an extirpated species if a recovery strategy has recommended the reintroduction of the species into the wild in Canada.

Section 2 of SARA defines "critical habitat" as:

> the habitat that is necessary for the survival or recovery of a listed wildlife species and that is identified as the species' critical habitat in the recovery strategy or in an action plan for the species.

Regarding critical habitat, Section 58 of SARA specifies that, subject to an order by the competent minister:

no person shall destroy any part of the critical habitat of any listed endangered species or of any listed threatened species – or of any listed extirpated species if a recovery strategy has recommended the reintroduction of the species into the wild in Canada – if

(a) the critical habitat is on federal land, in the exclusive economic zone of Canada or on the continental shelf of Canada;
(b) the listed species is an aquatic species; or
(c) the listed species is a species of migratory birds protected by the *Migratory Birds Convention Act,* 1994.

Assessment Method

A list of species of management concern that are likely to occur within the proposed works area was generated by reviewing species-at-risk listed by the CDC as occurring within the Metro Vancouver Regional District. The initial list was refined to include only those species listed by the CDC as occurring in the CWH or CDF biogeoclimatic zone. When subzone associations were specified by the CDC, the list was refined to exclude species that do not occur in the subzone describing Annacis Island (CWHxm1) or immediately surrounding areas (CDFmm or CWHdm)(Province of British Columbia 2016[40]). The list was further refined to exclude species restricted to broad habitat types (e.g. old-growth forest) that do not occur within the proposed works area (ibid.). Finally, the list was refined to include only species-at-risk whose habitat requirements at critical life stages (e.g. breeding, nesting/denning, or hibernating, for animals; or germination, flowering, and seed dispersal for plants) were met by existing environmental conditions within the proposed works area.

An assessment was made of ecological communities-at-risk that are likely to occur on the subject properties by reviewing Red- and Blue-listed ecological communities documented by the CDC to occur within the Chilliwack Forest District. This list was refined to include only those communities documented to occur within the CWHxm1, CDFmm, or CWHdm. This list was compared to plant communities documented during the current assessment and assessments

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[40] **BC Ministry of Environment. 2016.** Species and Ecosystems at Risk – Publicly Available Occurrences – Conservation Data Centre. Ecosystems, Ministry of Environment. Retrieved July 20, 2016. http://maps.gov.bc.ca/ess/sv/imapbc

associated with historical projects in the immediate vicinity, to assess whether ecological communities-at-risk are likely to occur within the proposed works area.

CDC-documented element occurrences of species-at-risk and ecological communities-at-risk were queried within 10 kilometres (km) of the Project, using the provincial online mapping tool (ibid., Klinkenberg 2016a[41]) for historical and publicly available occurrences. Anecdotal and museum records of species-at-risk occurrences within the 10 km radius were investigated for species for which CDC element occurrences do not exist within that radius (eBird Canada 2015[42], Klinkenberg 2016b[43]). For species and ecological communities mapped by the CDC (Province of British Columbia 2015), whose distributions are well known due to systematic provincial or federal survey efforts or citizen science initiatives, these occurrence records were used to determine whether species-at-risk or ecological communities-at-risk have previously been recorded in or near the proposed works area, and to corroborate assessments of the likelihood of these elements occurring within the proposed works area. Masked occurrences along the Fraser River downstream of its confluence with the Pitt River were obtained through direct inquiry to the CDC.

Assessment Findings

A total of 33 species of management concern have been identified to occur within the broader regional landscape (i.e the Lower Mainland) that incorporates the project area, as included in Table 2. These species include 11 birds, 11 fish, 7 mammals, and 6 herptiles.

An assessment of the potential utilization by these species of habitats within and adjacent to the Project was undertaken to determine if these species are expected or not expected to utilize these habitats (Table 2). The list of expected species utilization of these habitats was reduced to a total of 18 upon review of specific life history requirements of each identified species and the habitats sustained in and around the Project. Of the species expected to occur in the Project area, 6 are birds, 10 are fish, and 3 are mammals. Herptiles are not expected to be present within the Project area.

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[41] **Klinkenberg, B. (ed.) 2016a.** E-Flora BC: Electronic Atlas of the Plants of British Columbia [eflora.bc.ca]. Lab for Advances Spatial Analysis, Department of Geography, University of British Columbia, Vancouver, BC. Retrieved July 20, 2016, http://ibis.geog.ubc.ca/biodiversity/eflora

[42] **eBird Canada. 2015.** Range and Point Maps. Retrieved October 08, 2015. Available at http://ebird.org/ebird/canada/map/.

[43] **Klinkenberg, B. (ed.). 2016b.** E-Fauna BC: Electronic Atlas of the Fauna of British Columbia. Lab for Advanced Spatial Analysis, Department of Geography, University of British Columbia, Vancouver, BC. Retrieved July 20, 2016 from http://www.geog.ubc.ca/biodiversity/efauna/

Table 2 Regional Species of Management Concern Potentially Occurring in the Project Area

Common Name	Scientific Name	SARA Schedule 1	CDC	Project Area Occurrence
Birds				
Great blue heron	*Ardea herodias fannini*	Special Concern	Blue	Expected
Green heron	*Butorides virescens*	Not Included	Blue	Expected
Black-crowned heron	*Nycticorax nycticorax*	Not Included	Red	Expected
Double-crested cormorant	*Phalacrocorax auritus*	Not Included	Blue	Expected
Caspian tern	*Hydroprogne caspia*	Not Included	Blue	Expected
Marbled murrelet	*Brachyrhamphos marmoratus*	Threatened	Blue	Not Expected
Common nighthawk	*Chordeiles minor*	Threatened	Yellow	Not Expected
Black swift	*Cypseloides niger*	Not Included	Blue	Not Expected
Peregrine falcon	*Falco peregrinus anatum*	Special Concern	Red	Not Expected
Sandhill crane	*Grus canadensis*	Not Included	Yellow	Not Expected
Barn swallow	*Hirundo rustica*	Not Included	Blue	Expected
Fish				
White sturgeon	*Acipenser transmontanus pop. 4*	Not Included	Red	Expected
Green sturgeon	*Acipenser medirostris*	Special Concern	Red	Not Expected
Cutthroat trout	*Oncorhynchus clarkii clarkii*	Not Included	Blue	Expected
Coho salmon	*Oncorhynchus kisutch*	Not Included	Yellow	Expected
Sockeye salmon	*Oncorhynchus nerka*	Not Included	Yellow	Expected
Chinook salmon	*Oncorhynchus tshawytscha*	Not Included	Yellow	Expected
Pink salmon	*Oncorhynchus gorbuscha*	Not Included	Yellow	Expected
Chum salmon	*Oncorhynchus keta*	Not Included	Yellow	Expected
Bull trout coastal lineage	*Salvelinus confluentus*	Not Included	Blue	Expected
Dolly Varden char	*Salvelinus malma*	Not Included	Yellow	Expected
Eulachon	*Thaleichthys pacificus*	Not Included	Blue	Expected
Mammals				
Pacific water shrew	*Sorex bendirii*	Endangered	Red	Not Expected
Stellar sea lion	*Eumetopias jubatus*	Special Concern	Red	Expected
Wolverine	*Gulo gulo luscus*	Not Included	Blue	Not Expected
Mountain beaver	*Aplodontia rufa*	Special Concern	Yellow	Not Expected
Harbour seal	*Phoca vitulina*	Not Included	Yellow	Expected
California sea lion	*Zalophus californicanus*	Not Included	Yellow	Expected
Grizzly bear	*Ursus arctos*	Not Included	Blue	Not Expected
Herptiles				
Western pond turtle	*Actinemys marmorata*	Extirpated	Red	Not Expected
Western toad	*Anaxyrus boreas*	Special Concern	Blue	Not Expected
Coastal tailed frog	*Ascaphus truei*	Special Concern	Blue	Not Expected
Northern rubber boa	*Charina bottae*	Special Concern	Yellow	Not Expected
Northern red legged frog	*Rana aurora*	Special Concern	Blue	Not Expected
Oregon spotted frog	*Rana pretiosa*	Endangered	Red	Not Expected

Thirteen (13) species-at-risk are documented by the CDC and Klinkenberg (2016a) to utilize the Project area during critical life stages. Of these organisms, twelve (12) are plants and one (1) is a fish.

Non-sensitive occurrences of ten (10) plant species-at-risk are identified by the CDC to occur within 10 km of the Project location (BC Ministry of Environment 2016), as summarized by Table 3.

Table 3 **CDC Non-Sensitive Plant Occurrences**

Common Name	**Botanical Name**	**SARA Schedule**	**CDC List**
Chaffweed	*Anagallis minima*	Not included	Blue
Vancouver Island Beggarticks	*Bidens amplissima*	Schedule 1 Special Concern	Blue
Two-edged water-starwort	*Callitriche heterophylla* var. *heterophylla*	Not included	Blue
Green-fruited sedge	*Carex interrupta*	Not included	Blue
Three-flowered waterwort	*Elatine rubella*	Not included	Blue
Pointed rush	*Juncus oxymeris*	Not included	Blue
Flowering quillwort	*Lilaea scilloides*	Not included	Blue
False-pimpernel	*Lindernia dubia* var. *anagallidea*	Not included	Blue
Streambank lupine	*Lupinus rivularis*	Schedule 1, Endangered	Red
Henderson's checker-mallow	*Sidalcea hendersonii*	Not included	Blue

Two (2) additional species-at-risk that were not included in the CDC database but were identified by Klinkenberg (2016a) to be located within 10 km of the Project include short-tailed rush (*Juncus brevicaudatus*) and yellowseed false-pimpernel (*Lindernia dubia* var. *dubia*). Short-tailed rush is red-listed by the CDC but not included in Schedule 1 of SARA. Yellowseed false-pimpernel is also red-listed by the CDC but not included in Schedule 1 of SARA.

Plant species-at-risk with potential to occur within the project area are most likely to be found on the riverbank or within the muddy intertidal region with the exception of Vancouver Island beggarticks that may occur more upland of the river and streambank lupine that may occur within the railway corridor. Proposed critical habitat identified for streambank lupine (Environment Canada 2016[44]) does not engage Annacis Island.

Pointed rush (*Juncus oxymeris*) was observed in 1989 to occur at the upstream extent of Annacis Island in the riparian zone (BC Conservation Data Centre 2014a[45]). A few scattered flowering quillwort (*Lilaea scilloides*) were also observed in 1989 along the intertidal shoreline (mudflat) of Annacis Island BC Conservation Data Centre 2014b[46]).

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[44] **Environment Canada. 2016.** Recovery Strategy for the Streambank Lupine (*Lupinus rivularis*) in Canada [Proposed]. *Species At Risk Act* Recovery Strategy Series. Environment Canada, Ottawa. 13 pp. + Annex.

[45] **BC Conservation Data Centre. 2014a**. Occurrence Report Summary, Shape ID:3514, pointed rush. BC Ministry of Environment. Available: http://delivery.maps.gov.bc.ca/ess/sv/cdc (accessed April 28, 2016)

[46] **BC Conservation Data Centre. 2014b**. Occurrence Report Summary, Shape ID:3490, flowering quillwort. BC Ministry of Environment. Available: http://delivery.maps.gov.bc.ca/ess/sv/cdc (accessed April 28, 2016)

Non-sensitive occurrences of a single fish species-at-risk is identified by the CDC to occur within 10 km of the Project location , specifically White Sturgeon (lower Fraser River population) (BC Ministry of Environment 2016). White sturgeon (lower Fraser River population) is red-listed by the Conservation Data Centre but is not included in Schedule 1 of SARA.

