Restoration Options for Nicomekl River Anadromous Salmonids – Elgin Road Bridge Sea Dam

by

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Bachelor of Science, British Columbia Institute of Technology, 2014

Project Submitted in Partial Fulfillment of the
Requirements for the Degree of
Master of Science

in the
Ecological Restoration Program

Faculty of Environment (SFU)
and
Applied and Natural Sciences (BCIT)

SIMON FRASER UNIVERSITY
BRITISH COLUMBIA INSTITUTE OF TECHNOLOGY
2017

Approval

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Executive Summary

The Nicomekl River flows through historic Katzie First Nation territory in Surrey, British Columbia. The river provides salmon the linkage between their upland spawning and rearing grounds and the Pacific Ocean where they mature. Anthropogenic development has reduced habitat connectivity along the river, denuded the banks of vegetation, removed instream complexity, constrained the channel, regulated flow, and altered the water chemistry. A tidally controlled 7-gate sea dam is the source of the critical connectivity bottleneck on the river. It impairs free longitudinal migrations of adult and juvenile salmonids and increases adult and juvenile predation.

Through literature review and site assessment, this study suggests a suite of restoration treatments to restore connectivity and site-based habitat attributes to the Nicomekl River. The study then considers management options in light of climate change, sea level rise, and how to generate public involvement to support the proposed treatments. The study concludes that urban stream restoration faces challenges as it must find a balance between the environmental and social needs of the Nicomekl River beyond simply repairing ecosystem damage and degradation.

Keywords: salmonids, migration bottlenecks; connectivity, riparian restoration

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Dedication

To my grandmother, Aileen Peggy Hutchings.
Sometimes it takes a little crazy to make change happen.
All the world’s a stage.

Acknowledgements

I want to express gratitude to my supervisor, Dr. Ken Ashley for his continued patience and enthusiasm. I would also like to thank all the instructors that got me to this point in time: Dr. Leah Bendell for introducing me to the joy of a graduate environment, Dr. Scott Harrison for demanding more out of ecologists, and Dr. Doug Ransome for making this program real and helping build my critical thinking toolkit. I would also like to thank Jim Armstrong for pointing me in the right direction and Dave Harper for teaching me how to do salmon habitat work, for always being available, and making sure we have the right tools for the job. Special thanks to Giti Abouhamzeh for keeping the ER program and every other program I have been a part of on target; but most importantly for the support. Finally, endless thanks go to my constantly supportive peers in ER who I learned and laughed with every day.

I close with a special thanks to my family. Your role in my journey is always significant, though surely never adequately acknowledged. My success is primarily a product of your support, patience, and love.

List of Acronyms and Abbreviations

ALR – Agricultural land reserve
BOD – Biochemical oxygen demand
CWD – Coarse woody debris
DFO – Department of Fisheries and Oceans Canada
DO – Dissolved oxygen
FREMP – Fraser River Estuary Management Program
HBC – Hudson Bay Company
LWD – Large woody debris
NHC – Northwest Hydraulic Consultants
NPS – Non-point source (pollution)
PPT – Parts per thousand
SLR – Sea level rise

1: Introduction

Fitness and productivity of fish populations is intrinsically connected to the aquatic and adjacent riparian conditions that support their biological functions (Larinier, 2001). As migratory fish, anadromous salmonids require free longitudinal movement along a stream during migratory life phases (Larinier, 2001; Letcher, Nislow, Coombs, O'Donnell, & Dubreuil, 2007). Dispersal, or in this case temporally appropriate migration, is a key process influencing population dynamics (Clobert, Galliard, Cote, Meylan, & Massot, 2009; Pepino, Rodríguez, & Magnan, 2012), as limiting dispersal can reduce genetic diversity in species and increase extinction risk (Thomas, 2000). Anthropogenic regulation of rivers has led to the decline and extinction of migratory fish populations on every continent that it occurs (Larinier, 2001). Pacific salmon have been lost in over 100 streams within Metro Vancouver, and of the remaining 238 streams, 97 percent are either threatened or endangered (Department of Fisheries and Oceans Canada, 1998a).

The Nicomekl River is home to five species of anadromous salmonids that have been nearly extirpated by anthropogenic developmental pressures since the colonization of Surrey, British Columbia, thus making it a candidate for instream restoration projects (DFO, 1998a; Roni et al., 2002). Anthropogenic activities have created an environment of reduced fish access, poor water quality, and altered hydrological function (DFO, 1998b). The Nicomekl River is endangered and on a negative ecological trajectory, due to being constrained by urban development and agricultural practices thus making it a candidate for instream projects (DFO, 1998a; Roni et al., 2002). In particular, the river has been categorically noted as an extreme conservation concern for steelhead (Ministry of Environment, 2006). This project will apply one of the core tenants of ecological restoration, i.e., restore habitat connectivity. Connectivity being a contiguous pathway that the biotic constituents within the system can freely move through in response to fluctuations in biological requirement (e.g. life-stage, food availability, and predation) (Galatowitsch, 2012).

Loss of habitat connectivity on the Nicomekl has created a temporal bottleneck at the 7-gate sea dam at Elgin Road Bridge. The dam contributes to pre-spawn mortality from increased predation (NHC, 2015), stress and increased energy expenditure due to altered behavioral patterns (Caudill et al., 2007), and habitat degradation (Gregory &

Bisson, 1991). Ultimately, the survival of the salmonid populations relies on the resolution of the passage barrier.

The critical salmonid life stages affected by the sea dam are (1), during downstream juvenile smolting period of saltwater adaption and (2) upstream adult migratory spawning return. By alleviating the temporal bottleneck to fish passage, we can reduce juvenile and adult predation mortality resulting from the sea dam obstruction. This will require assessing the extent of the salt-water intrusion upstream of the sea dam to determine to what extent the sea dam acts as a barrier to upstream salt-water intrusion, and build a case for resolving the habitat connectivity barrier. Salinity upstream of the dam poses a risk to agricultural crops and livestock for agricultural users (Kim, Fonseca, Choi, Kubota, & Kwon, 2008; Liu, Yoshikawa, Miyazu, & Watanabe, 2015; Munns & Tester, 2008; NHC, 2015).

Unfortunately, salmon enhancement has historically focused on the big rivers such as the Columbia and Fraser. This is due to a legacy of diminishing allocation of conservation and management funding for governmental agencies (DFO, 1998b). The Fraser is the greatest Pacific salmon river in the world and it needs to be protected, but our local streams and rivers are just as important. Salmon productivity grows incrementally and population resilience comes from genetic diversity. Therefore, it is important to have many streams contributing to the overall welfare of salmonids (Downing, Van Nes, Mooij, & Scheffer, 2012). This study intends to prescribe a suite of restoration treatments that present solutions to the current lack of connectivity within the Nicomekl River system, providing ecological integrity and resiliency while still delivering ecosystem services for present and future users (Cairns, 2000; Kentula, 2000; Quammen, 1986).

2: Site Description

2.1 Location

The sea dam is located just south-west of King George Boulevard. It is integral to the Elgin Road Bridge designed to prevent flooding and control discharge and salt water incursion into the agricultural zone east of the dam. The area of interest for this project is 6 km upstream from Blackie Spit immediately before and directly after the Elgin Road bridge within the municipal boundary of the City of Surrey in British Columbia, Canada (Fig. 1). The northern bank is diked and is privately owned agricultural land beyond the

Surrey Dyking District easement. The water way itself is under the Department of Fisheries and Oceans Canada (DFO) mandate as it is salmon bearing. City of Surrey holds ownership of the south bank.

Figure 1: Overview map of Nicomekl River study area (red square) (49°04'12.73" N 122°49'30.85" W) immediately east of Elgin Road sea dam in Surrey, BC Canada. Showing Boundary Bay(east) and division of Surrey residential areas (north and south) by agriculturally dominated lowland area (from Google Imagery, 2017).

The headwaters of the Nicomekl River and its two major tributaries, Murray and Anderson creeks, are located within Township of Langley and City of Langley respectively. The Nicomekl watershed encompasses an area of 175.2 km^2 including the Chantrell, Elgin, Mackereth, Erickson, Anderson, Murray, Logan, and Fraser Creek tributaries (DFO, 1998a). The channels are underlain by stoney marine clays, except Anderson Creek which is sand and gravel (Holmes & Swain, 1988). The riverbed profile displays a gradual change from moderate slope at the upstream reaches to a low gradient (<1.3 m above sea level) west of 192nd street (KPA, 1994). This low gradient causes the Nicomekl River to be susceptible to tidal effects that extend deeply inland, approximately 1.3 km beyond the sea dam (NHC, 2015). The upper reaches drain agricultural and residential lands across a gently sloping plateau with the remaining 21 km meandering across the lowland floodplain (DFO, 1998a). The total channel distance of the Nicomekl River system is 34 km with a mean annual flow of 3.47 m^3/s (DFO, 1998a; Fig. 2). Daily average flow has been noted as low as 0.125 m^3/s and is more representative of lower reach velocity where this project is located (Holmes & Swain, 1988).

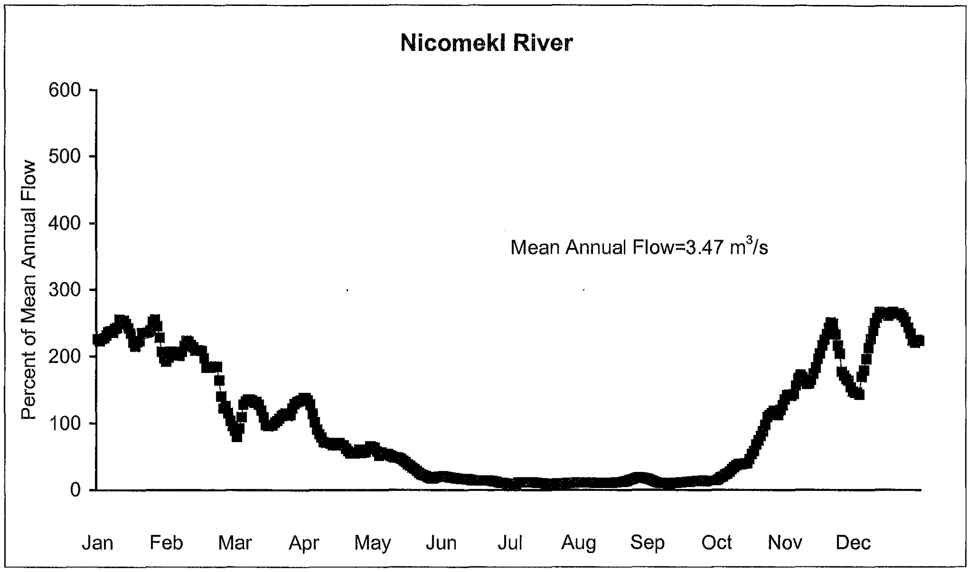

Figure 2: Nicomekl river, Surrey BC. hydrograph, mean annual flow by month (from DFO, 1998b).

The Nicomekl river watershed supports a diversity of fish species including five anadromous salmonids (asterisk following; Table 1).

Table 1: Nicomekl River fish species list (DFO, 1998a).

Common name	**Latin**
Coho salmon*	*Oncorhynchus kisutch*
Chum salmon*	*Oncorhynchus keta*
Chinook salmon*	*Oncorhynchus tshawytscha*
Pink salmon*	*Oncorhynchus gorbuscha*
Steelhead* and Rainbow trout	*Oncorhynchus mykiss*
Cutthroat trout	*Oncorhynchus clarki clarki*
Three-spined sticklebacks	*Gasterosteus aculeatus*
Western brook lamprey	*Lampetra richardsoni*
Brown bullhead	*Ameiurus nebulosus*
Carp	*Cyprinus carpio*
Prickly Sculpin	*Cottus asper*

The Nicomekl Enhancement Society (NES) operates a hatchery (232nd St. and 52nd Ave in Langley) that releases Chinook, Coho, and Chum salmon annually, and Pink salmon biannually. Additionally, Coho and Cutthroat trout are stocked in the headwaters of Chantrell Creek (DFO, 1998a). The sea dam is approximately 26 km south-west from the Nicomekl Enhancement Society hatchery.