Please contact the undersigned at sickmuller@envirowest.ca or 604-944-0502 should you have any questions regarding this correspondence.

Sincerely,
ENVIROWEST CONSULTANTS INC.

COLLEGE OF APPLIED BIOLOGY
Rolf W. Sickmuller
R.P. Bio
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Rolf Sickmuller, R.P.Bio.
Senior Biologist

RWS/HS/EF

Attachment A Table 1 Fish Occurrence in the Lower Fraser River

ATTACHMENT A
Fish Occurrence in the Lower Fraser River

Table 1. Fish Occurrence within the Lower Fraser River

		Sources								
Scientific Name	**Common Name**	**(A)**	**(B)**	**(C)**	**(D)**	**(E)**	**(F)**	**(G)**	**(H)**	**(I)**
Acipenser medirostris	green sturgeon	*				*		*		
Acipenser transmontanus	white sturgeon	*				*		*		
Acrocheilus alutaceus	chiselmouth chub or chiselmouth					*				
Agonus acipenserinus	sturgeon poacher	*								
Alosa sapidissima	American shad	*				*				
Ammodytes hexapterus	Pacific sandlance	*	*		*		*		*	
Anoplopoma fimbria	Sablefish	*								
Apodichthys flavidus	penpoint gunnel		*							
Artedius lateralis	smoothhead sculpin		*							
Asemichthys taylori	spinynose sculpin		*							
Atheresthes stomias	turbot or arrowtooth flounder	*								
Aulorhynchus flavidus	tube-snout		*							
Bathymaster signatus	Searcher	*								
Catostomus catostomus	longnose sucker	*				*				
Catostomus columbianus	bridgelip sucker					*				
Catostomus commersonii	white sucker					*				
Catostomus macrocheilus	largescale sucker		*	*		*	*	*	*	
Catostomus platyhyncus	northern mountain sucker					*				
Cetorhinus maximus	basking shark	*								
Citharichthys sordidus	Pacific sanddab	*	*							
Citharichthys stigmaeus	speckled sanddab	*								
Clevelandia ios	arrow goby	*	*							
Clinocottus acuticeps	sharpnose sculpin	*								
Clupea harengus pallasi	Pacific herring	*	*		*			*	*	
Cottus aleuticus	coastrange sculpin	*				*		*	*	
Cottus asper	prickly sculpin			*		*		*	*	
Cottus cognatus	slimy sculpin					*				
Couesius plumbeus	lake chub					*				
Cymatogaster aggregata	shiner perch	*	*					*		
Cyprinus carpio	Carp	*		*		*		*	*	
Dasycottus setiger	spinyhead sculpin	*								
Enophrys bison	buffalo sculpin		*							
Eopsetta jordani	petrale sole	*								
Gadus macrocephalus	Pacific cod	*								
Galeorhinus zyopterus	soupfin shark	*								
Gasterosteus aculeatus	threespine stickleback	*	*		*	*	*	*	*	*
Glyptocephalus zachirus	rex sole	*								
Hexagrammos decagrammus	kelp greenling		*							
Hexagrammos stelleri	whitespotted greenling	*								
Hexanchus griseus	sixgill shark	*								
Hippoglossoides elassodon	flathead sole	*								
Hippoglossus stenolepis	Pacific halibut	*								
Hybognathus hankinsoni	brassy minnow		*	*		*		*	*	*
Hydrolagus colliei	ratfish	*								
Hypomesus pretiosus pretiosus	surf or silver smelt	*	*			*			*	
Icelinus tenuis	spotfin sculpin	*								
Ictalurus nebulosus	brown bullhead or catfish	*		*		*		*	*	
Isopsetta isolepis	butter sole	*	*							
Lamna ditropis	salmon shark	*								
Lampetra ayresi	river lamprey	*		*		*		*	*	
Lampetra tridentatus	Pacific lamprey	*		*		*		*	*	
Lepidogobius lepidus	bay goby	*								
Lepidopsetta bilineata	rock sole	*								

Table 1 contd. Fish Occurrence within the Lower Fraser River

		Sources								
Scientific Name	**Common Name**	**(A)**	**(B)**	**(C)**	**(D)**	**(E)**	**(F)**	**(G)**	**(H)**	**(I)**
Lepomis gibbosus	pumpkin seed					*	*			
Leptocottus armatus	Pacific staghorn sculpin	*	*		*	*		*	*	
Limanda aspera	yellowfin sole	*								
Lumpenus sagitta	Pacific snake prickleback	*	*							
Lycodopsis pacifica	blackbelly eelpout	*								
Lyopsetta exilis	slender sole	*								
Mallotus villosus	capelin	*	*							
Merluccius productus	Pacific hake	*								
Microgadus proximus	Pacific tomcod	*						*	*	
Micropterus salmoides	largemouth bass					*				
Microstomus pacificus	Dover sole	*								
Mylocheilus caurinus	peamouth chub	*	*	*		*	*	*	*	*
Notorhynchus maculosus	sevengill shark	*								
Notropis atherinoides	emerald shiner					*				
Notropis hudsonius	spottail shiner					*				
Oligocottus maculosus	tidepool sculpin	*	*							
Oligocottus rimensis	saddleback sculpin	*								
Oncorhynchus gorbuscha	pink salmon	*	*	*		*	*		*	
Oncorhynchus keta	chum salmon	*	*	*		*	*	*	*	*
Oncorhynchus kisutch	coho salmon	*	*	*		*	*	*	*	*
Oncorhynchus nerka	sockeye salmon	*		*		*	*	*	*	
Oncorhynchus nerka	kokanee					*				
Oncorhynchus tshawytscha	chinook salmon	*	*	*		*	*	*	*	*
Oncorhynchus clarkii clarkii	coastal cuttroat trout	*		*		*	*	*	*	
Oncorhynchus clarki lewisi	westslope cuttroat trout	*				*				
Oncorhynchus mykiss	steelhead trout or rainbow trout	*				*		*		
Ophiodon elongatus	lingcod	*								
Parophrys vetulus	lemon or English sole	*	*							
Pholis laeta	crescent gunnel		*						*	
Pholis ornata	saddleback gunnel		*							
Pholis sp.	blennie or gunnel	*	*							
Platichthys stellatus	starry flounder	*	*	*	*	*	*	*	*	*
Pomoxis nigromaculatus	calico bass or black crappie	*		*	*	*		*		*
Porichthys notatus	plainfin midshipman	*								
Poroclinus rothrocki	whitebarred prickleback	*								
Prionace glauca	blue shark	*								
Prosopium coulterii	pygmy whitefish					*				
Prosopium williamsoni	mountain whitefish	*				*	*	*	*	
Psettichthys melanostictus	sand sole	*								
Psychrolutes paradoxus	tadpole sculpin	*								
Ptychocheilus oregonesis	northern pike-minnow	*		*		*	*	*	*	*
Radulinus asprellus	slim sculpin	*								
Raja binoculata	big skate	*								
Raja rhina	longnose skate	*								
Rhacochilus vacca	pile perch	*								
Rhinichthys cataractae	longnose dace			*		*			*	
Rhinichthys falcatus	leopard dace			*		*				
Richardsonius balteatus	redside shiner	*		*		*	*	*	*	*
Ronquilus jordani	northern ronquil	*								
Salvelinus confluentus	bull trout					*				
Salvelinus malma	Dolly Varden	*				*		*	*	*
Sebastes maliger	quillback rockfish	*								
Sebastode	rockfish	*								

Table 1 contd. Fish Occurrence within the Lower Fraser River		**Sources**								
Scientific Name	**Common Name**	**(A)**	**(B)**	**(C)**	**(D)**	**(E)**	**(F)**	**(G)**	**(H)**	**(I)**
Spirinchus thaleichthys	longfin smelt	*			*	*	*	*	*	*
Squalus suckleyi	dogfish	*								
Synchirus gilli	manacled sculpin							*		
Syngnathus griseolineatus	bay pipefish	*	*							
Thaleichthys pacificus	eulachon	*	*	*		*	*	*	*	*
Theragra chalcogrammus	whiting, big-eye, or walleye pollock	*								

Scientific names, where they differ from current nomenclature, are utilized as printed in the source document.

A **Hoos, L.M. and G.A. Packman. 1974**. The Fraser River Estuary - Status of Environmental Knowledge to 1974. Report of the Estuary Working Group. Environment Canada. pp 275-277.

B **Gordon, D.K. and C.D. Levings. 1984**. Seasonal Changes of Inshore Fish Populations on Sturgeon and Roberts Bank, Fraser River Estuary British Columbia. Canadian Technical Report of Fisheries and Aquatic Sciences No. 1240. Department of Fisheries and Oceans, West Vancouver, B.C. pp18-19.

C **Whitehouse, T.R., D.E. Boyle, C.D. Levings, J. Newman, and J. Black. 1993**. Fish Distribution within a Tidal Freshwater Marsh in the Lower Fraser River. Canadian Data Report of Fisheries and Aquatic Sciences 917. Department of Fisheries and Oceans, West Vancouver, B.C. pp10-15.

D **Tuominen, T., 1986.** Letter Correspondence dated June 23, 1986 (T. Tuominen, Environment Canada to F. Fraser, Department of Fisheries and Oceans).

E **Fisheries Inventory Data Queries 2016**. FIDQ Summary of Fish Present. Accessed February 1, 2016.

F **Scott, K.J., R. Susanto. 1992**. Analysis of Fish Occurrence in Restored, Unvegetated and Natural Habitats in the Fraser River Estuary. Scott Resource Services. p63.

G **Northcote, T.G., N.T. Johnston, and K. Tsumura. 1978**. A regional comparison of species distribution, abundance, size and other characteristics of lower Fraser River fishes. Technical Report No. 14. Westwater Research Center, University of British Columbia. pp7-10.

H **Levy, D.A., T.G. Northcote, and G.J. Birch. 1979.** Juvenile salmon utilization of tidal channels in the Fraser River Estuary, British Columbia. Technical Report No. 23, Westwater Research Center, University of British Columbia. p11.

I **Envirowest Consultants Inc. 2009**. Fish sampling conducted at the mouth of Jerry Rogers Creek, North Arm Fraser River, British Columbia from 2007 to 2009. Unpublished data on file and data submitted to Fisheries and Oceans Canada.