I have selected the 100 m directly downstream of the sea dam as the study area. The proposed site identifies as a unique reach defined by the sea dam passage barrier in the east, and the boundary of a previous inter-tidal salt marsh that was built to offset impacts of the residential development on the south shore and the boat moorages to the west (Fig. 3).

Figure 3: Area of interest for this project. Total distance approximately 100 m immediately downstream of the sea-dam at Elgin road bridge in Surrey, BC (from City of Surrey, 2016).

2.2 History

The word nicomekl is from the Halq'emeylem language spoken by the Katzie people and means *the pathway* or *the route to go* (Jenness, 1955). The Nicomekl River was first documented in writing, on December 13, 1824, during James McMillan's Hudson's Bay Company expedition. This was historically Katzie First Nation territory. The Katzie traditionally occupied and used the land and water around Pitt Lake, Pitt River, Surrey, Langley, New Westminster, and Vancouver (City of Surrey, 2006). The people of Smakwec (founding chief of Point Roberts) were one of the five founding Katzie communities and their descendants become the Nicomekl as a distinct people. The Nicomekl were wiped out by smallpox in the 18th century (Jenness, 1955).

The river was used by the Nicomekl people to travel inland and connect with the Coweechin River (Fraser River). They went up the Nicomekl and then portaged to the Salmon River which connected to the Fraser River 80.5 km inland. John Work, a clerk with the HBC expedition, described the Nicomekl as often barred with driftwood, uncommonly thick with willows, and had low banks that were well wooded with pine, cedar, and alder (Brown, 2014b). Work also noted signs of there being numerous beavers on the river.

Prior to European settlement in Boundary Bay area, approximately 58 km^2 of the Nicomekl and Serpentine Lowlands, were inundated at every high tide (City of Surrey, 2016). In 1911, Surrey council barred navigation up the Nicomekl and Serpentine rivers so as to construct a system of sea dikes and sea dams to reclaim the lowlands for agricultural practices. Under the Dyking, Ditch and Drainage Act, 4,250 hectares of land were claimed by the Surrey Dyking District for agricultural use (City of Surrey, 2016; Brown, 2014a). The Elgin Bridge sea dam consists of seven large one-way gates that open when tides are low to allow fresh water to flow to Mud Bay at Crescent Beach in Surrey BC, Canada (KPA, 1994) (Fig. 4). The gates are controlled hydraulically by tidal forces. When tides are high, the gates close preventing salt-water intrusion up the river into the agricultural zone and holding water for agricultural drawdown.

Figure 4: Elgin road sea dam on Nicomekl River west side, Surrey lowlands BC (JC Taft, 2016).

Presently there are 52 water licenses on the Nicomekl that have a total allowable draw of 5,280,792.517 m^3/ year (Appendix 1; Province of British Columbia, 2017). All of this development has created a state of continual perturbation on the Nicomekl that has suppressed environmental heterogeneity and biodiversity, diminishing the productive capacity if biotic resources (Frissell, 1993; Stanford et al., 1996).

2.3 Current Conditions

Primary land use in the Nicomekl watershed is agriculture, and it has resulted in the precipitous decline in water quality (Bull & Freyman, 2013; DFO, 1998a, 1998b). In addition, the sea dam and extensive diking have disabled the floodplain, slowed water velocities, raised water temperature, impeded flushing in the system and led to the aggressive removal of riparian vegetation along the river (Page et al., 1999). The DFO identified the following persistent stressors in the Nicomekl watershed (1998b):

- Water quality issues (i.e. pH, BOD, nutrients, temperature), pesticides and herbicides, and low dissolved oxygen from urbanization and agricultural practices
- Loss of riparian vegetation, >50% within fish frequented areas (DFO, 1998b)
- Channelization/ diking/ armourization, >50% of fish frequented areas (DFO, 1998b)
- Low summer baseflows
- Increasing amounts of impervious surfaces from urbanization
- Barrier to passage from sea dam and related cumulative impacts

Non-point source pollution in the form of chemical and nutrient-rich agricultural runoff reduces instream water quality and has resulted in low dissolved oxygen levels, turbidity, and fecal contamination (Bull & Freyman, 2013). This has compromised environmental, agricultural, and recreational water quality objectives that has resulted in large scale fish kills and contamination of the human food chain (MoE, 1999; Payette, 2004; Rood, 1995; Town, Mavinic, & Moore, 1989). Salmonids are exposed to abnormally high nutrient levels due to the absence of riparian buffers (Appendix 2; Holmes & Swain, 1988), pesticides that disrupt migration habits and provoke stress responses (Tierney, Sampson, Ross, Sekela, & Kennedy, 2008; Tierney, Williams, Gledhill, Sekela, & Kennedy, 2011), marginal and periodically unsafe pH levels (above 9.0) from agricultural and urban runoff, (Appendix 3) and build-up of toxic constituents in the sediment (Appendix 4; Holmes & Swain, 1988).

High temperature events exceeding 23°C have been noted on the Nicomekl system due to: depleted riparian cover, diking, and aggressive development (DFO, 1998b; Rood, 1995). During migration salmon are sensitive to water temperatures (Morrison, Quick & Foreman, 2002), and there is a correlation between high-water temperatures and pre-spawn mortality (Crossin et al., 2008; Gilhousen, 1990; Rand & Hinch, 1998; Williams, 2000). Temperatures between 22 and 24 °C over a period of several days can be fatal for salmon (Servizi & Jansen, 1977). Water temperatures meeting or exceeding 24°C are fatal within a few hours to salmonids (Bouke, Chapman, Schneider Jr., & Stevens, 1975). Even an elevated temperature of 20 °C can have adverse effect on spawning success if experienced for an extended period of time (Gilhousen, 1990).

Structurally, the Nicomekl River is highly unnatural and absent of natural channel form, ecological function, and riparian complexity (Table 2; Fig. 5).

Table 2: Results from modified level 1 FHAP for Nicomekl River study area in Surrey, BC.

Habitat Unit		Length (m)	Gradient (%)	Depth (m)	Width (m)	Bed Material	
Type	Cat.					Dom.	Sub-Dom
Glide	Primary	100	< 1	0.3 - 3.0	62.7	Gravel	Fine/V.Fine

LWD Tally	Cover		Disturbance Indicators	Riparian Vegetation			Barriers
	(%)	Type		Type	Structure	C. Closure	
0	< 5	1: 0 -20%	Channelization	Unvegetated	INIT	None	Sea Dam

This loss of structural diversity is due to aggressive streambank modification, removal of riparian features for the dike and agriculture, and the presence of the 7-gate sea dam (Fig. 5). Baseline analysis suggests that water quality and riparian habitat within the project area have not improved appreciably from those described by the DFO in 1998, demonstrating the need for restoration. The probability of passive (spontaneous) restoration seems insignificant as the stressors have not been alleviated. The Nicomekl Rivers is now in such degraded condition that requires restoration to redirect its current trajectory to rebuild the social, ecological and economic aspects and create a vibrant and functional salmon bearing waterway.

Figure 5: Absence of structural complexity of the Nicomekl River: bed (a), north bank (b) and south bank (c) (JC Taft, 2016).

The combination of altered temperature patterns, continual export of agricultural runoff (organic matter and dissolved nutrients), simplification of channel structure and river bed, and loss of floodplain connectivity has altered the environment so rapidly and severely that it may exceed adaptation capability of salmonids that could cause a population collapse (Stanford et al., 1996). Development has severed the critical connections of the river continuum, reduced native biodiversity and productivity, and created opportunities for non-native species to proliferate (Bain et al., 1988; Shannon et al., 1994; Stanford et al., 1996).

Anadromous fish passage on the Nicomekl River is limited to the low tide outflow period, when hydraulic forces recede allowing the gates along the sea dam to open. This disrupted river connectivity prevents timely upstream and downstream migration reducing the quality and quantity of fish and habitat (Hatry et al., 2013). This alteration of daily and seasonal migration dynamics can result in sharp population declines and even extinction (Larinier, 2001). Impaired migration may also disrupt optimal entry into seawater for smolts (Mahnken et al., 1982).

The sea dam may also be contributing to increased predation pressure from resident Pacific harbor seals (*Phoca vitulina).* When anadromous salmonids are blocked passage by closed sea dam gates at high tide predation is easier due to anunnaturally high concentration of fish (Dynesius & Nilsson, 1994; Poff et al., 1997). In addition, predation may be increased due to absence of in-stream structural complexity for refuge immediately downstream of the sea-dam (Ebel, Tanonaka, Monan, Raymond, & Park, 1979; Gowans, Armstrong, Priede, & Mckelvey, 2003; Raymond, 1979; Williams, 1989).

Pacific harbour seals are often accused of being detrimental to fish stocks, and have been persecuted by fishermen for this reason. Harbour seals are opportunistic predators, able to switch prey per annual and seasonal variability (Härkönen, 1987; Payne & Selzer, 1989; Hall, Watkins, & Hamond, 1998; Brown, Pierce, Hislop, & Santos, 2001). Studies of harbour seal foraging behaviour in Moray Firth, Scotland show selective preference for fish densely packed near the seabed (Thompson, Pierce, Hislop, Miller, & Diack, 1991). Adult and juvenile salmonids become more attractive to seals when moving in relatively large concentrations along the coast, when confined in river estuaries, or in this case corralled at the sea dam. Scat sampling has found that when salmon are available (April through November) harbor seal diet can exceed 50% salmon (Thomas et al., 2016).

There is also a knowledge gap in respect to age-specific predation data, but it is believed that juvenile salmonids experience significantly greater pressure than their adult counter parts (National Marine Fisheries Service, 1997; Yurk & Trites, 2000). An adult harbor seal requires ~2 kg per day of fish, this can be achieved in less than one adult Coho but would require ~100 juveniles (Thomas et al., 2016). This disproportionate pressure by age category could be detrimental to salmon survival patterns, particularly coho and chinook (Thomas et al., 2016). Greater effort per catch may then disperse harbor seal predation pressure on Nicomekl salmonids.

Diet in many parts of their range shows salmonids to be a non-existent or negligible component, generally less than 5% composition (Carter, Pierce, Hislop, Houseman, & Boyle, 2001; Thomas, Nelson, Lance, Deagle, & Trites, 2016), mainly taken in rivers and estuaries (DFO, 2009). Thus, salmon can become a seasonal part of the diet of harbour seals living in vicinity of salmon rivers (Carter et al., 2001). The harbour seal population in the Strait of Georgia has grown steadily under the Marine Mammal Protection Act enacted in 1972; from fewer than 5,000 in 1970 to about 40,000 in 2008 (DFO, 2009a; Jeffries, Huber, Calambokidis, & Laake, 2003; Luxa & Acevedo-Gutiérrez, 2013). The Pacific harbor seal is the most abundant pinniped, and the only one present year-round in the waters of British Columbia (Jefferies et al., 2003). The current population is thought to be similar to the 1880s pre-exploitation levels (DFO, 2009a), this corresponds with the highest densities of harbour seals occurring in the protected waters of the Strait of Georgia (13.1 seals per km shoreline) (DFO, 2009a).

Harbour seal populations correspond with a period of marked declines in coho and chinook species, that are thought to be preferentially selected prey species (Nelson, 2016). Applying the five per cent rate of consumption across the entire seal population, predation would account for about 55% of natural mortality of juvenile coho and 45% of chinook (Nelson, 2016). The matter of seal abundance is further complicated by interspecific competition for chinook between Pacific harbour seals and Southern resident orcas (SRKW) (*Orcinus orca*). SRKW are fish-eaters. 78%of their diet consists of chinook salmon (adults during late spring and fall) (National Marine Fisheries Service, 2008). SRKW are a federally recognized in Canada and the United States as being endangered, thus making restoration of the locally unique Boundary Bay chinook stocks (DFO, 1998a, 2013) of critical importance to the survival of the SRKW (DFO, 2009b) and a legal obligation pursuant to Section 58 (5) of the *Species at Risk Act* (SARA), S. C. 2002, c. 29 (Species at Risk Public Registry, 2008).