APPENDIX D

Species at Risk Tables

Table 1: Regionally Occurring Provincially and Federally Designated Wildlife Potentially Occurring in the Project Area

Common Name	Scientific Name	SARA[a)]	COSEWIC[b)]	BC List[c)]	Provincial Status[d)]	Range and Habitat Requirement[e)]	Potential to Occur in Project Area
Birds							
Great Blue Heron, *fannini* subspecies	*Ardea herodias fannini*	1-SC	SC	Blue	S2S3B,S4N	The great blue heron *fannini* subspecies is found throughout southern Canada, the United States and in coastal Mexico. In BC, it is found year round in coastal habitats and in the southern interior. It forages along water margins including marine habitat and slow moving freshwater.	**Expected –** foraging along shoreline; nesting opportunities very limited
Green Heron	*Butorides virescens*	NI	NA	Blue	S3S4B	The range in North America extends from southeastern Canada and south to Florida, where it breeds throughout the eastern United States. In the west it is found from southern BC, south to Baja California and Mexico where it occurs in coastal habitats. In BC, this species occurs along the south coast and is restricted to the Lower Mainland, as far east as Hope and Vancouver Island from Sooke north to Campbell River. The green heron is a resident along the south coast. Green heron occur in swamps, mangroves, marshes and riparian zones along creeks and streams. Nests are in trees, thickets or bushes over water, dry woodlands and orchards.	**Expected –** occasional foraging along shoreline; nesting opportunities absent
Black-crowned Night-heron	*Nycticorax nycticorax*	NI	NA	Red	S1	Range extends across North America though status varies by province/state. The breeding range includes Washington State, Idaho, Saskatchewan, Michigan, and Nova Scotia and south into South America. Winter habitat includes states as far north as Oregon, also in Utah, New Mexico, Texas, Gulf Coast, and southern New England. In BC, they are a transient species in the Kootenies, Thompson, and on Vancouver Island, a seasonal resident in the Okanagan region, and a year-round resident and confirmed breeder in Lower Mainland. This species is found in wetlands, mangroves, streams and lakes. Nesting occurs in a variety of habitats such as wetlands, orchards, and on marine islands.	**Expected –** occasional foraging along shoreline; nesting opportunities absent

Common Name	Scientific Name	SARA[a)]	COSEWIC[b)]	BC List[c)]	Provincial Status[d)]	Range and Habitat Requirement[e)]	Potential to Occur in Project Area
Double-crested Cormorant	*Phalacrocorax auritus*	NI	NAR	Blue	S3S4B	The range extends from Alaska south along the Pacific Coast to Mexico. This species occurs in the interior of Canada and the United States and Florida and the Caribbean. In BC, it breeds in the Strait of Georgia and over winters in coastal areas. Nests occur on protected offshore islands and rocks or on bridges, shipwrecks, docks and nesting-towers. The double – crested cormorant forages mainly in marine habitats but may also visit inland lakes and the estuaries of large rivers.	**Expected –** foraging in Fraser River, nesting opportunities absent
Caspian Tern	*Hydroprogne caspia*	NI	NAR	Blue	S3B	Breeding is scattered around Canada and the United States. In BC, breeding occurs along the Pacific Coast in the southwest of the province on the Fraser River delta. Nests occur on sandy or gravelly beaches along coasts or lakes. Foraging habitat includes beaches, mudflats and sheltered bays.	**Expected -** occasional foraging along shoreline; nesting opportunities absent
Marbled murrelet	*Brachyramphus marmoratus*	1 (T)	T	Blue	S3B, S3N	Breeding habitat extends along coastal BC, and up to 100 kilometers inland. Breeding habitat heavily dependent on old trees with substantially large branches providing a platform for 'nesting'. Foraging in marine waters.	**Not Expected –** foraging habitat absent, nesting opportunities absent
Common nighthawk	*Chordeiles minor*	1 (T)	T	Yellow	G5	Established throughout BC, but rare west of Coast mountains north of Vancouver and on Haida Gwaii. Nesting and foraging occurs generally on and over open ground, respectively. Nesting on flat rooftops has also been documented.	**Not Expected –** nesting and foraging opportunities are absent from shoreline
Black swift	*Cypseloides niger*	NI	E	blue	S2S3B	Breeding restricted to south BC and southwest Alberta, primarily on cliffs, caves, and behind waterfalls. Species is an aerial insect hunter	**Not Expected -** nesting and foraging opportunities are absent from shoreline
Peregrine falcon anatum subspecies	*Falco peregrinus anatum*	1 (SC)	SC	Red	S2?B	Rare raptor occurring in BC. Cliffs are preferred nesting habitat, although species has been documented to nest on similar anthropogenic structures (e.g. bridges, high rise towers). Aerial ambush predator, diving from height to capture prey (mostly birds).	**Not Expected –** nesting has occurred on Patullo Bridge substructure, but opportunities are absent from shoreline

Common Name	Scientific Name	SARA[a]	COSEWIC[b]	BC List[c]	Provincial Status[d]	Range and Habitat Requirement[e]	Potential to Occur in Project Area
Sandhill crane	*Grus canadensis*	NI	NAR	Yellow	S4B	Large migrant bird typically found in wetlands, meadows and marshes. Poor knowledge of nesting in British Columbia. An opportunistic omnivore, this species has been documented in agricultural fields in Delta and Richmond	**Not Expected -** nesting and foraging opportunities are absent from shoreline
Barn swallow	*Hirundo rustica*	NI	T	Blue	S3S4B	Migrant bird occurring throughout BC, and often associated with anthropogenic structures for nesting (e.g. sheds, barns). Aerial insectivore over open spaces (including freshwaters)	**Expected –** foraging opportunities exist along shoreline, but nesting opportunities scarce
Fish							
White Sturgeon (Lower Fraser River population)	*Acipenser transmontanus* pop. 4	NI	T	Red	S2	The range of this species extends along the Pacific coast of North America in the Fraser River, Columbia and Sacramento rivers. This population is found in the Lower Fraser River. Spawning occurs in side channels of large rivers characterized by gravel, cobble or sand substrate. Spawning generally occurs during flooding events at a depth of 3 to 4.5 meters. Juveniles occur in the lower reaches of tributaries, within wetlands and side channels deeper than 5 meters. Suitable habitat for adults occurs in deep near-shore environments characterized by sand or gravel substrate and located close to areas of heavy, turbulent flow.	**Expected –** multiple captures of juvenile white sturgeon along Annacis Island shoreline
Cutthroat Trout, *clarkii* subspecies	*Oncorhynchus clarkii clarkii*	NI	NA	Blue	S3S4	The range of this species extends from Alaska south to northern California. In BC this species occurs as marine populations, freshwater-resident populations and headwater stream populations. Suitable habitat occurs in relatively small streams characterized by gravel substrates and a low gradient. Spawning generally occurs in streams.	**Expected** – as anadromous migrant
Coho Salmon	*Oncorhynchus kisutch*	NI	E	Yellow	S4	The range in North America extends from Alaska south to Baja California. Suitable habitat occurs in coastal habitat in marine environments, lakes and streams. Spawning occurs in streams.	**Expected –** as adult and juvenile migrants

Common Name	Scientific Name	SARA[a)]	COSEWIC[b)]	BC List[c)]	Provincial Status[d)]	Range and Habitat Requirement[e)]	Potential to Occur in Project Area
Bull Trout – South Coast Lineage	*Salvelinus confluentus - coastal lineage*	NI	SC	Blue	S3	The range extends from the southern Yukon south to include the Columbia River drainage and McCloud River drainages (west coast USA). In BC, bull trout generally occur in the interior of the province. It inhabits streams and coastal habitats where large rivers traverse the Coast Mountains to the Pacific Ocean. Cold water specialists.	**Not Expected –** closest occurrence recorded at Pitt River confluence (1998)
Eulachon	*Thaleichthys pacificus*	NI	E/T	Blue	S2S3	This anadromous fish is inhabits near coastal waters extending from central California to the Bering Strait. Adults spawn in fresh waters including the Fraser River; this population has declined substantially since 1960s. Spawning documented up and downstream of New Westminster in north and south arms of the River, although locations are variable each year.	**Expected –** migrants to spawning (adult) and marine (juvenile) habitats
Green Sturgeon	*Acipenser medirostris*	1-SC	SC	Red	S1N	Nearly all captures this species in BC have occurred in marine waters; fresh water captures in Fraser River are extremely rare. Conversely, presence in the Columbia River (USA) is well documented.	**Not Expected**
Sockeye salmon	*O. nerka*	NI	E	Yellow	S4	Anadromous species well documented throughout BC, in particular Fraser River.	**Expected –** as adult & juvenile migrants
Chinook salmon	*O. tshawytscha*	NI	T	Yellow	S4	Anadromous species well documented throughout BC, in particular Fraser River.	**Expected –** as adult & juvenile migrants
Pink salmon	*O. gorbuscha*	NI	NA	Yellow	S5	Anadromous species well documented throughout BC, in particular Fraser River.	**Expected –** as adult & juvenile migrants
Chum salmon	*O. keta*	NI	NA	Yellow	S5	Anadromous species well documented throughout BC, in particular Fraser River.	**Expected –** as adult & juvenile migrants
Dolly Varden (southern form)	*Salvelinus malma*	NI	NA	Yellow	S4	Anadromous and non-anadromous fish occur in the Fraser River. Occasional records in tidal waters of the Fraser River (e.g. near Steveston and around Barnston Island). Spawning occurs in cold water streams	**Expected –** as occasional adult or juvenile migrant

Common Name	Scientific Name	SARA[a)]	COSEWIC[b)]	BC List[c)]	Provincial Status[d)]	Range and Habitat Requirement[e)]	Potential to Occur in Project Area
Mammals							
Pacific watershrew	*Sorex bendirii*	1-E	E	Red	S1S2	The range for this species is restricted to western North America where it occurs from southwestern BC, south to northern California. In BC, it occurs in the Lower Fraser River valley, as far east as the Chilliwack River and Harrison Lake. This species primarily inhabits riparian areas in wet coniferous or mixed forests, along low gradient streams, and marshes. Provincial occurrence reports along South Fraser Perimeter Road in Surrey and Delta	**Not Expected –** breeding and foraging habitats are absent along shoreline
Steller sea lion	*Eumetopias jubatus*	1-SC	SC	Blue	S3B,S4N	The range extends from California to the Bering Sea and Kurile Islands. In BC, three breeding populations are recognized and are located in the Scott Islands, Cape St. James and offshore of Banks Island. Aquatic habitat includes coastal waters of the North Pacific Ocean, where feeding occurs mainly on the continental shelf. Terrestrial habitat includes rookeries, year-round haul-out sites and winter haul-out sites. Terrestrial habitat tends to be limited to areas devoid of predators such as bears or wolves and generally occurs on small rock islets.	**Expected** – occasional foraging along shoreline during adult salmon migrations
Wolverine luscus subspecies	*Gulo gulo luscus*	NI	SC	Blue	S3	Solitary predator from badger family, typically occurring in absence of people but occasionally venturing into outskirts of settlements	**Not Expected –** breeding and foraging opportunities absent along shoreline
Mountain beaver	*Aplodontia rufa*	1 (SC)	SC	Yellow	S4	Small tunneling rodent with primitive urinary system typically associated with sloped terrain close to permanent waters; forage crop include sword fern	**Not Expected -** breeding and foraging opportunities absent along shoreline
Grizzly bear	*Ursus arctos*	NI	SC	Blue	S3?	Large opportunistic omnivore with extensive range requirements. Extirpated from lower Fraser River with arrival of European settlers	**Not Expected -** breeding and foraging opportunities absent along shoreline