This collection of factors has created an environment that, for decades, diminished salmonid populations due to cumulative effects in the waterway and its adjacent tributaries leading to the river's endangered status (Brown, 2002; DFO, 1998a, 1998b). There have been no formal nor regular salmon counts done on the Nicomekl River since 1995 and what was done only looked at coho population numbers (DFO, 1998b). Figure 6 shows declining coho escapement over a fifty-year period, with a peak of nearly 8,000 in 1964 diminishing to a couple hundred in 1992 (DFO, 1998b).

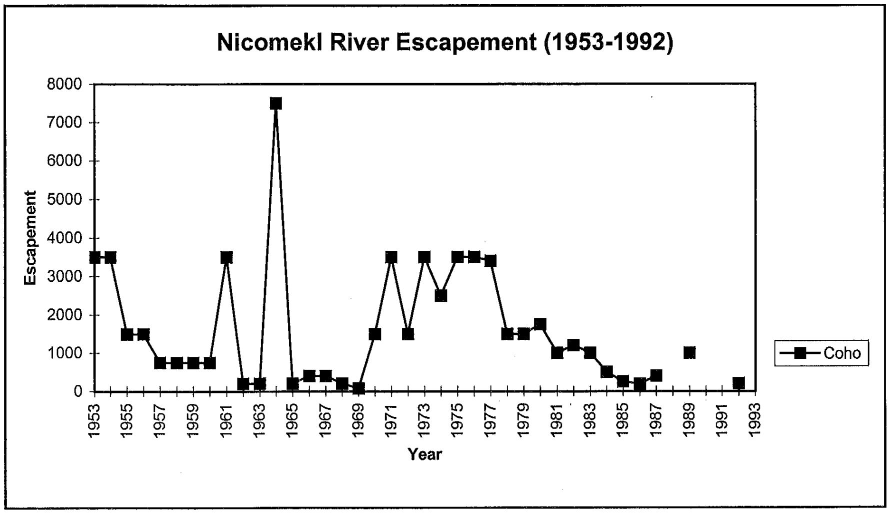

Figure 6: Nicomekl River Coho escapement 1953- 1992 (from DFO, 1998b).

Due to decreased resources, the DFO stopped doing fish counts on many stream systems in the mid-1980s to the early 1990s, focusing instead in indicator streams to establish escapement trends (DFO, 1998b). In respect to pink salmon the DFO has simply noted that the Nicomekl River population is small but persistent without a noted commercial fishery (2009). The Nicomekl River chinook population is noted as having a high degree of uncertainty regarding long-term outlook and are considered very low (DFO, 2013). Nicomekl River chinook are noted as being genetically distinct from Lower Fraser stocks, and are considered ‘Boundary Bay’ stocks with a different ocean migration pattern than Lower Fraser stocks (DFO, 1998a, 2013). Sport fishing for coho was noted in the lower reaches 1955 through 1966. In 1967, extensive water demand created low flow conditions that affected coho fry rearing (DFO, 1979). It is reasonable to foresee the Nicomekl River becoming a lost stream in respect to salmonid values without active intervention, (Ricciardi & Rasmussen, 1999; Richter, Braun, Mendelson, & Master, 1997).

3: Goals & Objectives

The overarching goal of this project is to assess and prescribe restoration options to increase anadromous fish survival during the fresh water migratory life stages that are impaired by the connectivity barrier (the sea dam) at Elgin Road Bridge. I will accomplish this by:

1) Assessing methods of improving fish passage for adult and juvenile salmonids to restore connectivity through literature review and supplemental water column sampling (salinity). This will determine the viability of opening one of the gates during key upstream migratory periods of anadromous salmonids.
2) Developing a refuge system for migratory salmonids to reduce marine mammal predation. This will buy time for resolving the river connectivity impairment by reducing pre-spawn mortality.
3) Propose a riparian treatment to increase on-site functional habitat.
4) Community and municipal engagement to build project support and educate the agricultural community towards improving practices that can benefit both users and salmon.
5) Address the forecasted effects of climate change and associated sea level rise (SLR).

Guiding documents include Fish Habitat Rehabilitation Procedures (Slaney & Zaldokas, 1997) and Ecological Restoration Guidelines for British Columbia (MoE, 2002).

To achieve this, I propose the following goals and objectives:

3.1 Goal 1: Facilitate Habitat Connectivity

Objective 1.1: Assess vertical salt-water intrusion above Elgin Road Bridge through literature review and water column sampling

Objective 1.2: Provide options to resolve passage impairment during high water periods

3.2 Goal 2: Implement Instream Refuge System

Objective 2.1: Conduct literature review to inform decision making

Objective 2.2: Reintroduction of LWD to waterway to provide instream structure for juvenile salmonids along the littoral zone

Objective 2.3: Develop instream refuge system for adult salmonids moving through pelagic zone

3.3 Goal 3: Riparian Restoration

Objective 3.1: Assess existing riparian structure on south bank to evaluate functionality.

Objective 3.2: Prescribe treatment to increase on-site functional riparian habitat

3.4 Goal 4: Community Engagement

Objective 4.1: Generate community support through involvement with local interest groups, agricultural water users, First Nations, municipal jurisdiction and federal regulators.

Objective 4.2: Provide alternatives to agricultural users of Nicomekl River waters to limit potential saltwater uptake and promote modernization of water management techniques

3.5 Goal 5: Climate Change and Sea Level Rise

Objective 5.1: Evaluate the potential effect of sea level rise and climate change on existing diking and dam structures

4: Methods

4.1 Data collection

Preliminary water sampling was conducted August 29, September 1, and September 5, 2016. Due to safety concerns regarding upstream ingress and prevalence of ice, no winter sampling occurred. Background analysis of the sea dam function and fish gates was conducted by Northwest Hydraulic Consulting (NHC) in 2015. They produced a 3D modeling study that quantified horizontal and vertical extent of saline intrusion upstream.

4.2 Water Survey Methodology

Methods for water quality sampling are based on the *Protocols Manual for Water Quality Sampling in Canada* (Water Quality Task Group, 2011) and the *British Columbia Field Sampling Manual* (Ministry of Water, Land and Air Protection, 2003). The key variable for the Nicomekl River assessment is salinity (ppt). Even though all measured variables were not utilized in this project a broad suite was collected to build knowledge for future works and assessment.

A YSI Pro Plus multi-parameter water quality meter was used to measure these parameters. The meter was calibrated prior to the sampling period according to protocols provided by the meter's manufacturer. Sampling occurred within 2 hours around peak tide at locations above Elgin road bridge sea dam. Upstream sampling commenced each session within 10 m (randomized) of the dam and then proceeded upstream along the thalweg at intervals of 125 m for a total of 8 stations (approximately 1.0 km total distance).

Downstream salinity measurements used in the NHC model assumed a value of 25 ppt as representative of conditions at the sea dam during high tide (2015). Field measurements were conducted by the City of Surrey (July 2012 – August 2014) (NHC, 2015). All water quality variables were measured from the thalweg at each sampling point taken at surface (approximately 25 cm) then followed by 0.5 m increments until reaching the bed at which point the device was retracted 10 cm prior to data collection.

4.3 Vegetation Survey Methodology

Percent cover was estimated by each species, rather than using cover classes, because this is what the standards recommend due to the absence of a developed vegetation community within the site (Ministry of Sustainable Resource Management Terrestrial Information Branch, 2002; Resources Information Standards Committee, 2003). The sampling units were 2 x 2 m plots at 15 m increments along two transects spaced 4 m apart each with 6 plots (n=12). For each plot, the estimated percent cover (ground level) of each plant species and surface features (water, bare ground, organic debris) was recorded. The first plot was placed at a random distance (0 -10 m) from the starting point for each transect. The transects were parallel to the waterway.

5: Results

5.1 Water Sampling

All preliminary data can be found in Appendix 6. Data from September 1st was discarded due to erratic readings. The remaining data shows the presence of upstream salinity at all stations and all depths (0.8 – 14.37 ppt) during high tide gate closure period (Fig. 7). Salinity exceeded baseline standard for agricultural usage (4 ppt; NHC, 2015) at all stations' deepest measurement (riverbed) with six stations exceeding 8 ppt and above 14 ppt in proximity of the dam. Samples taken within the first 0.75 cm upstream of the dam were <1 ppt. Downstream behind the dam, maximum salinity ranged from 25.13 ppt at the surface to 26.73 ppt at the river bed.

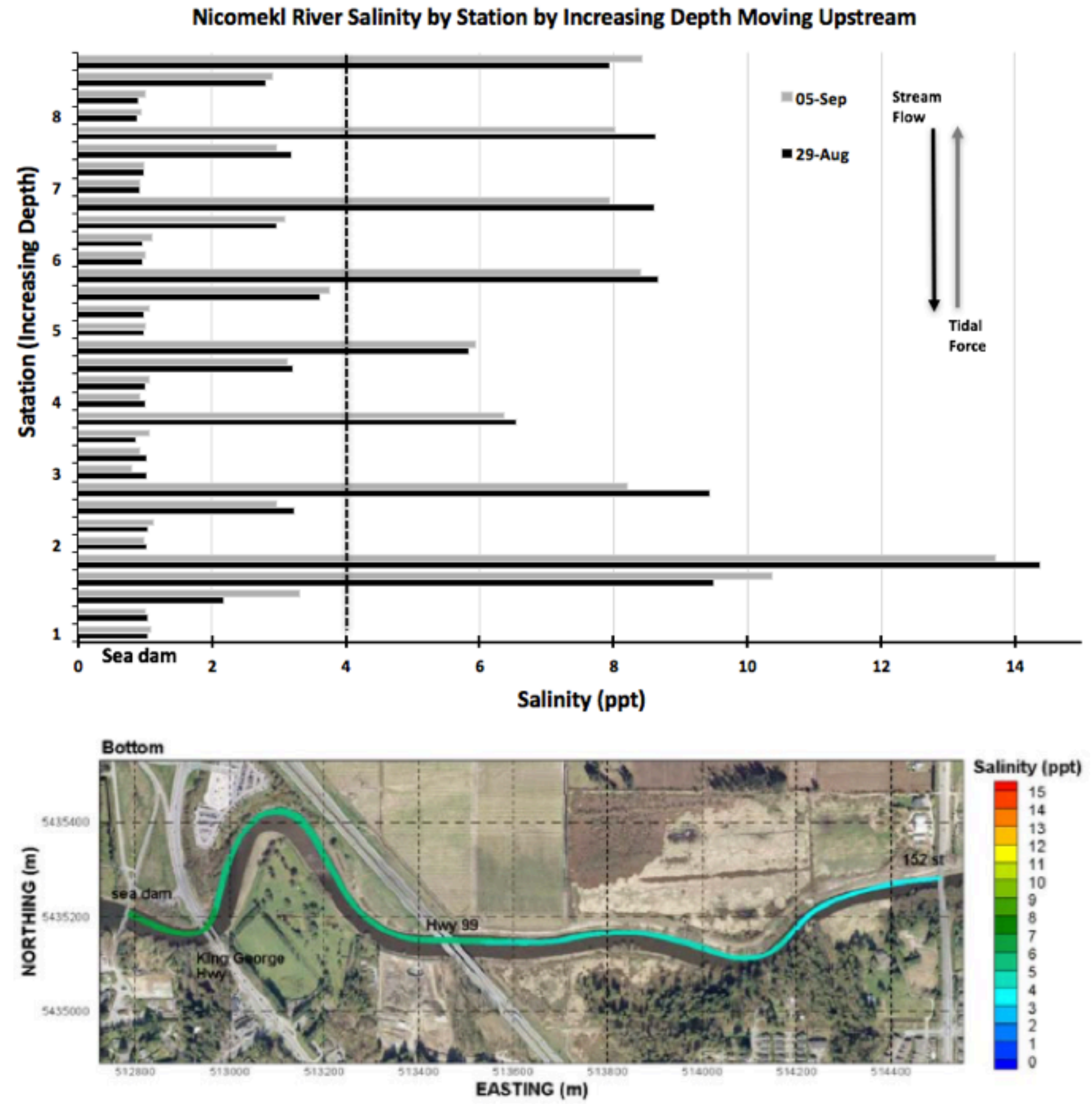

Figure 7: Comparison between collected salinity data (top) and NHC modelled data (bottom). Preliminary salinity testing upstream of sea dam at Elgin road bridge during high tide when gates are closed (August 29 and September 5, 2016) salinity ranged from 0.8 to 14.37 ppt. Dashed line shows acceptable salinity (ppt) for agricultural usage. Data collected at 0.5 m increments (depth) at eight stations spaced 125 m apart from randomly determined station 1 (5 m and 7 m respectively from sea dam). Modelled data shows expected upstream salinity (sea dam + 1.3 km) after having 1.0x0.3 m fish gate open for 12 hours, salinity ranging from 7 - 4 ppt (from NHC, 2015).

5.2 Vegetation Sampling

The site is approximately 675 m^2 and has a monoculture of saltmarsh bulrush (*Bolboschoenus maritimus*). The total mean sample site coverage of vegetation was 25.83 %. The southern transect (T1-S) was partially vegetated (49.2%) and the riverside transect (T2-N) had sparse of vegetation cover (2.5 %) (Fig. 8). There was a significant difference in mean (%) coverage between transects (T-test: P = 0.0010027, see

Appendix: 7). In channel aquatic sampling (observational) found an absence of macrophytes of any growth form (submergent, emergent, or floating-leaf).

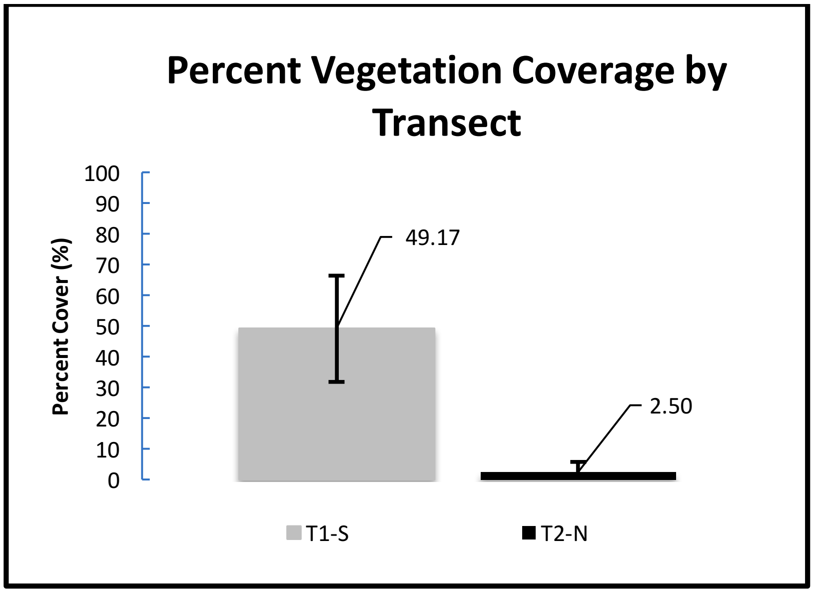

Figure 8: Vegetation coverage (%) with (95% CIs) by transect (n=12; bearing of 284°) for proposed remedial treatment along the Nicomekl River in Surrey, BC.

6: Proposed Treatments

Figure 9 depicts the instream study area during high-tide (green line: approximately 100 m x 68 m) highlighting the location of proposed restoration treatments.

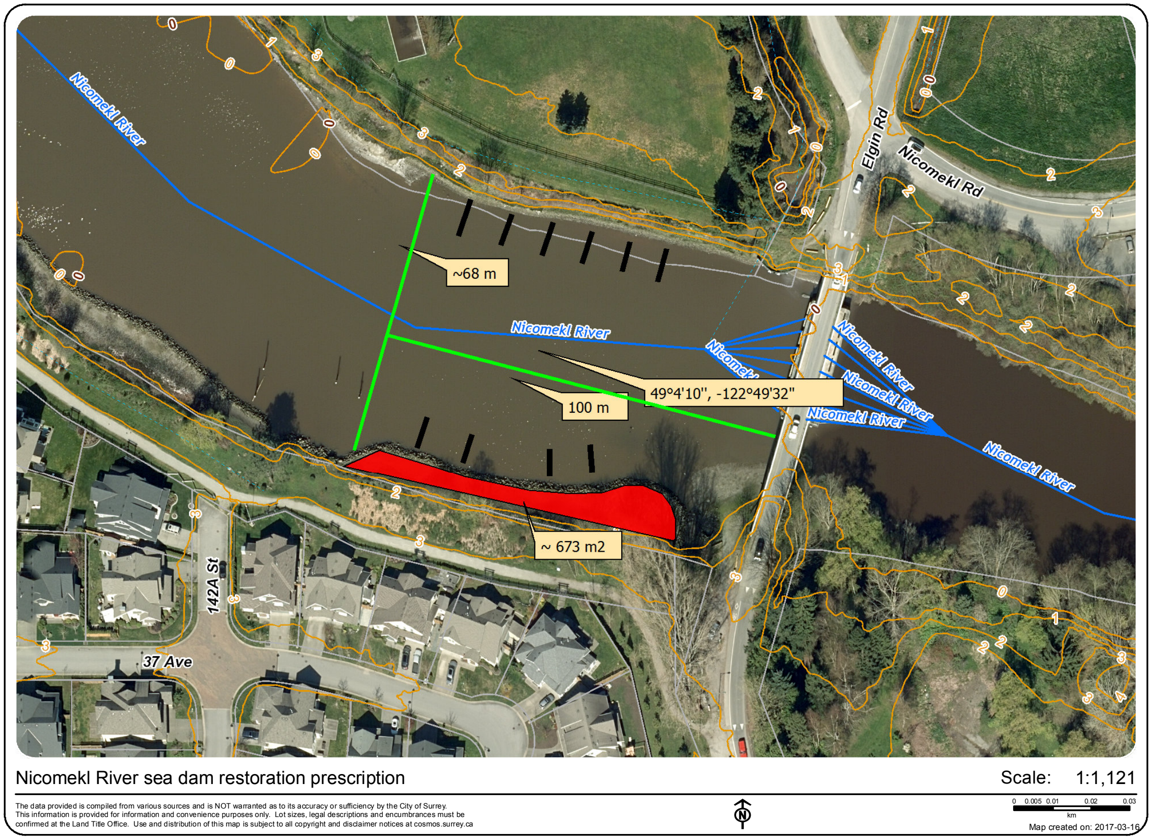

Figure 9: Proposed treatments at the sea dam on the Nicomekl River. The red polygons are re-naturalization areas, the black lines are single log structures and the blue line represents the thalweg from which instream structures will radiate (Adapted from City of Surrey Mapping Online System, 2017).

6.1 Fish Passage

The 2015 NHC report modelled the upstream salt water incursion in respect to three different size configurations of single slot gates in sea dam to allow seasonal fish passage during high tide. NHC determined that a gate 1.0 x 0.3 m (Slot 3) would have a negligible impact on upstream flood levels and a maximum increase in salinity of 0 ppt at the surface and 5 ppt along the river bed (2015). A spare gate could be retrofitted outside of the waterway and be installed during low tide so as not to impair sea dam function (NHC, 2015).

The key metric for the NHC study was to find a passage solution that did not impact (hydraulic and salinity) existing Nicomekl River water license holders (2015). Hydraulically, river water levels should not affect upstream water levels and water quality should show zero increase in background salinity at any point beyond 1.3 km (approximately 300 m beyond intersection with No. 99 Highway) upstream of the sea dam (NHC, 2015).

To assess conceptual slot gate dimensions over a range of flood conditions NHC utilized CCFR Phase 2 HEC-RAS model (Table 3).

Table 3: Fish slot model geometries, passage width standardized, invert and obvert elevations based on average downstream water levels during high tide, and variable height as comparable metric of saline intrusion variability (from NHC, 2015).

Geometry	Slot 1	Slot 2	Slot 3
Width	300 mm	300 mm	300 mm
Invert	5th percentile -1.4 m GD	15th percentile -0.9 m GD	25th percentile -0.5 m GD
Obvert	95th percentile 1.26 m GD	95th percentile 1.26 m GD	65th percentile 0.5 m GD
Height	2.66 m	2.16 m	1.0 m

Table 4 shows the calculated mean salinity by slot, assuming fully mixed conditions and downstream salinity at 25 ppt, for a distance of 1.3 km upstream of sea dam (NHC, 2015).

Table 4:Computed upstream salinity (ppt) after 12 hours of constant flow rate through each of three modelled fish slot sizes at the Nicomekl sea dam (from NHC,2015).

	Computed salinity (St) (ppt)			
	Base Case	**Slot 1**	**Slot 2**	**Slot 3**
Max	0.0	10.1	7.2	4.8
Mean	0.0	4.0	2.8	1.8
Min	0.0	0.0	0.0	0.0

A simplified 1D model of the channel was then applied to simulate upstream (1.0 km and 1.3 km) vertical distribution of salinity. This model showed that water salinity levels would be less than 1.5 to 2.0 ppt for the top meter of water and a maximum of 5 ppt at the river bed after 12 hours of constant discharge if Slot 3 was utilized (Fig. 10; Table 4; NHC, 2015).

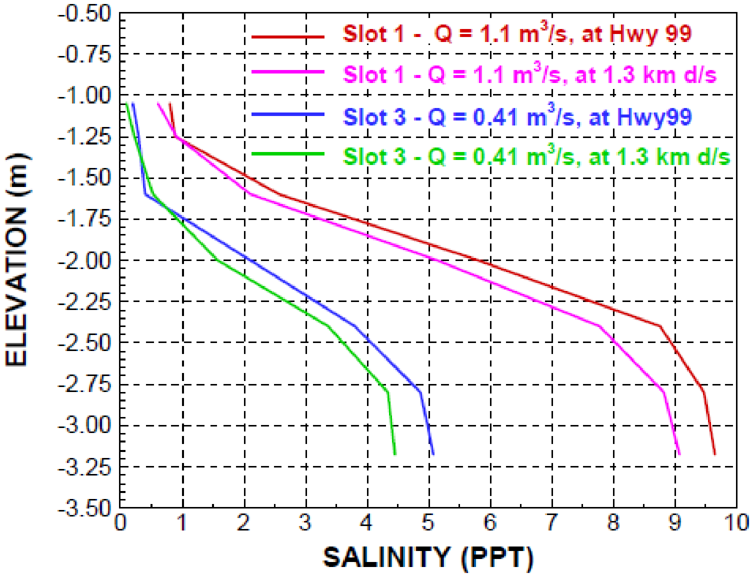

Figure 10: Modelled (simplified 3D) vertical salinity profiles at 1.0 and 1.3 km after 12 hours of constant discharge for Slot 1 and Slot 3, upstream of the Nicomekl sea dam (from NHC, 2015).

The period of upstream migration for salmonids generally occurs in October. This is outside of the growing season but water continues to be withdrawn for other agricultural uses. NHC suggests that further assessment and monitoring of licensee's water intake locations and depths may be required to see if intakes are within the modelled zone of saline influence (2015).

The sea dam is a structure administered and regulated under the Dike Maintenance Act, therefore any modifications to the Nicomekl sea dam will require approval under Section 9 of the Water Act. Approval will be dependent on the review of impacts to flood levels and water quality impacts to existing water license holders (NHC, 2015).

6.2 Instream Refuge Structures

I propose the novel usage of elevated concrete pipes radiating from the thalweg and oriented with stream flow (blue line; Fig. 9). The purpose of this treatment is to provide instream refuge across salmonid life-stages. The assumption is that fish will selectively use the structures out of necessity to avoid predation. Due to the low stream velocity, adult salmonids do not need to seek out pathways of lesser resistance by traveling along the littoral edges of the water way to conserve to resources (Hughes, 2004). Thus, adult salmonids will likely preferentially select the pelagic zone (thalweg) to reduce wave drag and skin friction during migration (Hughes, 2004; Makiguchi, Nii, Nakao, & Ueda, 2007). Alternatively, juvenile fish tend to utilize structures in the littoral zone where they select for refuge, rest, and forage opportunities away from larger animals in deeper waters. However, Katzman et al. (2010) suggest that juvenile Coho select for faster water velocities as the parr-smolt period proceeds, and therefore could utilize the refuge system Refuge pipes will serve to reduce predation pressure through increased effort, but not eliminate it entirely.