Common Name	Scientific Name	SARA[a)]	COSEWIC[b)]	BC List[c)]	Provincial Status[d)]	Range and Habitat Requirement[e)]	Potential to Occur in Project Area
California sea lion	*Zalophus californicanus*	NI	Not At Risk	Yellow	S5N	Large marine mammal with extensive range along coastal BC. Follows upstream migrations by adult salmon and eulachon	**Expected** – occasional forager during adult salmon and eulachon migrations
Harbour seal	*Phoca vitulina*	NI	Not at Risk	Yellow	S5N	Medium sized marine mammal with extensive range along coastal BC. Follows upstream migrations by adult salmon and eulachon	**Expected** – occasional forager during adult salmon and eulachon migrations
Herptiles							
Western pond turtle	*Actinemys marmorata*	1 (XX)	XT	Red	SX	This species inhabits large rivers, slow-moving streams, sloughs, and is infrequently found in brackish water. The species prefers areas with emergent vegetation and requires deep pools with large woody debris for refuge from predators. The species has not been reported to occur in Canada since the late 1950s.	**Not Expected** – required habitat not sustained along shoreline
Western toad	*Anaxyrus boreas*	1 (SC)	SC	Blue	S3S4	Western toads use three different types of habitat: breeding, terrestrial summer range, and winter hibernation sites. This species will breed in a variety of aquatic habitats with sandy substrates, including the shallow margins of lakes to roadside ditches. Outside the breeding season, adults spend most of their time on land and can be found in forested areas, wet shrublands, avalanche slopes, and meadows. Adults are active from January until October. Tadpoles are highly gregarious and eat algae, as well as organic matter in the water, but will scavenge on carrion. The species hibernates in burrows below the frost-line up to six months of the year.	**Not Expected** – required habitat not sustained along shoreline

Common Name	Scientific Name	SARA[a)]	COSEWIC[b)]	BC List[c)]	Provincial Status[d)]	Range and Habitat Requirement[e)]	Potential to Occur in Project Area
Coastal tailed-frog	*Ascaphus truei*	1 (SC)	SC	Blue	S3S4	The tailed frog requires steep, cold mountain streams in older forests as breeding habitat, along with damp litter on the forest floor to survive as metamorphosed adults. The frogs prefer creeks with a variety of gradients, but are generally absent from creeks with either low or excessively steep gradients. In addition, the substrate of the drainage is boulders or cobbles and the drainage must remain ice free in winter. Eggs are attached to the underside of a boulder or large rock in the stream Adults will winter under rocks or at the stream surface	**Not Expected** – required habitat not sustained along shoreline
Northern rubber boa	*Charina bottae*	1 (SC)	SC	Yellow	S4	West of the Cascade Mountains, this species occupies a variety of habitats, including oak woodlands, savannas, and coniferous forests. Occasionally it is found in open areas along riparian zones. Rubber boas are commonly found in rotting stumps, under logs, bark, rocks, and other objects in grassy openings among trees or near streams.	**Not Expected** – required habitat not sustained along shoreline
Northern red-legged frog	*Rana aurora*	1 (SC)	SC	Blue	S3S4	The red-legged frog is typically associated with streams, ponds, and marshes characterized by slow-moving water. The frog is also found within terrestrial environments associated with moist forest conditions far from open water characterized by mature vegetation, leaf litter, and large woody debris. This low elevation species hibernates from November until late February, either in water or on land. Breeding occurs in late winter/early spring in shallow water of permanent ponds or lakes, slow-moving streams, marshes, bogs, and swamps. In the summer, hatchlings typically occur within vegetation along streams, in moist sedge or brush, on shaded pond edges, and/or under logs or debris.	**Not Expected** – required habitat not sustained along shoreline

Common Name	Scientific Name	SARA[a)]	COSEWIC[b)]	BC List[c)]	Provincial Status[d)]	Range and Habitat Requirement[e)]	Potential to Occur in Project Area
Oregon spotted frog	*Rana pretiosa*	1 (E)	E	Red	S1	The Oregon spotted frog is typically associated with aquatic environments and typically inhabits marshes, edges of permanent ponds, streams, and lakes, usually with abundant aquatic vegetation. Breeding occurs in warm, shallow margins of ponds, rivers, and temporary pools. In southwestern BC, eggs are typically deposited in March. The species hibernates during the winter in muddy bottom habitats near breeding sites.	**Not Expected** – required habitat not sustained along shoreline

a) **SARA:** Federal *Species at Risk Act* Schedule number (1-3) for this species. See the SARA website for more information (Government of Canada 2016). E = Endangered, T = Threatened, SC = Special Concern, DD = Data Deficient, NA = Not Assessed.

b) **COSEWIC:** Committee on the Status of Endangered Wildlife in Canada. Ranks have the following meanings: E = ENDANGERED: A species facing imminent extirpation or extinction, T = THREATENED: A species that is likely to become endangered if limiting factors are not reversed, SC = SPECIAL CONCERN: A species of special concern because of characteristics that make it is particularly sensitive to human activities or natural events, NAR = NOT AT RISK: A species that has been evaluated and found to be not at risk, DD = DATA DEFICIENT: A species for which there is insufficient scientific information to support status designation. NA = Not assessed (Government of Canada 2015).

c) **BC CDC List**: The provincial list to which the species or ecological community is assigned (BC CDC 2016). Possible values: Extinct, Red (Any indigenous species, subspecies or plant community that is extirpated, endangered, or threatened in BC.), Blue (Any indigenous species, subspecies or community considered to be of special concern in BC. Blue-listed elements are at risk, but are not extirpated, endangered or threatened), Yellow (Any indigenous species, subspecies or community considered to be secure in British Columbia –encompasses all those not listed as red or blue), Accidental, Unknown and No Status.

d) **Provincial Conservation Status** = Provincial Ranks apply to a species' or ecological community's conservation status in British Columbia. The number in parenthesis is the year the rank was last reviewed. The ranks have the following meaning: X = presumed extirpated, H = possibly extirpated, 1 = critically imperilled, 2 = imperilled, 3 = special concern, vulnerable to extirpation or extinction, 4 = apparently secure, 5 = demonstrably widespread, abundant, and secure, NA = not applicable, NR = unranked, U = unrankable. N= non-breeding; B= breeding, ? = inexact or uncertain (BC CDC 2016).

e) Habitat Requirement information taken from BC CDC 2016.

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APPENDIX E

Development Activity in the Study Area

Table 1: Summary of Current and Reasonably Foreseeable Projects or Activities Located on or near the Lower Fraser River within 17 km of the proposed Annacis Wastewater Treatment Plant Proposed New Outfall Diffuser

Project Name	Description	Approx. Distance to Proposed AWWTP New Outfall Diffuser
Present Projects		
Seaspan Ferries Corporation Tilbury Terminal	Seaspan commercial ferries Tilbury terminal is currently in operation and provides a daily, scheduled truck, trailer, and railcar ferry service.	5 km
FortisBC Tilbury LNG Plant	Tilbury LNG plant is currently in operation as a peak-shaving LNG Unit. The plant was originally built in 1971.	5.5 km
Varsteel	Varsteel is currently in operation.	5.5 km
Lehigh Hanson Cement Plant	Lehigh Hanson Cement Plant is currently in operation.	5.5 km
Coast 2000 Terminals	Coast 2000 Terminals is currently in operation as a warehouse, container yard and barge loading dock mainly handling pulp and paper products and other forest products.	5.5 km
Fraser Wharves	Fraser Wharves is currently in operation as a large marine terminal for importing automobiles. The terminal is part of Port Metro Vancouver.	7.8 km
Vancouver International Airport (YVR)	Vancouver International Airport is currently in operation with two terminals.	14.5 km
Deltaport Terminal, Road and Rail Improvement Project (DTRRIP)	The causeway overpass was the first component of the Deltaport Terminal, Road and Rail Improvement Project (DTRRIP) to be completed, in December 2014. The new overpass separates road and rail traffic, improving the flow of trucks and trains accessing the terminal, reducing truck and vehicle idling and increasing safety, as well as contributing an estimated 150,000 to 200,000 twenty-foot equivalent units (TEUs) of additional capacity annually at Deltaport.	16.8 km
Present Activities		
Dredging of the Fraser River Main and Secondary Channels	Dredging policy addresses the maintenance dredging of deep sea and domestic shipping channels. Comprises the removal and disposal of sediment from navigational channels.	Adjacent
Fishing in the Fraser River	Commercial, Recreational and Aboriginal Fishing in the Fraser River.	Adjacent
Seaspan Ferry Operation	Daily commercial Seaspan ferry operation from Tilbury to Nanaimo and Swartz Bay.	5 km
Reasonably Foreseeable Projects		
FortisBC Tilbury LNG Plant Expansion Project	The proposed expansion of the Tilbury LNG plant will include an additional 1.1 million gigajoules of LNG storage and 34,000 gigajoules of liquefaction capacity per day. Construction of an additional storage tank commenced in October 2014. LNG from the expanded facility will supply vehicles by Q4 2016. Should additional information become available regarding future expansion projects these will be included in the cumulative effects assessment.	5.5 km

Project Name	**Description**	**Approx. Distance to Proposed AWWTP New Outfall Diffuser**
Wespac Tilbury Marine Jetty Project	The proposed construction and operation of a marine jetty for loading Liquefied Natural Gas (LNG) onto LNG carriers and LNG barges on Tilbury Island along the South Arm of the Fraser River, in Delta, BC. The purpose of the Project is to transfer LNG to carriers and barges for delivery to both offshore export markets and local fuel markets. The Project comprises the removal of existing abandoned marine infrastructure currently occupying a portion of the water lots and the construction of a new marine jetty, including a vessel loading platform, four berthing dolphins, four mooring dolphins, and an access trestle. The assessment will consider the effects of the proposed Project across three temporal boundaries, these being Construction (2017-2018: 15 months), Operation (2018-2048: 30 years minimum) and Decommissioning (2048 or later: 2 months).	5.5 km
Vancouver Airport Fuel Facilities Corporation (VAFFC) Fuel Delivery Project	The VAFFC Fuel Delivery Project comprises the construction of a marine terminal and fuel receiving facility on the north bank of the South Arm of the Fraser River and a 13 km underground pipeline to YVR. A barge could be expected to deliver fuel once every two weeks with an unloading time around 12 hours, while a Panamax class vessel could be expected once a month with an unloading time of between 24 to 36 hours. Construction on the marine terminal and pipeline is proposed to commence in early 2016.	6 km
Pattullo Bridge Replacement Project	TransLink is proceeding with a rehabilitation project to design and implement improvements to seismic resiliency and the bridge deck. TransLink is currently planning to begin construction work in mid-2016. It is expected that the construction will continue for no less than 18 months.	7 km
George Massey Tunnel Replacement Project	Existing tunnel to be replaced on the Highway 99 corridor with a new 10-lane bridge. The new bridge will be constructed above the tunnel. Project construction expected to begin in 2017, with bridge completion in 2022.	8.4 km
Fraser Surrey Docks Direct Transfer Coal Facility Project	Port Metro Vancouver is currently reviewing an application from Fraser Surrey Docks (FSD) to amend its existing Direct Transfer Coal Facility project permit. Proposed changes to the existing permit include: • Taller and longer marine vessel loader that would accommodate both vessels and barges; • Relocation of the transfer station between the out feed conveyor and the marine vessel loader; • Mounting the marine vessel loader control room above the out feed conveyor transfer point; • Relocation of the rail receiving building and associated infrastructure; • Relocation of the waste water settlement basins; • Realignment of the rail services to the rail receiving building and related rail infrastructure modifications; and • Removal of Shed 4 (one-storey steel building, 4,600 m² in size).	14.5 km