The point of ingress on the proposed concrete structures needs to be an appropriate diameter for fish to enter and bar seals from entering. Both species have similar fusiform body shape but different radial characteristics; harbour seals are rounded with large heads while salmon are oval in cross-section (Banfield, 1974). Pipe bore dimensions were comparatively selected based on animal girth measurements. Adult harbor seals range from 85 to 128 cm on average (Blanchet, Lydersen, Ims, Lowther, & Kovacs, 2014; Eguchi & Harvey, 2005), this was compared to Chinook Salmon that have an average girth range of 35 to 50 cm (Evenson & Jasper, 2006; Petrell & Jones, 2000). The installation will include three uniquely sized pipes sized to include average sized Chinook Salmon, as proxy for salmonids that utilize the waterway, and exclude average sized adult harbour seals:

- Pipe 1: 6 m x 38.1 cm (15”) approximate circumference 94 cm
- Pipe 2: 6 m x 45.72 cm (18”) approximate circumference 125 cm
- Pipe 3: 6 m x 53.34 cm (21”) approximate circumference 157 cm

The pipes shall be installed at the same gradient and flow as the natural channel (Forest Practices Branch, 2002) with footings that elevate the structures 10 cm from river bed to minimize sediment infill and promote usage. Pipes will be set 25 m heading downstream (west) of the sea dam. Placement will be done by 60-ton crane from the Elgin Road Bridge. The operation can also be conducted from immediately south of the bridge with a 90-ton crane if the municipality is concerned with bridge load. Installation shall occur in accordance with DFO appropriate work window for works in and about salmon bearing streams. In this case, it will be during the summer months when salmonids are not present at the Lower Nicomekl site.

This project will use LafargeHolcim ultra-high performance concrete (UHPC) under the tradename of Ductal. This product was chosen for its properties of strength, ductility, durability, impermeability, impact resistance and lighter weight than conventional concrete products (LafargeHolcim, 2017)**.** LafargeHolcim offers custom design that will allow for the refuge pipes and footings to be a one-piece construction. All concrete pipes manufactured by LafargeHolcim meet or exceed to the relevant CSA specifications

(A257: standards for concrete pipe) with a greater than 75-year lifespan (LafargeHolcim, 2017).

6.3 Large Wood and Boulders

Historically all waterways in British Columbia had LWD, creating instream structure that juvenile salmonids conducted their instream lifecycles in and around. LWD provides cover, refuge, and feeding opportunities (Beechie, Liermann, Beamer, & Henderson, 2005; D'Aoust & Miller, 1999; Gregory, Boyer, & Gurnell, 2003; Roni et al., 2002; Whiteway, Biron, Zimmermann, Venter, & Grant, 2010; Young, Hinch, & Northcote, 1999). Grette suggests an approximate average of 80 m^3 of LWD per 100 m stream length to mimic debris volume of an unlogged low gradient (<2 %) Pacific Northwest tributary (1985). Logs will be from coniferous trees rather than deciduous due to generally higher decay rate of deciduous trees (Roni et al., 2015). Western red-cedar (*Thuja plicata*), western hemlock (*Tsuga heterophylla*), Sitka spruce (*Picea sitchensis*) or Douglas-fir (*Pseudotsuga menziesii*) will be the species of preference (based on wood density and availability locally), and if possible some will have intact root wads. Nominal dimensions shall be: a diameter of 75 cm and a length of 12 m, providing 5.3 m^3 per piece. Physical LWD dimensions were derived from Grette's estimated wood volume table. Root wad volume has not been included (1985). A total of 15 wood and boulder structures will be installed; nine on the north bank and five on the south (Derived from Slaney & Zaldokas, 1997; Equation 1):

$$N = \frac{80\,m^3}{V_a} \times \frac{L}{100} \qquad N = \frac{80\,m^3}{5.3\,m^3} \times \frac{100}{100} = 15.09$$

Equation 1: Required number LWD pieces by volume (m^3). Where N = number of pieces, V_a = average volume/ piece of LWD, L = length of stream reach (from Slaney & Zaldokas, 1997)

Larger diameter pieces of wood have been selected in hopes of countering presumed accelerated decomposition associated with tidally influenced salt water environments. Estimated decay rates range from 0.5 – 3.5% per year suggesting LWD could persist for 70 -100 years in an aquatic environment (Naimen, Balian, Bartz, Bilby, & Latterell, 2002). Due to the saltwater and tidal influence I believe it to be prudent to expect persistence to be on the low end of the spectrum.

Johnson and Slaney argue that larger order streams, i.e. those greater than 20 m diameter and of low velocity, would tend to have LWD of large diameter often with rootwads (1996). I would argue that this volume exceeds what would have been historically present due to actual geographic location and gradient of the lower Nicomekl.

However, the selected LWD volume is being used to make up for the absence of riparian structure and fish passage impairment. North bank placement will be contingent on permission from the Surrey Dyking Commission based on their risk assessment as to actual proximity to the dike. Structures will be single LWD type as defined by D'Aoust and Miller, and ballast will vary based on presence of rootwad (1999).

LWD will be placed low on the bank to provide structural value across tidal cycles. Logs will solely rely on affixed boulders for anchoring. There will be no modification to existing surfaces. Affixing of logs to boulders will be done with ½" stainless steel braided cable that is epoxied into drilled points on rock ballast. Actual size of boulders used for ballast is derived from the peak annual flow to determine design velocity (Fig. 11):

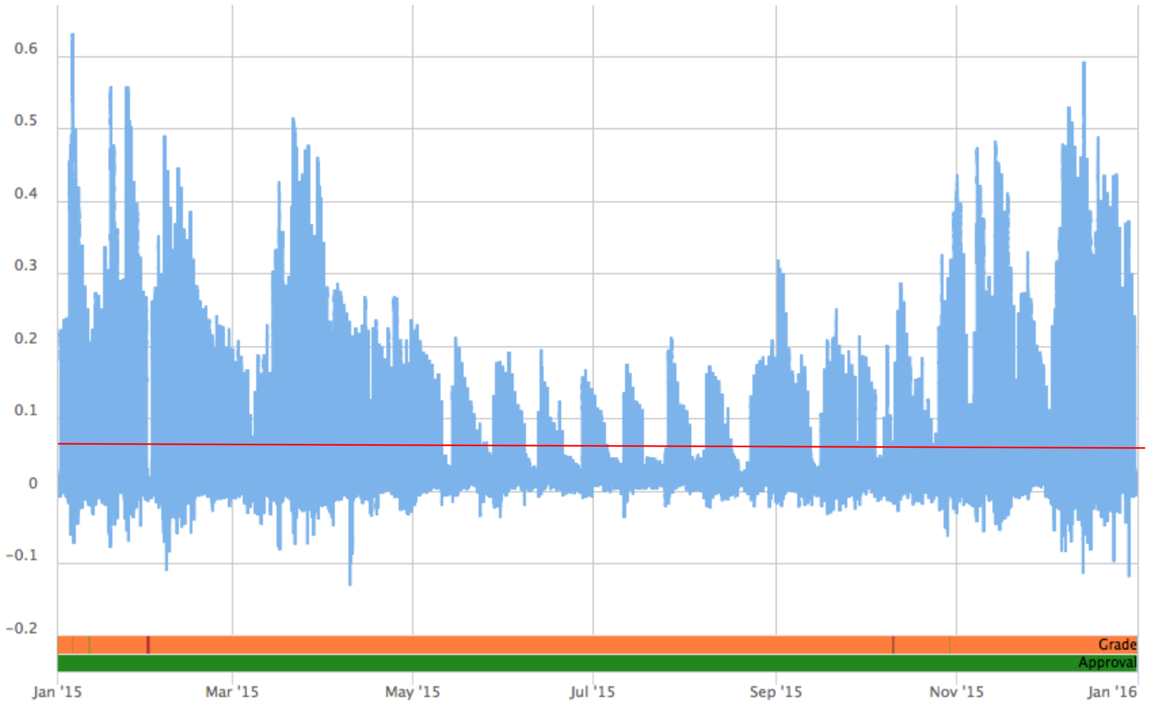

Figure 11: Mean discharge velocity in blue (m/s) of Nicomekl river for 2015 at the upstream side of Elgin Road Bridge sea dam, Surrey BC. Red line depicts average daily flow (0.0551 m/s), peak flow 0.631 m/s (Jan 1, 2015 21:35). Data collected January 1, 2015 0:00 thru January 1, 2016 0:00 (from NHC, 2017).

Ballast requirement is modified by effective log length the amount actively in the waterway; this will be 8 m to maximize fish interaction. I have elected to add an additional safety factor, increasing design flow to 1.0 m/s from 0.63 m/s, to manage for slide and buoyancy of each piece of LWD due to periodic submerged conditions (D'Aoust & Miller, 1999). Applying the modified design velocity to the ballast determination table each piece of LWD requires 125 kg/m of active length. Therefore, each log structure requires 1000 kg total ballast (Derived from Slaney & Zaldokas, 1997). I intend to use four boulders of 250 kg of approximately 0.5 m diameter on each structure (Derived from Slaney & Zaldokas, 1997). If these results do not satisfy municipal risk tolerance a safety factor can be applied to the base design velocity to derive an acceptable amount of ballast.

6.4 Riparian Restoration

The proposed riparian treatment area is a diurnal tidally flooding estuarine marsh (MacKenzie & Moran, 2004). Works cover an area of approximately 673 m^2. The treatment area is irregularly shaped, approximately 85 m long by 9 m (east) tapering down to 5 m width (west). This is within a previously constructed dike structure that housed an inter-tidal saltmarsh treatment that has only become marginally established along the south bank (blue polygon; Fig. 12). With the use of appropriate native species and installation of exclusion barriers, the vegetation establishment should require a period of 1 – 5 years (Roni et al., 2002). Post-monitoring will determine actual exclosure duration based on propagation.

Figure 12: Riparian treatment area within blue polygon, 85 m x 10 m (west) and 15 m (east) approximately 673 m^2, at Nicomekl restoration project area Surrey, BC (Adapted from City of Surrey Mapping Online System, 2017).

The project area is on a low bench floodplain with plants adapted to extended flooding, abrasion and salinity influence; low or tall shrubs being most common (Adamoski, Clark & Meidinger, 2014). Due to the salt water intrusion resulting from the low channel gradient and elevation, salt tolerance is the prominent plant selection characteristic for vegetation (MacKenzie & Moran, 2004). The prevalence of salinity within the soil will increase with sea level rise (SLR) and climate change (Roman & Burdick, 2012). Estuarine marsh plant communities are commonly dominated by salt-tolerant emergent graminoids and succulents (MacKenzie & Moran, 2004; Roman & Burdick, 2012), generally resulting in the dominance of C_4 grasses (Roman & Burdick, 2012).
USDA suggests that in an environment that is exposed to salt water, soil saturation, and flooding, plant selection should be based on a strong tolerance to salinity (25 – 35 ppt sodium chloride concentration) (n.d.). NHC stated that average salinity concentration immediately downstream of the sea dam is 25 ppt (2015). Therefore, preliminary assessment has identified three candidate species for planting at this site:

- Seashore saltgrass (*Disticlis spicata*)
- Saltmarsh bulrush (*Bolboschoenus maritimus*)
- Lyngby's sedge (*Carex lyngbyei*)

One plant plug per meter square will be planted at the site. Seashore saltgrass will be the predominate species as it is very salt tolerant (USDA, 2012). Seashore saltgrass will be planted at an overall ratio of 5:2 and will be the sole plant within 3 m of the waterline as it has a high salt tolerance. Saltmarsh bulrush and Lyngby's sedge will be planted in blocks of four with the pattern repeating from the left (Table 5). Planting should occur late spring to maximize early season establishment prior to high summer drought period.

Table 5: Sample planting block pattern from waterline (bottom), Seashore saltgrass (Ss) yellow, Saltmarsh bulrush (Sb) green, and Lyngby's sedge (Ls) represented in blue.

Ss	Sb	Sb	Ss	Ls	Ls
Ss	Sb	Sb	Ss	Ls	Ls
Ss	Ss	Ss	Ss	Ss	Ss

There is invasive species encroachment by Himalayan blackberry (*Rubus armeniacus*) and English ivy (*Hedera helix*) from the river side park associated with the Elgin village residential development on the upper south bank. This will require removal and ongoing management. I strongly recommend commencement of this treatment only after in-depth analysis of soils, construction of structure, and risk abatement measures provided from City of Surrey.