APPENDIX E
Development Activity in the Study Area

Project Name	Description	Approx. Distance to Proposed AWWTP New Outfall Diffuser
Roberts Bank Terminal 2 Project	The Roberts Bank Terminal 2 Project is a proposed new three-berth container terminal at Roberts Bank in Delta, B.C. The Project would provide 2.4 million TEUs (twenty-foot equivalent units) of container capacity and is needed to meet forecasted demand for trade of goods in containers. Subject to regulatory approvals and permits, market conditions and a final investment decision, construction of the Project would begin in 2018 and would take approximately five-and-a-half years to complete. This would allow the Project to be operational by the mid-2020s, when its capacity will be required.	21 km
PMV Habitat Enhancement Program (HEP)	The PMV Habitat Enhancement Program is an initiative focused on creating and enhancing fish and wildlife habitat. The HEP program is being undertaken independently from any specific development project; its goal is to enhance habitat values and balance a range of future potential development projects that may be required for PMV operations. The following enhancement projects have been proposed within the Fraser River estuary:	
	Point Grey Tidal Marsh Project (Point Grey)	22 km
	South Arm Jetty Tidal Marsh Project (South Arm Jetty)	19 km
	Steveston Island Tidal Marsh Project (Steveston)	14 km
	Tsawwassen Eelgrass Project (Tsawwassen Eelgrass)	22 km
Seaspan Ferries Tilbury Expansion	Proposed expansion of the Tilbury Seaspan ferries jetty	5 m
Trans Mountain Pipeline Expansion	Proposed expansion of the Trans 1,150-kilometre pipeline between Strathcona County (near Edmonton), Alberta and Burnaby, BC. The proposed expansion, if approved, would create a twinned pipeline that would increase the nominal capacity of the system from 300,000 barrels per day, to 890,000 barrels per day.	10 km (closest point)

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Golder Associates

December 7, 2016 File: ME-000387

Metro Vancouver
4330 Kingsway
Burnaby, BC V5H 4G8

Attention: Mr. Ken Massé, P.Eng.,
Senior Project Engineer, Project Delivery

Re: Review of Annacis Outfall Up-grade - Stage 1 Environmental Impact Study

The Ministry of Environment (Ministry) and the Ministry of Forest, Lands & Natural Resource Operations (MFLNRO) have completed a review of the Golder Associates Report, "*Annacis Island Wastewater Treatment Plant Transient Mitigation and Outfall Project – Stage 1 Environmental Impact Study"* dated August 26, 2016 (the Report).

The Report appears to satisfy the requirements of a Stage 1 Environmental Impact Study (EIS) as detailed within the "*Environmental Impact Study Guideline – A Companion Document to the Municipal Sewage Regulation*" issued December 2000 (Guideline).

Review and comment from Ministry and MFLNRO staff identified themes that should be addressed during the Stage 2 Environmental Impact Study (EIS) and can be generally summarized as follows:

1. Water quality predictions and modelling considering 2 times Average Dry Weather Flow as identified in the Guideline and the Municipal Wastewater Regulation;
2. The collection of continuous site-specific temperature and salinity/conductivity data to determine stratification levels to reduce uncertainty in dilution modelling;
3. The inclusion of additional effluent and ambient modelling data in the Stage 2 EIS to address uncertainties in the predicted Water Quality Guidelines and/or Objectives exceedances;
4. Discussion of all water quality parameter exceedances;
5. Impacts to aquatic species as a result of outfall design and construction should be addressed in the Stage 2 EIS; and
6. A construction and mitigation, and monitoring plan should be developed during the Stage 2 EIS and should identify species of greatest concern at the site.

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Specific information related to the above summary has been attached for your reference.

In addition to the information referenced above, Erin Stoddard, Fisheries Biologist with MFLNRO has identified concerns related to the outfall expansion location, specifically, but not limited to the following:

"*The reach of the Fraser River into which the existing and upgraded discharge structure is located and effluent discharged is very important to lower Fraser River White Sturgeon. It contains "critical" juvenile sturgeon rearing habitat and is the location of a juvenile population monitoring index site. The juvenile index program includes the assessment of this site for 3 consecutive years out of every five years (three years sampling followed by two years of no sampling). The next three year sampling period will start in early September 2017. The upgraded discharge structure will likely result in significant impacts to these habitats and to the juvenile sturgeon that use them during construction of the upgraded discharge structure, after initial start-up and over the full period of the facilities operation.*"

It is important that you contact Mr. Stoddard (604-586-5644) to discuss his concerns, as they may need to be addressed through approvals required under the *Water Sustainability Act*.

It is acknowledge that some of the information identified above has already been collected for consideration in the Stage 2 EIS. Proceed with the Stage 2 EIS by following the Golder Associate's recommended monitoring considerations for the Stage 2 EIS, address the uncertainties identified within the Report and address Ministry and MFLNRO recommendations.

For the Stage 2 EIS, please consider developing a Terms of Reference for Ministry review.

If you have any questions, please do not hesitate to contact me at 604-582-5275 or to arrange a meeting to discuss Ministry comments.

Sincerely,

Trevor Hamelin

Trevor Hamelin, AScT
A\Section Head – Municipal Liquid Waste
Authorizations – South

Encl. Memo Assessment from Michelle Hawryluk, Environmental Impact Assessment Biologist, Ministry of Environment

Memo Assessment from Erin Rainey, Regional Hydrologist, Ministry of Environment

BRITISH
COLUMBIA

MEMORANDUM

Date: October 06, 2016
File: ME-000387

To: Trevor Hamelin
South Authorization Unit
Regional Operations

Re: Metro Vancouver Operational Certificate ME-000387, Review of Stage 1 Environmental Impact Study for the Annacis Island Wastewater Treatment Plant Transient Mitigation and Outfall Project.

I have completed my review of the Stage 1 Environmental Impact Study (EIS) for the Annacis Island Wastewater Treatment Plant (AIWWTP) transient mitigation and outfall project, as written by Golder Associates in August 2016. This document satisfies many of the requirements of a Stage 1 EIS as outlined in the *Environmental Impact Study Guideline – A Companion Document to the Municipal Sewage Regulation*, Section 5.2 *Greater Risk – e.g., Maximum Daily Flow >10,000* m^3*/d with Discharge to Open Marine Waters or to Streams with <100:1 dilution* (MELP, 2000). Furthermore, the document identifies areas of uncertainty, with corresponding plans for reducing that uncertainty for inclusion in the Stage 2 EIS. There remain several areas that require consideration as this permit amendment progresses toward the Stage 2 EIS, namely predicted exceedances at the Initial Dilution Zone (IDZ) for several water quality parameters.

The results of the study indicate that a number of water quality parameters will exceed instantaneous or monthly average applicable objectives and/or guidelines at the IDZ. Specifically, the following parameters are predicted to exceed either the instantaneous Fraser River Water Quality Objectives (FRWQOs), lowest applicable BC Water Quality Guideline (BCWQG) or the recreational screening criterion during one or more of the three river flows modeled: total Cd, total Fe, total Cu, total Mn, dissolved Al, Benzo-a-pyrene, Total Polychlorinated Biphenyls (PCBs), 17α-ethinyl-estradiol (EE2), and Total Residual Chlorine (TRC). Similarly, the results of the modeling indicate the monthly average concentrations for following parameters will exceed the applicable FRWQOs, BCWQGs, or the federal guidelines as developed by the Canadian Council of Ministers of Environment (CCME): un-ionized ammonia, total Cu, total Cr, total Zn, total Pb, total Al, total Fe, dissolved Al, total Hg, and EE2. A brief summary of the explanation provided for each exceedance and further discussion based on the policies of the Environmental Protection Division will follow.

…/2

Instantaneous Total Cd & Total Fe

The predicted exceedances for instantaneous concentrations of both total Cd (2 times the BC Working WQG) and total Fe (3.7 times the BCWQG) are considered in the Stage 1 EIS not to be of concern given the dissolved, bioavailable form of the element is below the corresponding guideline. It should be noted that the BC Working WQG for total Cd has been replaced with an approved WQG for dissolved Cd and as such the former guideline no longer applies. In the case of Fe, the *Ambient Aquatic Life Guidelines for Iron* identify the dissolved form of primary importance, recognizing that total Fe may exceed the recommended guideline due to natural causes; for instance, it can be caused by a high load of suspended material in water during high flow conditions where the association of total iron content is with the suspended materials. **In these cases the guidelines suggest the use of background total Fe concentration as a guideline; this information was not included as a comparison in the body of the report and as such it is difficult to determine whether the rationale for negating this exceedance is reasonable.**

Instantaneous & Monthly Average Total Cu

The predicted exceedances for instantaneous concentrations of total Cu (maximum of 2.9 times the FRWQO at high flow) are noted in the report to be discernible from the ambient concentration, and the predicted mean monthly concentrations for total Cu exceed the FRWQO discernibly from ambient conditions April through August (maximum of 2.9 times the FRWQO). According to the Stage 1 report, these exceedances are not a concern despite being above ambient background, given dissolved Cu is the most biologically available form. While the instantaneous and monthly averaged dissolved Cu are less than the respective total Cu guidelines, the *Water Quality Criteria for Copper, Overview Report* cautions against using dissolved Cu in comparison to the total Cu as the former can both overestimate and underestimate the bioavailable copper, depending on the water body. **If predicted exceedances persist in the Stage 2 EIS, rationale for ensuring the protection of the environment against copper toxicity will be required.**

Instantaneous Total Mn & Dissolved Al

The predicted exceedances for instantaneous concentrations of total Mn (1.17 times the FRWQO) and dissolved Al (1.4 times the BCWQG), although minor, are not addressed in the body of the report.

Instantaneous Total PCBs

The predicted exceedances for instantaneous concentration of total PCBs are double the BCWQG during all three river flows, and although there is no chronic guideline, the predicted monthly average concentrations are also nearly double the maximum guideline in all 12 months. The report identifies some uncertainty in the predictions as they are based on effluent quality characterized by only six samples and a mean ambient river concentration based on only four samples. **The inclusion of additional effluent and ambient data in the Stage 2 EIS is anticipated to reduce this uncertainty. This will be an important parameter for discussion for the Stage 2 EIS and future work.**

Instantaneous Benzo-a-pyrene & TRC

The predicted instantaneous concentrations for Benzo-a-pyrene and TRC have Method Detection Limits (MDL) above applicable guidelines or screening criteria and as the report describes, **further sampling and analysis included in the Stage 2 EIS will aim to resolve this issue.**

Monthly Un-ionized Ammonia

The predicted monthly concentration for un-ionized ammonia exceeds the CCME guideline by a maximum of 1.1 times in 9 of the 12 months predicted. Given the uncertainty around these predictions, **a refined estimate is anticipated in the Stage 2 EIS given the additional site-specific pH and temperature data currently underway**.