6.5 Actions & Budget

A tabularized cost estimate for proposed activity for Nicomekl sea dam restoration project is in Table 6. Costs are solely for treatments; remedial works such as resolving the impaired drainage within the riparian structure are additive. Estimated total project duration (on site) is 8 days. Total pre-tax estimated cost for this project is $47,273.

Table 6: Projected Nicomekl River sea dam restoration project budget by activity.

Item	Type	Detail	Unit	Quantity	Rate	Cost
1. Project supervision	Labour	Supervision, material and equipment sourcing, permit acquisition, consultation, directing machinery, and leading treatments	day	8	300.00	$2,400.00
2. Professional services	Contractor	Confirm ballast equations, site QEP	day	7	600.00	$4,200.00
3. Concrete pipe A	Material	Ductal concrete 15" pipe	m	6	81.18	$487.08
4. Delivery pipe A	Freight		m	6	5.00	$30.00
5. Concrete pipe B	Material	Ductal concrete 18" pipe	m	6	112.00	$672.00
6. Delivery pipe B	Freight		m	6	7.00	$42.00
7. Concrete pipe C	Material	Ductal concrete 21" pipe	m	6	141.00	$846.00
8. Delivery pipe C	Freight		m	6	8.00	$48.00
9. 60-ton crane	Contractor	Mobile service, 4 hr min.	hr	4	330.00	$1,320.00
10. Crane transit	Contractor	Move in/ move out (portal to portal) @ $75 per/hr	hr	6	75.00	$450.00
11. Pilot car	Contractor		hr	6	70.00	$420.00
12. Crane operator	Contractor		hr	6	100.00	$600.00
13. Traffic control	Contractor		hr	4	60.00	$240.00
14. Pipe installation	Labour	2 person crew Instream pipe placement	hr	6	187.50	$1,125.00
15. Excavator	Contractor	200 series, LWD installation and cleanup earthworks	hr	16	145.00	$2,320.00
16. Excavator transit	Contractor	Move in/ move out @ $375 per/move	day	1	750.00	$750.00
17. LWD	Material	Sourced from Squamish Nation log sort, including trasport via self-loading logging or	each	15	400.00	$6,000.00
18. Boulders	Material	15,000 kg round habitat boulders and trasport from quarry	Load	9	1,000.00	$9,000.00
19. Cable	Material	1/2" stainless steel braided cable for horshoe type attachment, 60 m +10%	ft	217	4.50	$976.50
20. Epoxy	Material	Fast dry 2-part epoxy @ 1 tube/ 10 connections + safety	each	4	40.00	$160.00
21. Rental for LWD	Equipment	Generator, wood drill, rock drills (2), cable cutters, epoxy gun, cleaning equipment	day	2	150.00	$300.00
22. LWD installation	Labour	3 person crew@ $250/ day/ person (includes CPP, EI, Vacation)	day	2	750.00	$1,500.00
23. Invasive removal	Labour	3 person crew@ $250/ day/ person (includes CPP, EI, Vacation)	day	1	750.00	$750.00
24. Riprian treatment	Labour	3 person crew@ $250/ day/ person (includes CPP, EI, Vacation) Planting and	day	2	750.00	$1,500.00
25. Nursery stock Ss	Material	Seashore saltgrass plugs 50 ct tray @ $1.50/ plug	Tray	10	75.00	$750.00
26. Nursery stock Sb	Material	Seacoast bulrush plugs 50 ct tray @ $1.75/ plug	Tray	2	87.50	$175.00
27. Nursery stock Ls	Material	Lyngby's sedge plugs 50 ct tray @ $1.50/ plug	Tray	2	75.00	$150.00

Item	Type	Detail	Unit	Quantity	Rate	Cost
28. Exclusion fencing	Material	36" orange fencing	each	15	35.99	$539.85
29. Posts	Material	2"x6' one-end pointed stakes bundle of 6	bundle	6	33.30	$199.80
30. Straps	Material	10-12" heavy duty zap straps 100/bag	bag	4	8.51	$34.04
31. Flagging	Material	Red or yellow flagging tape	roll	4	5.49	$21.96
32. Rental for Riparian	Equipment	Steel post pounders (2), trowels (4)	day	2	50.00	$100.00
33. Project signage	Outreach	Design, procure and install at project site	each	1	3,000.00	$3,000.00
					SUBTOTAL	$41,107.23
34. Contingency		15% costing uncertaintly, approval, permitting, engineering support and	15%			$6,166.08
					TOTAL	$47,273.31
					GST (5%)	$2,363.67
					GRAND TOTAL	$49,636.98

7: Monitoring and Maintenance

Long-term monitoring is required to properly assess productivity change associated with restoration.10 years or more of monitoring is often required to detect a response to restoration due to large inter-annual variability in abundance of juvenile and adult salmonids (Bisson, Quinn, Reeves, & Gregory, 1992; Reeves, Hall, Roehlofs, Hickman, & Baker, 1991. This project will include both pre- and post-treatment monitoring components. Sampling design will use “Fish and Fish Habitat Inventory: Standards and Procedures” as prescribed by the BC Ministry of Environment Resource Information Standards Committee (RISC, 2001).

7.1 Pre-monitoring

Pre-monitoring component will come from historic Nicomekl Enhancement Society salmon return data; this provides a measurable baseline of salmonid population trends on the river. This is not an ideal situation, as the data will not be as robust as either passive or active fish count through the sea dam. Further knowledge will be built from connecting with expert individuals and other local organizations.

7.2 Post-treatment monitoring

Post monitoring will assess the same variables as pre-monitoring (salmon returns to hatchery) to determine the mean change in target variables and implement interventions as required. Monitoring will occur in conjunction with maintenance assessments and should be upheld for a minimum of 10 years. Post monitoring will fall into two overlapping categories (Adapted from Morrison, 2009):

1. Effectiveness Monitoring: Assessing trends in annual returns to Nicomekl hatchery fish counts.
2. Compliance Monitoring: Regular structural treatment stability assessment to ensure that the project upholds legal requirements.

7.3 Maintenance

Maintenance monitoring shall be conducted annually for the lifespan of structural treatments and bi-annually for the first five years. Riparian maintenance should be conducted concurrently. Actual activities for each treatment shall be assessing for and providing remedial intervention as necessary:

- Refuge structures: sedimentation, movement
- LWD: degradation, movement
- Riparian: weather dependent irrigation, exclusion fencing remedial upkeep, invasive ingrowth

8: Discussion

Natural processes that create ecological form and function operate on time scales that can span from decades to centuries (i.e., recruitment of LWD, riparian structural complexity) (Roni, et al., 2002). Development such as constructing diking and riparian removal, interrupts these natural ecological processes and can lead to the loss of fish productivity over the long term (Beechie & Bolton, 1999). Roni et al. (2002) suggest the simplest way restore natural processes is to focus on those that form to connect and sustain habitats. There is a limited range of habitat characteristics found within any given stream reach based on watershed position and site-specific physical characteristics (Roni et al., 2002). Literature review has suggested that the loss of stream connectivity is a critical limiting factor that causes genetic and numerical suppression of salmonid populations (DeVore, James, Tracy, & Hale, 1995; Sedell, Reeves, Hauer, Stanford, & Hawkins, 1990; Stanford, Frissell, & Coutant, 2006). As such this project utilizes a site based approach to address the connectivity shortfall

Restoring connectivity is the critical intervention for this site-specific restoration and will facilitate recovery of metapopulations (Stanford et al., 1996). Fish passage structures reconnect the features within the channel and restore natural watershed processes, effectively increasing available habitat and potential fish production at a cost that can be predictably shared across organizations (governmental and third party) (NHC, 2015; Roni, et al., 2002).

Water sampling measured the functionality of the sea dam in respect to salt water incursion to create further support for the NHC modelled data showing the viability of a fish gate (Slot 3). The data from the simplified 3D model indicated that salinity increase in the top meter of water would be 0 ppt and 5 ppt at the river bed (NHC, 2015). Initial water samples during high-tide, when the sea dam is closed, found notable salinity above 4.0 ppt at all stations beginning at 2.0 m depth and exceeding 14 ppt directly upstream of the dam. Therefore, the sea dam appears be a marginal obstacle to saltwater incursion, suggesting that baseline upstream salinity could be similar to the environment modelled by NHC as when a fish slot is open. The City of Surrey is not supportive of any potential for small changes in water quality resulting from installing a fish gate (NHC, 2015). However, agricultural users are already irrigating with water that is affected by saline concentrations. The installation of a fish passage structure will not significantly alter salinity, thus, supporting the argument for dam retrofit of a fish slot.

Agricultural users are not being monitored sufficiently in respect to runoff and water usage. There is a need to modernization the water uptake systems and implement of best management practices to regulate outflow (DFO, 1998b; NHC,2015). The Nicomekl River has a wedge of salt water that is heavier than fresh water and is horizontally stratified (NHC, 2015). Upgrading to floating intake designs that do not draw water from depth, will mitigate risk of saline water uptake to a greater extent than relying on the sea dam (NHC, 2015).

Vegetation sampling determined the south bank to have low overall coverage (~25%) within the riparian treatment area. The north bank is categorically a modified channel that also provides no riparian value in relation to the river. Detailed assessment of the soil and structure of the south bank riparian zone is required prior to any remedial undertaking. Analysis of the riparian offset structure will determine if construction is defective and is impeding natural flushing of tidally delivered salinity through the soil profile. There are two layers of geo-textile that may be the limiting factor by inhibiting proper drainage through the soil profile.

8.1 Rational

The intention of the prescription is to provide habitat spaces that are suitable to different species and life-stages. A modular approach towards restoration may be appropriate from a precautionary perspective. Each action has value individually but with a greater number of actions taken to towards reinstating river connectivity and survivorship the greater the likelihood of a significant increase in spawner returns and juvenile oceanic migration.

Restoration requires reconnection of isolated ecological segments and restoring the disrupted habitat-forming processes (Beechie & Bolton 1999). Roni et al. (2002) stated that manipulations (i.e., in- stream structures) are generally unnecessary except where adjacent land uses constrain restoration options. Such is the case within the study area at the Nicomekl proposed site. Successful restoration requires that we understand how and when salmonids use different parts of the river continuum (Beechie & Bolton, 1999).

Beechie and Bolton (1999) suggested three specific factors to guide treatments: the needs of individual species, locations of refugia, and cost effectiveness. Specific actions must also consider response time, variability and probability of success and expected duration of a treatment (Roni et al., 2002). Following the meta-analysis of stream restoration techniques my proposed treatments are as follows (from Roni et al., 2002):

- *Reconnect habitats (fish gate): Response 1 – 5 yrs., longevity 10 – 50+ yrs., low variability, high probability of success*
- *Riparian replanting: Response 5 -20 yrs., longevity 10 -50+ yrs., low variability, medium – high probability of success*
- *Instream habitat restoration (artificial log jams: single-log structures): response 1 -5 yrs., longevity 10- 50+ yrs., medium – high variability, medium (average) probability of success.*
- *Instream habitat restoration (artificial log structures: predation refuge pipes): response 1 -5 yrs., longevity 5- 20 yrs., medium – high variability, medium (average) probability of success.*

Techniques for marine mammal predation management around dams have included: culling, netting, harassment and acoustic deterrent (DFO, 2001; NOAA Fisheries, 2007). These systems that have been considered for usage around major projects along the Columbia River system and open-water salmon farming are not applicable in an urban environment for reasons of disturbance, danger, and lack of social license. This suggests that a novel solution may be the best option, to reduce the period of predation exposure due to the passage barrier. Due to recreational usage of the waterway we cannot install complex log and boulder structures that could create human risk. Concrete pipes provide a low profile in the water course and will not present features that could potentially entangle a recreational craft (e.g. kayak). Installation, removal, and repositioning of concrete pipes is relatively quick and simple.

If increased predation from harbor seals and piscivorous birds (for smolts) is indeed a significant driver of pre-spawn fish mortality due to the loss of connectivity, by providing refuge and cover instream pre-spawn anadromous salmonid mortality will be measurably reduced. NHC evaluated the month of October (dominate adult migration period) over a period of 47 years (1964 – 2010) to determine the amount of time fish have been vulnerable to predation due to the sea dam (2015). They found that for 80% of the hours (744 hrs. avg.) in the month of October fish were vulnerable to predation. This could be reduced to 9% (approximately 67 hrs.) if the Slot 3 fish gate was installed (NHC, 2015). Without an official fish count on the waterway the best measure will be from the Nicomekl Enhancement Society hatchery return counts.

Artificial LWD structures have over twenty-five years of use and monitoring in the Pacific Northwest (Roni, et al., 2002). However, instream structures are not a cure all. Instream manipulations or enhancements should either be undertaken after or in conjunction with efforts to restore watershed processes (Roni, et al., 2002). Instream treatments alone may be appropriate where short-term increases in fish production are needed for a threatened or endangered species (Beechie & Bolton 1999; Roni, et al., 2002). If fish passage cannot be resolved in the short-term, LWD structures may provide measurable productivity gains to generate support for further treatments.

Meta-analysis of trout response to riparian change has shown revegetation did not consistently influence trout populations but there was positive response to increasing LWD (Sievers, Hale, & Morrongiello, 2017). Adding instream LWD has proven to enhance fish populations (Howson, Robson, Matthews, & Mitchell, 2012; Roni et al., 2002; Roni, Pess, Beechie, & Hanson, 2015; Stewart, Bayliss, Showler, Pullin, &

Sutherland, 2006). This is accomplished by providing shelter from predation and serving as resting locations during migration for both adult and juvenile fish (D'Aoust & Miller, 1999). Due to the constraints of the site restoration treatments instream and on the north bank must neither impair the dike nor be permanent.

Riparian restoration is a challenging treatment to justify. This due to spatial constraints from the dike and private farm ownership on north bank and the underperforming inter-tidal saltmarsh treatment on the south bank. In addition, Sievers et al. (2017) conducted a meta-analysis to explore how trout respond to key drivers of riparian change. They found little evidence on the individual and population level to suggest that revegetation consistently influences population as much as increasing woody debris. However, they did find evidence that riparian changes may attract fish rather than enhance actual population (Sievers et al., 2017). By bringing fish to the study area and away from the unrestored peripheral areas, survivorship should improve and contribute to the justification of further works along the Nicomekl.

Simple soil analysis (hand texturing) found a high content of sand (>70%) with a surficial mixture of fine particles (silt and clay) that is present above the upper geo-textile layer. I theorize that the geo-textile has caused an impairment in drainage leading to salinity levels in the upper soil horizon that are inhospitable even to salt-tolerant species. Thus, the absence of colonization across the vast majority of the structure. A full soil assessment is required prior to commencement of treatment to determine if the structure is inhibiting plant establishment. Marginal waterside colonization suggests that salinity may be an agent as well. The selection of site appropriate species becomes very important for the site as riparian restoration may not produce results for many years or even decades for some functions (Roni, et al., 2002).

Consideration must be taken when deciding if another riparian treatment will have a better outcome than the original, if it will be cost effective, serve the needs of migratory salmonids, and have a reasonable response time. Riparian restoration may not directly serve the goal of improving survival at the sea dam bottleneck. Without a clear understanding of why the original riparian treatment failed, a precautionary approach is required. Further Roni et al. (2002) suggest that riparian treatments on average take five years to achieve response. Any action must consider that the projected effects of climate change and sea level rise (SLR) forecast a distinctly different tidal baseline that will be exacerbated by more extreme storm events (City of Surrey, 2014; Metro, 2016).

8.2 Climate Change

The climate in Coastal British Columbia is changing, and we must plan now for hotter summers with less precipitation and colder, wetter winters (Metro, 2016). This will have a negative impact on both aquatic and terrestrial species resulting in decreased plant growth, heat stress, colonization by more adaptive species, decreasing stream flow, and warmer water temperatures leading to early freshet (Metro, 2016). This will cause ever increasing stress to cold water aquatic species (Metro, 2016).

The BC Ministry of Environment projects sea level rise (SLR) for coastal BC to occur in three increments: short-term SLR 0.5 m (25- 50 yrs.), long-term SLR 1 m (50-100 yrs.), and future forecast 2 m SLR (>100 yrs.) (Fig. 13, Ausenco Sandwell, 2011).

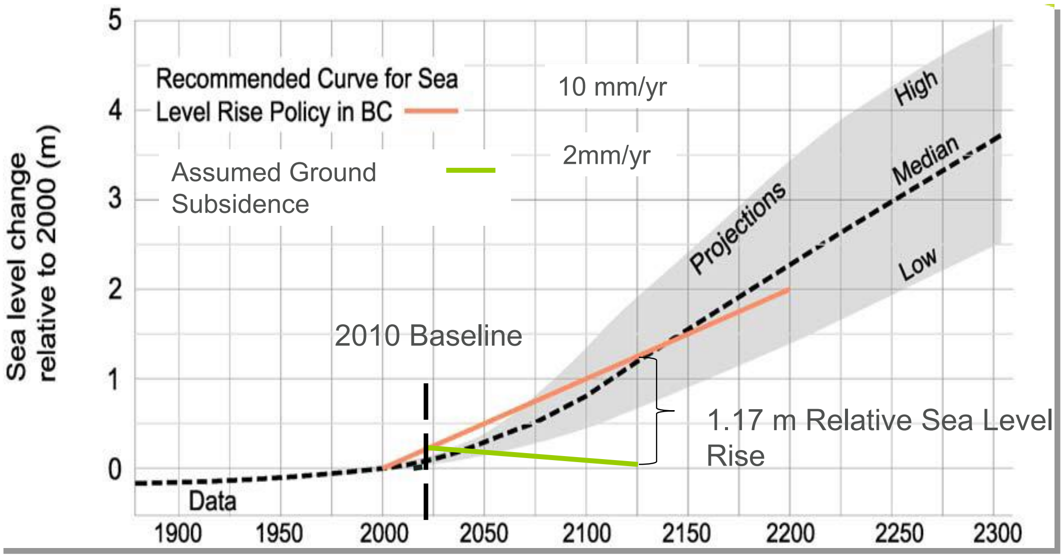

Figure 13: Projected relative sea level rise for coastal British (from City of Surrey, 2014 adaption of Ausenco Sandwell, 2011).

For this project, consideration will be made in respect to the first increment, the next 25 – 50 years. Instream structures, will not be permanently affixed in the channel, thereby allowing the imminent upgrades to the dike to occur without hindrance. The LWD structures and cement refuge pipes will be machine removable and relocatable when the imminent diking and dam structures are modified for future conditions.

Current projections suggest that storm surges by 2100 could completely undermine the existing infrastructure at the Elgin Road Bridge (City of Surrey, 2014; Figure 14). If this prediction is realized, the ramifications will push significantly beyond the boundaries of this restoration project and become a matter of regional management rather than a site-specific endeavor. I must accept that the location could be radically different 100 years from now and that efforts committed today may not survive beyond the next 50 years. The goal is to provide immediate triage to at-risk salmonid stocks on the Nicomekl River and begin rebuilding stocks.

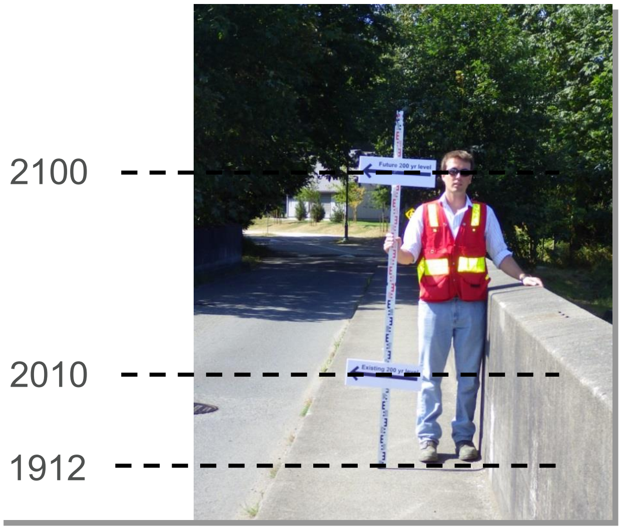

Figure 14: Historic (1912), baseline (2010) and projected future storm surge levels at the Elgin Road Bridge crossing the Nicomekl River in Surrey BC (from City of Surrey, 2014).

Climate change will pose another challenge that will require greater regulation and monitoring. Metro Vancouver projects the average temperature to increase by 3°C in this region by the 2050s (2016). This will at least double the number of days above 25°C in the summer months. Consequently, precipitation may decrease by 19% and the growing season will expand by 20% by the 2050s (Metro Vancouver, 2016). These changes could make many of the waterways within the Lower Mainland uninhabitable to anadromous salmonids, resulting in local and regional extirpations.

Higher sea level and less summer fresh water input, along with increased demand for fresh water, will make conservation and management of critical importance to avoid dewatering events upstream of the project area. This project is a good first step to starting to think about dealing with these challenges and building a management framework.

8.3 First Nations & Public Engagement

8.3.1 Engagement – First Nations

The project site is within historic Katzie Nation territory. Both Katzie and Tsawwassen First Nations have made overlapping statements of territorial claim to the Surrey Lowlands in respect to the GVRD land treaty settlement process (Government of Canada, 2009). However, with treaty finalization the Tsawwassen Nation has included the entirety of the Surrey lowlands as part of their territorial land (Government of

Canada, 2009). There are no specified land parcels along the Nicomekl. Neither the Nicomekl nor Serpentine are allocated as fishing area under the treaty, but the surrounding lands are included within the wildlife and migratory bird harvest area. Tsawwassen has no allocation of salmon outside the Fraser River stocks and their fishing grounds do not go beyond Mud Bay where the Nicomekl connects (Government of Canada, 2009). Prior to commencement of any actions, consultation with Tsawwassen Nation as respectful acknowledgement of treaty ceded territory and historical practices must occur.

8.3.2 Engagement – Agricultural Users

Ultimately, buy-in from the agricultural users along the Nicomekl system may be the most important group that hold the key to resolving the river's broken connectivity. Ostensibly, the sea dam protects agricultural interests through the Surrey lowlands and without any information to the contrary that is likely the belief held by farmers. NHC's modelling and preliminary sampling from study suggests that the sea dam is an imperfect barrier to salinity and an engineered fish portal will have no effect on the upper portions of the water column (0 – 1 m). Further, outdated water uptake systems may actually be the vector for salinity uptake.

If this project gained the support of the farming community, it would conceivably address the City of Surrey's aversion to act on the recommendations presented by NHC to install a fish gate. To achieve buy-in from the farming community will require education and engagement in the form of both community meetings and direct interaction. Through direct engagement farmers can become informed of the best practices to protect their livelihoods while at the same time fostering greater salmonid productivity in the Nicomekl system. Better practices would make them not only users, but stewards of the Nicomekl River.

8.3.3 Engagement – Interested Groups

Initial discussions with Friends of Semiahmoo Bay Society (FOSBS) has resulted in an expressed interest to participate in restoration works on the Nicomekl River. FOSBS is a provincially registered, non-profit society who focus on preservation, restoration, and education of ecological values of the Boundary Bay ecosystem.

The NES are in support of any action that could one day make their hatchery obsolete. They support efforts to mitigate the perceived elevated predation pressure from Mud Bay resident harbour seal colony caused by the sea dam. NES would like to see improved upstream returns to spawning grounds by anadromous salmonids in the Nicomekl River system.

Social license is a powerful tool and even more so within an urban context. To involve the public in the stewardship and buy-in of Nicomekl restoration, I recommend the following:

- Creating volunteer opportunities: In conjunction with FOSBS and NES, involving the public in a spring planting along the upper south side bank just outside of the project area. This should also involve invasive species management, and use the opportunity to educate the public on what invasive species are and why they should be concerned about them.
- Active Education: Post treatment, the site could be used as an educational tool for local schools, where students would learn about Pacific salmonid lifecycle, the plant community and wildlife, as well as the importance of estuaries.
- Passive Education: Interpretive signage acting as an educational and recruitment tool. I propose placement along the walking trail that overlooks the treatment area on the south shore.