Monthly Average Total Cr, Total Zn, Total Pb, Total AL, Total Fe, Total Hg, Dissolved Al

The report describes the predicted exceedances of monthly average concentrations of all total and dissolved metals (except total Cu, discussed above) to be indistinguishable from the "relevant ambient river condition." **It is unclear in the body of the report how the ambient river concentration was calculated and as such difficult to qualify if the data used represents a) the un-impacted waters and b) sufficient temporal data for a valid comparison.**

Instantaneous & Monthly Average EE2

The predicted and instantaneous concentration for EE2 is 4 times the BCWQG at all 3 river flows, and monthly average concentrations are double the BCWQG in all 12 months. The report suggests these may be overestimates based on high MDLs associated with the effluent samples used in the predictions. **This uncertainty will be addressed upon further sampling and analysis included in the Stage 2 EIS.**

It is unclear whether FRWQOs will be met for fecal coliforms, enterococci, *Escherichia coli*, Zn, dissolved oxygen or pH as they were not considered in the modeling included in the report (i.e., not listed in Table 6-1 and 6-2). Although I understand the modeling results are based on the lowest dilution expected to occur, **it is unclear when and for how long these concentrations are expected to occur; this information is critical in helping to determine the need for increased environmental protection.**

It is my understanding that the predicted concentrations at the IDZ will be refined in the Stage 2 EIS based on the final design, an expanded effluent and ambient water quality dataset, and refined water quality modeling procedures. Based on my review of the Stage 1 EIS, I would like to offer the following recommendations for consideration in development of the Stage 2 EIS:

1. Inclusion of all applicable FRWQOs in the modeling predictions for concentrations at the IDZ (e.g., fecal coliforms, enterococci, *Escherichia coli,* dissolved oxygen, pH, and Zn were missing from tables 6-1 and 6-2).

2. All Predictive modeling results to include estimates of timing, duration and frequency of any exceedances, as well as any correlation to biologic relevance given the receiving environment characterization and use (e.g. correlation to use by juvenile sturgeon, and other fish species).

3. Predictive modeling to include conditions consistent with two times the Average Dry Weather Flow (ADWF) as required by Section 5.2 of the *Environmental Impact Study Guideline.*

4. A description of the plume characteristics under various existing river conditions (e.g., trapping depth, horizontal distance at surface etc.).

5. Discussion of all water quality parameter exceedances (i.e., Total Mn and dissolved Al were not included in the discussion section of the report).

6. Where predicted IDZ concentrations that exceed objectives or guidelines are described to be indistinguishable from ambient concentrations, please include a direct comparison to that ambient concentration with a description of the location, date and frequency of sampling used to determine the concentration.

7. Use the approved BCWQG for dissolved Cd in place of the BC WWQG for total Cd in comparisons to the modeled concentrations at the IDZ.

8. Use ambient total Fe as a guideline in comparison to the predicted instantaneous total Fe in conditions of high flow where the predicted total Fe exceeds the BCWQG of 1.0 mg/L.

If you have any questions, please do not hesitate to contact me.

Yours truly,

Michelle Hawryluk, BSc. ES
Environmental Impact Assessment Biologist
Ministry of Environment, Nanaimo

BRITISH COLUMBIA

Ministry of Environment

Environmental Protection Division

Mining Operations

MEMORANDUM

File: ME-000387

September 27, 2016

To: Trevor Hamelin, Environmental Protection Officer, South Authorization Unit, Regional Operations, Ministry of Environment

From: Erin Rainey, Hydrologist, Mining Team, Regional Operations, Ministry of Environment

RE: Annacis Island Wastewater Treatment Plant– Ministry of Environment Review of Stage 1 Environmental Impact Study

INTRODUCTION

I have reviewed the Stage 1 Environmental Impact Study (EIS) for the Annacis Island Wastewater Treatment Plant (AIWWTP) outlined in the Golder report entitled "*Annacis Island Wastewater Treatment Plant Transient Mitigation and Outfall Project – Stage 1 Environmental Impact Study*" dated August 26, 2016.

The following sections of the Golder (2016) report formed the basis of my review on behalf of the Ministry of Environment (MOE):

- Section 2.0 – Receiving Environment and Characterization and Use
- Appendix A – Multiport Diffuser Design and Initial Dilution Modelling Report (CDM Smith, July 26, 2016)

The following paragraphs outline my review comments for the Stage 1 EIS and recommendations for the Stage 2 EIS, specifically related to the surface water hydrology and physical dilution modelling of the initial dilution zone (IDZ).

REVIEW COMMENTS

Temperature and Salinity Data

Section 3 of the initial dilution modelling report (CDM Smith, 2016) discusses the temperature and salinity data used as input to the modelling completed for Stage 1. The site-specific information is fairly limited at the depth of the proposed diffuser (10 m, minimum depth below surface) to support temperature-salinity profiles at this location. This is considered a weakness in the modelling, particularly for the stratified Fraser River scenario. These data inform the initial dilution model on the influences of the buoyance flux of the effluent plume, which impacts how high the effluent plume will rise within the water column before it may become trapped below a "freshwater" surface layer. A stratified temperature-salinity profile of the Fraser River may also effect initial dilution as it limits the mixing of effluent with entrained water from the ambient Fraser River.

For Stage 2, it is recommended to focus data collection on acquiring more continuous site-specific temperature and salinity/conductivity data, particularly during critical periods of low flow in the Fraser River (i.e. flow is less than 1000 m^3/s) when there is higher potential for the salt wedge intrusion at the discharge location (stratified conditions). Continuous data should be collected just upstream of proposed location of the diffuser for at least one month in order to define stratification levels. These data will help to reduce the uncertainty and validate the conceptual assumptions used in the Stage 1 initial dilution modelling.

Initial Dilution Model – Stage 1

The Stage 1 EIS (Appendix A) presented two separate approaches for predicting the initial dilution of effluent in the Fraser River based on whether the Fraser River was unstratified or stratified at the outfall location. The unstratified methodology used laboratory experimental data presented by Seo *et al.* (2001) to develop the "Shrivastava-Adams equation" based on similarities between conditions of the AIWWTP and Seo's experiments. For stratified conditions, the UM3 mixing model software was used.

Moving forward, a more consistent approach is recommended for the Stage 2 EIS dilution modelling. The stratified conditions in the Fraser River predict the lowest dilution, therefore representing the most critical period(s) for predicting water quality within and at the edge of the IDZ. The UM3 model was initially discarded in favour of using other modelling software (CORMIX2), given that UM3 does not allow for bounded waterbodies and does not provide predictions once the effluent plume reaches the surface. However CORMIX2 returned questionable results, so UM3 was decided upon as the best approach. The limitations of UM3 were assumed to provide conservative predictions for modelling scenarios when the plume was predicted to reach the surface before the edge of the defined IDZ. While this is a reasonable assumption for Stage 1, a more detailed characterization of the effluent plume within the IDZ (near-field) and beyond (far-field) is required for Stage 2, as detailed in Section 5.22 of MELP (2000), under the three defined Fraser River flow classifications (low, moderate and high) for stratified and unstratified conditions.

The scaled physical model proposed to be developed for Stage 2, as well as the additional temperature-salinity profile information (discussed above) should be used to calibrate and verify the initial dilution predictions estimated by the Shrivastava-Adams equation and UM3 model for unstratified and stratified Fraser River conditions, respectively.

Average Dry Weather Flow

For the Stage 1 EIS, it is a requirement to present water quality predictions at the edge of the IDZ for the effluent flow scenario defined as 2 times Average Dry Weather Flow (ADWF), according to Section 5.21 of MELP (2000) and to meet the applicable effluent quality requirements listed in Table 11 of the Municipal Wastewater Regulation (MWR). As noted by the MOE Impact Assessment Biologist reviewing the file, Michelle Hawryluk, this effluent flow scenario needs to modelled for the Stage 2 EIS as it was not included in Stage 1.

The average dry weather flow (ADWF) for the AIWWTP Stage V expansion was defined as 7.4 m^3/s in Section 4.1 of Appendix A (CDM Smith, 2016). Thus, the 2 times ADWF would have an effluent flow rate of 14.8 m^3/s, which is slightly less than the peak wet weather flow

(PWWF) design flow rate for Stage V of 18.9 m^3/s. For the 2 times ADWF effluent scenario, the water quality predictions should be presented for the three defined Fraser River flow classifications (low, moderate and high) under stratified and unstratified conditions for near-field and far-field dilution effects. Also, it will be important to present the water quality predictions for the 2 times ADWF effluent scenario in the context of probabilities of occurrence, similar to the Stage 1 EIS, in order to compare these results to the other (possibly more likely) effluent flow scenarios.

Missing Reference

The Lai *et al.* (2011) paper mentioned in Section 6.2.1.3 of Appendix A (CDM Smith, 2016) was not included in the references section of the report.

SUMMARY OF RECOMMENDATIONS

Based on my review of the Stage 1 EIS, I have the follow recommendations for the Stage 2 EIS:

1. Collection of a least one month of continuous site-specific temperature and salinity profile data during the critical low flow period in the Fraser River (flow less than 1000 m^3/s) to support Stage 2 dilution modelling,
2. A consistent and robust dilution modelling approach for both stratified and unstratified Fraser River conditions, and
3. Presentation of the water quality predictions for the 2 times Average Dry Weather Flow effluent scenario.

REFERENCES

Ministry of Environment, Lands and Parks (MELP), 2000. *Environmental Impact Study Guideline – A Companion Document to the Municipal Sewage Regulation*. December 2000.

Seo *et al*., 2001. *Performance of Tee Diffusers in Shallow Water with Crossflow*. Journal of Hydraulic Engineering, January 2001, 127(1):53-61.

Should you have any questions about the above, please contact me at 250-354-6358 or Erin.Rainey@gov.bc.ca.

Sincerely,

Erin Rainey, P.Eng.
Regional Hydrologist,
Ministry of Environment

cc: Sheldon Reddekopp, Environmental Impact Biologist, Ministry of Environment
Michelle Hawryluk, Environmental Impact Biologist, Ministry of Environment

21 March 2017 Reference No. 1525010-081-L-Rev0-702

Ken Masse
Metro Vancouver
4330 Kingsway
Burnaby, BC
V5H 4G8

ANNACIS ISLAND WASTEWATER TREATMENT PLANT TRANSIENT MITIGATION AND OUTFALL PROJECT: RESPONSES TO REVIEW COMMENTS ON THE STAGE 1 ENVIRONMENTAL IMPACT STUDY

Dear Mr. Masse,

Golder Associates Ltd. (Golder) is pleased to provide Metro Vancouver with the attached responses to review comments provided by BC Ministry of the Environment (MoE) on the Stage 1 Environmental Impact Study (EIS) for the Annacis Island Wastewater Treatment Plant Transient Mitigation and Outfall Project (herein referred to as the project). The EIS authors, Golder, CDM Smith Canada ULC (CDM Smith), and Envirowest Consultants Inc. (Envirowest) have provided responses to the Stage 1 EIS review comments, as indicated in Table 1.

The Stage 1 EIS was prepared in accordance with the associated terms of reference approved by MoE in 2016 (Reference# 1525010-009-TM-Rev0) in recognition of the Municipal Wastewater Regulation and provincial EIS guidance (BC MELP 2000[1]). The Stage 1 EIS was submitted to MoE by Metro Vancouver in August 2016 and MoE provided review comments in December 2016. In their review, MoE confirmed that the document satisfied the requirements of a Stage 1 EIS per BC MELP (2000)[1] and identified themes to be addressed during Stage 2 of the assessment process. These themes were discussed with MoE at a subsequent meeting in January 2017 prior to drafting the terms of reference for the Stage 2 EIS. As discussed at that meeting with MoE, the terms of reference for the Stage 2 EIS are being submitted to MoE by Metro Vancouver in conjunction with this letter that provides responses to the Stage 1 EIS review comments.

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[1] BC Ministry of Environment, Lands, and Parks (MELP) 2000. Environmental Impact Study Guideline – A Companion Document to the Municipal Sewage Regulation. Issued December 2000. Ministry of Environment, Lands and Parks, Pollution Prevention and Remediation Branch.

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CLOSURE

We trust that the content of this letter provides sufficient information for your present needs. If you have any questions, please do not hesitate to contact the undersigned at (604) 296-4200.

Yours very truly,

GOLDER ASSOCIATES LTD.

Elaine C Irving

Elaine Irving, Ph.D., R.P.Bio., P.Biol.
Senior Environmental Scientist

Adrian de Bruyn, Ph.D., R.P.Bio.
Associate, Senior Environmental Scientist

EI/AdB/kp/cmm

Attachment: Table 1: Responses to BC MoE Review Comments on the Stage 1 Environmental Impact Study for the Annacis Island Wastewater Treatment Plant Transient Mitigation and Outfall Project

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Table 1: Responses to British Columbia Ministry of the Environment (MoE) Review Comments on the Stage 1 Environmental Impact Study for the Annacis Island Wastewater Treatment Plant Transient Mitigation and Outfall Project

Comment #	Reviewer	Review Comment Description	Stage 1 EIS Author Response
1	Erin Stoddard (MFLNRO) via Trevor Hamelin (BC MoE)	The reach of the Fraser River into which the existing and upgraded discharge structure is located and effluent discharged is very important to lower Fraser River White Sturgeon. It contains "critical" juvenile sturgeon rearing habitat and is the location of a juvenile population monitoring index site. The juvenile index program includes the assessment of this site for 3 consecutive years out of every five years (three years sampling followed by two years of no sampling). The next three year sampling period will start in early September 2017. The upgraded discharge structure will likely result in significant impacts to these habitats and to the juvenile sturgeon that use them during construction of the upgraded discharge structure, after initial start-up and over the full period of the facilities operation. It is important that you contact Mr. Stoddard (604-586-5644) to discuss his concerns, as they may need to be addressed through approvals required under the *Water Sustainability Act*.	**Envirowest:** "*The reach of the Fraser River into which the existing and upgraded discharge structure is located and effluent discharged is very important to lower Fraser River White Sturgeon. It contains "critical' juvenile sturgeon rearing habitat and is the location of a juvenile population monitoring index site*." ■ If there has been a change to the status of the Lower Fraser population or if this is under consideration, we would appreciate that information as we have been proceeding with the project on the basis that "critical" habitat has not been identified in the context of the *Species at Risk Act*. "*The juvenile index program includes the assessment of this site for 3 consecutive years out of every five years (three years sampling followed by two years of no sampling). The next three year sampling period will start in early September 2017*." ■ We have attempted to locate data from this program but have not been successful. We take from MFLNRO comments that they are aware of the inferences from these data and their relevance to the project. We would appreciate if MFLNRO could provide those data so that they may be considered in the Stage 2 work. "*The upgraded discharge structure will likely result in significant impacts to these habitats and to the juvenile sturgeon that use them during construction of the upgraded discharge structure, after initial start-up and over the full period of the facilities operation.*" ■ We note that there is currently an operating outfall in the location of the habitat identified by MFLNRO. With regard to the new outfall, the construction methodology and mitigation measures that will be implemented to mitigate impacts to fish and fish habitats, including sturgeon and its habitats, have yet to be defined in detail. Therefore, at this early stage we have an opportunity to incorporate specific mitigation measures. We would appreciate MFLNRO's written response on their expected impact pathways of a replacement outfall structure and its construction so that we can address/plan measures to take those concerns into account. *It is important that you contact Mr. Stoddard (604-586-5644) to discuss his concerns, as they may need to be addressed through approvals required under the Water Sustainability Act.* Metro Vancouver, CDM, Envirowest, and Golder met with MFLNRO in January 2017 to discuss the project and concerns that Mr. Stoddard might have regarding the project. We would appreciate MFLNRO's concerns and needs for approval detailed in writing so that we have the necessary clarity moving forward.
2	Michelle Hawryluk (MoE)	The predicted exceedances for instantaneous concentrations of both total Cd (2 times the BC Working WQG) and total Fe (3.7 times the BCWQG) are considered in the Stage 1 EIS not to be of concern given the dissolved, bioavailable form of the element is below the corresponding guideline. It should be noted that the BC Working WQG for total Cd has been replaced with an approved WQG for dissolved Cd and as such the former guideline no longer applies. In the case of Fe, the Ambient Aquatic Life Guidelines for Iron identify the dissolved form of primary importance, recognizing that total Fe may exceed the recommended guideline due to natural causes; for instance, it can be caused by a high load of suspended material in water during high flow conditions where the association of total iron content is with the suspended materials. **In these cases the guidelines suggest the use of background total Fe concentration as a guideline; this information was not included as a comparison in the body of the report and as such it is difficult to determine whether the rationale for negating this exceedance is reasonable.**	**Golder:** The most recent water quality guidelines (WQGs) were used, which included the dissolved cadmium WQG as documented in Section 6.1.1, Table 6-1 (footnote i), and Table 6-2 (footnote k). The Stage 2 EIS will also use the dissolved cadmium WQG. The use of background total iron will be considered for the Stage 2 EIS based on the guideline recommendation.

Comment #	Reviewer	Review Comment Description	Stage 1 EIS Author Response
3	Michelle Hawryluk (MoE)	The predicted exceedances for instantaneous concentrations of total Cu (maximum of 2.9 times the FRWQO at high flow) are noted in the report to be discernible from the ambient concentration, and the predicted mean monthly concentrations for total Cu exceed the FRWQO discernibly from ambient conditions April through August (maximum of 2.9 times the FRWQO). According to the Stage 1 report, these exceedances are not a concern despite being above ambient background, given dissolved Cu is the most biologically available form. While the instantaneous and monthly averaged dissolved Cu are less than the respective total Cu guidelines, the Water Quality Criteria for Copper, Overview Report cautions against using dissolved Cu in comparison to the total Cu as the former can both overestimate and underestimate the bioavailable copper, depending on the water body. **If predicted exceedances persist in the Stage 2 EIS, rationale for ensuring the protection of the environment against copper toxicity will be required.**	**Golder:** Section 6.2.1 - the assessment will be refined in the Stage 2 EIS based on the final project design, an expanded effluent and ambient water quality dataset, refined water quality modeling procedures, and further consideration of copper bioavailability under site-specific conditions in the receiving environment.
4	Michelle Hawryluk (MoE)	**The predicted exceedances for instantaneous concentrations of total Mn (1.17 times the FRWQO) and dissolved Al (1.4 times the BCWQG), although minor, are not addressed in the body of the report.**	**Golder**: Comment acknowledged. Minor exceedances identified in the Stage 2 EIS screening will be addressed in the Stage 2 EIS.
5	Michelle Hawryluk (MoE)	The predicted exceedances for instantaneous concentration of total PCBs are double the BCWQG during all three river flows, and although there is no chronic guideline, the predicted monthly average concentrations are also nearly double the maximum guideline in all 12 months. The report identifies some uncertainty in the predictions as they are based on effluent quality characterized by only six samples and a mean ambient river concentration based on only four samples. **The inclusion of additional effluent and ambient data in the Stage 2 EIS is anticipated to reduce this uncertainty. This will be an important parameter for discussion for the Stage 2 EIS and future work.**	**Golder**: Section 6.2.1 - The Stage 2 EIS will consider a larger effluent and ambient dataset for PCBs due to inclusion of the 2015 and 2016 data (2012 to 2016). Additional monitoring of PCBs in effluent and the river under ambient conditions has been undertaken by Metro Vancouver and will be incorporated in the Stage 2 EIS. In addition, the potential for adverse effects on aquatic biota will be assessed based on a risk-based approach to the impact assessment.
6	Michelle Hawryluk (MoE)	The predicted instantaneous concentrations for Benzo-a-pyrene and TRC have Method Detection Limits (MDL) above applicable guidelines or screening criteria and as the report describes, **further sampling and analysis included in the Stage 2 EIS will aim to resolve this issue.**	**Golder**: Section 6.2.1 - Both effluent and ambient river water samples collected in fall 2016 were analysed at a detection limit lower than the provincial and federal WQG of 0.01 µg/L for B(a)P to reduce uncertainty in the impact assessment. Section 6.2.2 - TRC MDLs were improved in 2014, this will be reflected in updated dataset for the Stage 2 EIS.
7	Michelle Hawryluk (MoE)	The predicted monthly concentration for un-ionized ammonia exceeds the CCME guideline by a maximum of 1.1 times in 9 of the 12 months predicted. Given the uncertainty around these predictions, **a refined estimate is anticipated in the Stage 2 EIS given the additional site specific pH and temperature data currently underway.**	**Golder**: Section 6.2.1 - Ammonia will be assessed in further detail in the Stage 2 EIS in consideration of the final outfall design and additional effluent and ambient data.
8	Michelle Hawryluk (MoE)	Monthly Average Total Cr, Total Zn, Total Pb, Total AL, Total Fe, Total Hg, Dissolved Al The report describes the predicted exceedances of monthly average concentrations of all total and dissolved metals (except total Cu, discussed above) to be indistinguishable from the “relevant ambient river condition.” **It is unclear in the body of the report how the ambient river concentration was calculated and as such difficult to qualify if the data used represents a) the un-impacted waters and b) sufficient temporal data for a valid comparison.**	**Golder**: Characterization of ambient water quality is described in Section 2.1.2. of the Stage 1 EIS and summary statistics are reported in Appendix B. This characterization represents the ambient river condition referred to in the review comment. When making comparisons to ambient river conditions in the Stage 2 EIS, the text will be revised to improve clarity.
9	Michelle Hawryluk (MoE)	The predicted and instantaneous concentration for EE2 is 4 times the BCWQG at all 3 river flows, and monthly average concentrations are double the BCWQG in all 12 months. The report suggests these may be overestimates based on high MDLs associated with the effluent samples used in the predictions. This uncertainty will be addressed upon further sampling and analysis included in the Stage 2 EIS.	**Golder:** Section 6.2.1 - Uncertainty associated with the EE2 predictions will be addressed for the Stage 2 EIS through review of the 2012 to 2016 dataset that will include 2015 and 2016 data not included in the Stage 1 EIS. The dataset considered for Stage 2 will be substantially larger than that considered for Stage 1. Limitations associated with analytical procedures currently available in both commercial and research laboratories will also be considered and the implications for uncertainty in the assessment discussed.

Comment #	Reviewer	Review Comment Description	Stage 1 EIS Author Response
10	Michelle Hawryluk (MoE)	It is unclear whether FRWQOs will be met for fecal coliforms, enterococci, Escherichia coli, Zn, dissolved oxygen or pH as they were not considered in the modeling included in the report (i.e., not listed in Table 6-1 and 6-2). Although I understand the modeling results are based on the lowest dilution expected to occur, it is unclear when and for how long these concentrations are expected to occur; this information is critical in helping to determine the need for increased environmental protection.	**Golder:** ■ The FRWQO for total zinc is listed in Tables 6-1, 6-2. These tables show that total zinc concentrations predicted at the edge of the IDZ are below this objective. ■ Predicted 30-day geometric mean concentrations of fecal coliforms, enterococci, and Escherichia coli were below the FRWQOs for the months specified by these objectives (i.e., April to October) but as noted by the reviewer the FRWQOs were not provided in Tables 6-1 and 6-2 due to an oversight. The FRWQOs for these bacteriological parameters were provided in Appendix B (Fraser River Water Quality Ambient Summary). These FRWQOs will be included in relevant tables included in the Stage 2 EIS for both screening of predicted and ambient water quality. ■ Predictions for dissolved oxygen at the edge of the IDZ were not provided because a measure of the oxygen demand of the effluent (as CBOD) was assessed at the end of the pipe and compared to National Performance Standards. If the CBOD concentration is below the National Performance standards, dissolved oxygen conditions at the IDZ are expected to remain within the range specified in the FRWQO. This expectation will be verified by the post-discharge monitoring program that will include in situ measurements of dissolved oxygen in the receiving environment. ■ Predictions for pH at the edge of the IDZ were not provided because the pH of the effluent at the end of the pipe is assessed by comparing to the FRWQO in the effluent assessment. ■ The Stage 1 EIS was intended to be preliminary assessment of the potential impact of the proposed effluent discharge based on conservative assumptions and the preliminary outfall design. The Stage 2 EIS will provide more information with respect to when elevated concentrations of constituents of potential concern would be expected to occur.
11	Michelle Hawryluk (MoE)	**Recommendations for consideration in development of the Stage 2 EIS:** 1. Inclusion of all applicable FRWQOs in the modeling predictions for concentrations at the IDZ (e.g., fecal coliforms, enterococci, *Escherichia coli*, dissolved oxygen, pH, and Zn were missing from tables 6-1 and 6-2).	**Golder:** Please see response to Comment #10 above.
12	Michelle Hawryluk (MoE)	2. All predictive modeling results to include estimates of timing, duration and frequency of any exceedances, as well as any correlation to biologic relevance given the receiving environment characterization and use (e.g., correlation to use by juvenile sturgeon, and other fish species).	**CDM Smith:** The cumulative frequency distribution of dilution provides an estimate of the percent of time that an exceedance may occur and the conditions in the river (i.e., velocity, presence of stratification, and to some degree season) associated with the exceedances. In the Stage 2 EIS this information will be used to the extent practicable to comment on timing and duration of any predicted exceedances.
13	Michelle Hawryluk (MoE)	3. Predictive modeling to include conditions consistent with two times the Average Dry Weather Flow (ADWF) as required by Section 5.2 of the Environmental Impact Study Guideline.	**CDM Smith:** The Stage 2 EIS will include an effluent flow condition that is equal to two times the Average Dry Weather Flow, and comparison to FRWQOs will occur at this flow condition.
14	Michelle Hawryluk (MoE)	4. A description of the plume characteristics under various existing river conditions (e.g., trapping depth, horizontal distance at surface etc.).	**CDM Smith:** For stratified condition scenarios, the Stage 2 EIS will include additional information regarding plume characteristics for various river conditions. The technique available for predicting dilution when the river is not stratified does not allow for dimensions of the plume to be determined. Though when the river isn't stratified the plume will not be trapped.
15	Michelle Hawryluk (MoE)	5. Discussion of all water quality parameter exceedances (i.e., Total Mn and dissolved Al were not included in the discussion section of the report).	**Golder:** Comment acknowledged, please see response to comment 10.
16	Michelle Hawryluk (MoE)	6. Where predicted IDZ concentrations that exceed objectives or guidelines are described to be indistinguishable from ambient concentrations, please include a direct comparison to that ambient concentration with a description of the location, date and frequency of sampling used to determine the concentration.	**Golder:** Comment acknowledged.
17	Michelle Hawryluk (MoE)	7. Use the approved BCWQG for dissolved Cd in place of the BC WQG for total Cd in comparisons to the modeled concentrations at the IDZ.	**Golder:** Comment acknowledged, please see response to comment 2.
18	Michelle Hawryluk (MoE)	8. Use ambient total Fe as a guideline in comparison to the predicted instantaneous total Fe in conditions of high flow where the predicted total Fe exceeds the BCWQG of 1.0 mg/L.	**Golder:** Comment acknowledged, please see response to comment 2.

Comment #	Reviewer	Review Comment Description	Stage 1 EIS Author Response
19	Erin Rainey (MoE)	Temperature and Salinity Data Section 3 of the initial dilution modelling report (CDM Smith, 2016) discusses the temperature and salinity data used as input to the modelling completed for Stage 1. The site-specific information is fairly limited at the depth of the proposed diffuser (10 m, minimum depth below surface) to support temperature-salinity profiles at this location. This is considered a weakness in the modelling, particularly for the stratified Fraser River scenario. These data inform the initial dilution model on the influences of the buoyance flux of the effluent plume, which impacts how high the effluent plume will rise within the water column before it may become trapped below a “freshwater” surface layer. A stratified temperature-salinity profile of the Fraser River may also effect initial dilution as it limits the mixing of effluent with entrained water from the ambient Fraser River. For Stage 2, it is recommended to focus data collection on acquiring more continuous site specific temperature and salinity/conductivity data, particularly during critical periods of low flow in the Fraser River (i.e., flow is less than 1000 m3/s) when there is higher potential for the salt wedge intrusion at the discharge location (stratified conditions). Continuous data should be collected just upstream of proposed location of the diffuser for at least one month in order to define stratification levels. These data will help to reduce the uncertainty and validate the conceptual assumptions used in the Stage 1 initial dilution modelling. **Recommendation: Collection of a least one month of continuous site-specific temperature and salinity profile data during the critical low flow period in the Fraser River (flow less than 1000 m3/s) to support Stage 2 dilution modelling.**	**CDM Smith:** Site-specific temperature and salinity measurements were successfully collected in Q1 of 2017. A QuadPod with various water quality instrumentation was deployed for a month on the river bottom. This device monitored water quality data continuously at the approximate proposed discharge depth. Up to eight days of temperature and salinity profile data were collected in the region of the proposed diffuser during low river flow periods and over a range of tidal conditions, which were mostly in the low flow range. Continuous temperature/salinity data were also collected at a moored location close to shore thus adding to the existing 2016 dataset. The aim of these three data collection efforts (two continuous locations, one shallow and one at the project site; and the water column profiling) was to provide a better understanding of the density structure and timing of the salinity wedge at the project site.
20	Erin Rainey (MoE)	**Initial Dilution Model – Stage 1** The Stage 1 EIS (Appendix A) presented two separate approaches for predicting the initial dilution of effluent in the Fraser River based on whether the Fraser River was unstratified or stratified at the outfall location. The unstratified methodology used laboratory experimental data presented by Seo et al. (2001) to develop the “Shrivastava-Adams equation” based on similarities between conditions of the AIWWTP and Seo’s experiments. For stratified conditions, the UM3 mixing model software was used. Moving forward, a more consistent approach is recommended for the Stage 2 EIS dilution modelling. The stratified conditions in the Fraser River predict the lowest dilution, therefore representing the most critical period(s) for predicting water quality within and at the edge of the IDZ. The UM3 model was initially discarded in favour of using other modelling software (CORMIX2), given that UM3 does not allow for bounded waterbodies and does not provide predictions once the effluent plume reaches the surface. However CORMIX2 returned questionable results, so UM3 was decided upon as the best approach. The limitations of UM3 were assumed to provide conservative predictions for modelling scenarios when the plume was predicted to reach the surface before the edge of the defined IDZ. While this is a reasonable assumption for Stage 1, a more detailed characterization of the effluent plume within the IDZ (near-field) and beyond (far-field) is required for Stage 2, as detailed in Section 5.22 of MELP (2000), under the three defined Fraser River flow classifications (low, moderate and high) for stratified and unstratified conditions. The scaled physical model proposed to be developed for Stage 2, as well as the additional temperature-salinity profile information (discussed above) should be used to calibrate and verify the initial dilution predictions estimated by the Shrivastava-Adams equation and UM3 model for unstratified and stratified Fraser River conditions, respectively. **Recommendation: A consistent and robust dilution modelling approach for both stratified and unstratified Fraser River conditions.**	**CDM Smith:** Data collected as part of the field monitoring program and the findings from the physical modeling study will inform the Stage 2 EIS initial dilution predictions. The predictions will be based on the Shrivastava-Adams equation and the UM3 mixing model software under stratified and unstratified conditions and for a range of Fraser River flow classifications.

Comment #	Reviewer	Review Comment Description	Stage 1 EIS Author Response
21	Erin Rainey (MoE)	Average Dry Weather Flow For the Stage 1 EIS, it is a requirement to present water quality predictions at the edge of the IDZ for the effluent flow scenario defined as 2 times Average Dry Weather Flow (ADWF), according to Section 5.21 of MELP (2000) and to meet the applicable effluent quality requirements listed in Table 11 of the Municipal Wastewater Regulation (MWR). As noted by the MOE Impact Assessment Biologist reviewing the file, Michelle Hawryluk, this effluent flow scenario needs to modelled for the Stage 2 EIS as it was not included in Stage 1. The average dry weather flow (ADWF) for the AIWWTP Stage V expansion was defined as 7.4 m3/s in Section 4.1 of Appendix A (CDM SMITH Smith, 2016). Thus, the 2 times ADWF would have an effluent flow rate of 14.8 m3/s, which is slightly less than the peak wet weather flow (PWWF) design flow rate for Stage V of 18.9 m3/s. For the 2 times ADWF effluent scenario, the water quality predictions should be presented for the three defined Fraser River flow classifications (low, moderate and high) under stratified and unstratified conditions for near-field and far-field dilution effects. Also, it will be important to present the water quality predictions for the 2 times ADWF effluent scenario in the context of probabilities of occurrence, similar to the Stage 1 EIS, in order to compare these results to the other (possibly more likely) effluent flow scenarios. **Recommendation: Presentation of the water quality predictions for the 2 times Average Dry Weather Flow effluent scenario.**	**CDM Smith:** Acknowledged, please see response to comment 13.
22	Erin Rainey (MoE)	The Lai *et al.* (2011) paper mentioned in Section 6.2.1.3 of Appendix A (CDM Smith, 2016) was not included in the references section of the report.	**Golder:** Comment acknowledged, this reference will be included in the Stage 2 EIS if cited.

Notes:

Golder: Golder Associates Ltd; CDM Smith: CDM Smith Canada ULC; Envirowest: Envirowest Consultants Inc.

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