Using these three methods of public involvement would instill a sense of ownership in the local community, encourage stewardship for the site, and most importantly build social license for further works along the Nicomekl.

8.4 Limitations

This report cannot address all impairing factors. Instead I have attempted to identify a logical and achievable first step in a larger restoration of the waterway. This plan is cognizant of the temporal imperative for action on an endangered stream (DFO, 1998b) and creates minimal societal disturbance. Implemented strategies must integrate the existing man-made features when addressing the migratory bottleneck created by the sea dam at Elgin Road and structural deficiencies caused by surrounding anthropogenic development.

The ideal condition would be one of free fish passage with a structurally diverse riparian and instream zones, providing fish refuge from predation, rest areas, and forage opportunities. Mitigation through the choke point could be achieved through implementation of a seasonal fish pass through the dam. The scope of a complete restoration for the Nicomekl River is well beyond this report and is not feasible in the context of the existing anthropogenic stressors. The river requires numerous projects over a protracted period to find a social and ecological balance.

There is a distinct absence of recent knowledge regarding the abiotic and biotic communities of the Nicomekl River watershed. Highlighting the requirement for further research to specifically identify and measure the stressors occurring within the Nicomekl watershed.

9: Conclusion

The challenges faced by Nicomekl River salmonids is focused around the loss of habitat connectivity created by the sea dam which has amplified predation in juvenile and adult salmon. I have prescribed realistic restoration treatments by addressing these two critical limiting factors, thereby moving towards resolving the challenges faced by anadromous salmonids in a denuded waterway with impaired passage. This plan will help restore habitat connectivity, reduce predation, and engage the public on the Nicomekl River.

Assessment has identified that the greatest barrier is the temporally disconnected stream continuum imposed by the sea dam. Upstream and downstream river sections must be reconnected to allow salmonids passage. Restoring connectivity increases habitat availability and can result in notable increases in productivity potential for a nominal cost (Roni et al., 2002). The modelling done by NHC shows that this can be done at virtually no risk to the water licenses on the river. I believe that there is an urgency if we want to save Nicomekl River wild stocks, and that is in part why this project is about more than just passage resolution. We must provide some semblance of ecological values, not just a barren channel for animals to interact within. Reintroducing structural complexity both instream and terrestrial will normalize behaviour, function, and predation levels for Nicomekl River salmonids. Adults and juvenile life-cycles can then return to a more normal spectrum with available refuge and rest sites. This will buy us time to come to a lasting resolution to the passage barrier rather than passively allowing wild Nicomekl salmonid populations to further diminish.

This plan also includes a strong public engagement component. The Nicomekl River is an urban waterway greatly affected by anthropogenic pressures that may be reticent towards changes. An engaged public creates social license and can sway policy and convert neighbours to a new paradigm. The value of an engaged public is possibly the critical determining factor on whether the Nicomekl can be redirected from the current trajectory of degradation.

Present management practices have shown to be largely ineffective in protecting the Pacific salmonids of Surrey, British Columbia. A wide variety of private land stewardship options need to be implemented to repair connectivity and preserve riparian areas and fish habitat in urban areas. No single group, agency, or tool unaided can provide a comprehensive program to restore Nicomekl salmonid stocks (Inglis, Child & Thomas, 1995). It requires cooperation and coordination between federal, provincial, and local levels of government, non-governmental organizations, private land owners, and First Nations if we intend to protect our salmonids (Inglis, Child & Thomas, 1995).

This project is a critical intervention for a river in an imperiled state. Flow regulation on the Nicomekl River will continue as long as agricultural practices persist along its course. Restoring to an untouched state is not achievable, nor desirable to the rivers users. Recovering a portion of lost capacity to sustain native salmon is possible by managing for processes that maintain normative habitat conditions (Stanford et al., 1996). The river can do most of the work if allowed to flow.

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10.1 Map Credits

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11: Appendices

Appendix 1: Nicomekl water licenses, purpose and quantity of authorized water usage (from Province of British Columbia, 2017)

Licence No	Stream Name	Purpose	Quantity	Units
C049815	Nicomekl	Irrigation: Private	12334.8	MY
C052203	Nicomekl	Irrigation: Private	71541.84	MY
C052204	Nicomekl	Irrigation: Private	56912.767	MY
C052206	Nicomekl	Irrigation: Private	54766.512	MY
C052207	Nicomekl	Irrigation: Private	42727.747	MY
C052208	Nicomekl	Irrigation: Private	34044.048	MY
C052896	Nicomekl	Irrigation: Private	76475.76	MY
C054898	Nicomekl	Irrigation: Private	3083.7	MY
C054900	Nicomekl	Irrigation: Private	9251.1	MY
"	Nicomekl	Irrigation: Private	9251.1	MY
C055003	Nicomekl	Irrigation: Private	18502.2	MY
C055184	Nicomekl	Irrigation: Private	11101.32	MY
C055984	Nicomekl	Irrigation: Private	308.37	MY
C057416	Nicomekl	Irrigation: Private	6167.4	MY
C058054	Nicomekl	Irrigation: Private	6167.4	MY

C064120	Nicomekl	Irrigation: Private	28616.736	MY
C065303	Nicomekl	Irrigation: Private	6290.748	MY
C068142	Nicomekl	Irrigation: Private	88070.472	MY
C068144	Nicomekl	Irrigation: Private	7400.88	MY
C069887	Nicomekl	Irrigation: Private	17823.786	MY
C072215	Nicomekl	Irrigation: Private	27629.952	MY
"	Nicomekl	Livestock & Animal: Stock	2.273	**MD**
C102066	Nicomekl	Grnhouse & Nursery: Grnho	13.638	**MD**
C102067	Nicomekl	Irrigation: Local Provide	1111365.48	MY
C102070	Nicomekl	Irrigation: Local Provide	1205726.7	MY
C102071	Nicomekl	Irrigation: Private	52422.9	MY
"	Nicomekl	Irrigation: Private	52422.9	MY
"	Nicomekl	Irrigation: Private	52422.9	MY
C102391	Nicomekl	Irrigation: Private	50325.984	MY
C102591	Nicomekl	Irrigation: Private	22202.64	MY
C105316	Nicomekl	Grnhouse & Nursery: Grnho	45.461	**MD**
C106437	Nicomekl	Irrigation: Private	7400.88	MY

C106696	Nicomekl	Irrigation: Private	1233.48	MY
C108256	Nicomekl	Irrigation: Private	5242.29	MY
C114791	Nicomekl	Grnhouse & Nursery: Nurse	26828.19	MY
C114792	Nicomekl	Grnhouse & Nursery: Nurse	19427.31	MY
C116819	Nicomekl	Irrigation: Private	51645.808	MY
C118075	Nicomekl	Irrigation: Private	60933.912	MY
C118616	Nicomekl	Irrigation: Private	71504.836	MY
C119187	Nicomekl	Irrigation: Private	60687.216	MY
C120513	Nicomekl	Grnhouse & Nursery: Grnho	68.191	**MD**
C125187	Nicomekl	Irrigation: Private	36177.968	MY
C125530	Nicomekl	Irrigation: Private	32711.89	MY
C127232	Nicomekl	Irrigation: Private	50165.632	MY
F016624	Nicomekl	Irrigation: Private	7400.88	MY
F019184	Nicomekl	Domestic	4.546	**MD**
"	Nicomekl	Irrigation: Private	42555.06	MY
"	Nicomekl	Domestic	4.546	**MD**
"	Nicomekl	Irrigation: Private	42555.06	MY

F020921	Nicomekl	Irrigation: Private	308370	MY
"	Nicomekl	Irrigation: Private	308370	MY
F020943	Nicomekl	Irrigation: Private	93744.48	MY
F021575	Nicomekl	Irrigation: Private	122114.52	MY
F021585	Nicomekl	Irrigation: Private	18933.918	MY
F039612	Nicomekl	Irrigation: Private	6167.4	MY
F040202	Nicomekl	Land Improve: General	2.728	**MD**
F044325	Nicomekl	Irrigation: Private	24669.6	MY
F044486	Nicomekl	Irrigation: Private	207224.64	MY
F044654	Nicomekl	Pond & Aquaculture	0.014	**MS**
F072269	Nicomekl	Irrigation: Private	46255.5	MY
		MY	4787678.612	
		MD	141.397	51609.905
		MS	0.014	441504
		Total (m3/yr)	5280792.517	

Appendix 2: Estimated nutrient loading (nitrogen and phosphorus) from diffuse agricultural sources on the Nicomekl River Surrey, BC (Holmes & Swain, 1988).

ESTIMATED NUTRIENT LOADINGS FROM DIFFUSE AGRICULTURAL SOURCES

NITROGEN VALUES kg/year

DISCHARGE TO	FINISHING CATTLE	COWS	CALVES	YEARLINGS	TOTAL
Sam Hill Cr.	3 400			11 970	15 370
Little Campbell R.	9 044	1 972	49		11 064
Nicomekl R.	5 100	5 304	141	160	10 704
Serpentine R.	345 100	5 644	163	42 972	393 879

PHOSPHORUS VALUES kg/year (P)

DISCHARGE TO	FINISHING CATTLE	COWS	CALVES	YEARLINGS	TOTAL
Sam Hill Cr.	235			966	1 201
Little Campell R.	625	230	6		861
Nicomekl R.	352	618	17	13	1 000
Serpentine R.	23 842	657	20	3 471	28 001

Appendix 3: Water quality assessment 1972 thru 1983, Nicomekl River at King George highway in Surrey BC (Holmes & Swain, 1988).

SITE 0300060: NICOMEKL RIVER KING GEORGE HIGHWAY

Constituent	Period of Record	No. of Values	Values* Maximum	Minimum	Mean
Alkalinity:total	1972-1983	47	81.7	18	50.6
Arsenic	1975-1983	9	<0.25	<0.005	-
Carbon:organic	1982-1983	12	18	2	7
inorganic	1982	8	21	12	18.5
Chloride	1972-1983	41	9800	10.3	762
Coliform fecal	1973-1983	38	9200	<2	95$^+$
Colour:True	1972-1982	11	200	20	65.5
Cobalt	1982	6	<0.1	<0.1	<0.1
Hardness:total	1972-1983	38	2342	32.1	251
calcium	1972-1982	32	155	7.9	27.9
magnesium	1972-1983	42	475	3.0	44.5
Metals:total					
Aluminum	1977-1983	8	1.44	0.18	0.44
Cadmium	1982-1983	7	<0.01	<0.01	<0.01
Chromium	1972-1983	31	0.016	<0.005	<0.005$^+$
Copper	1972-1983	34	0.03	<0.001	0.006
Iron	1973-1983	36	3.4	0.14	1.27
Lead	1972-1983	35	<0.1	<0.001	0.003$^+$
Manganese	1979-1983	12	0.16	0.02	0.08
Molybdenum	1982-1983	76	0.01	<0.01	<0.01
Nickel	1972-1983	27	<0.05	<0.01	<0.01$^+$
Zinc	1972-1983	38	0.04	<0.005	0.016
Nitrogen					
nitrate/nitrite	1974-1983	31	4.85	0.24	1.54
Kjeldahl	1974-1983	41	3	0.34	1.18
Ammonia	1974-1983	38	0.428	<0.005	0.127
Un-ionized Ammonia	1974-1983	38	0.0226	0.00023	0.0026
Nitrate	1976-1983	31	4.82	0.22	1.51
Nitrite	1972-1983	48	0.127	<0.005	0.027
Organic	1973-1983	39	2	0.33	0.94
Oxygen					
dissolved	1972-1983	46	17.9	1.3	10.2
COD	1982-1983	13	49	<10	26.8
% saturation	1972-1983	46	188.5	12.7	98.8
pH	1972-1983	44	9.3	6.5	7.2$^+$
Phenol	1982	4	0.002	<0.002	0.002
Phosphorus					
ortho diss.	1974-1983	45	0.324	<0.003	0.073
total diss.	1976-1983	31	0.249	0.018	0.085
Potassium:Dissolved	1972-1983	37	47	1.9	7.43
Silica	1982	2	0.154	0.052	-
Sodium:Dissolved	1972-1983	37	5500	8.7	276
Solids:					
Suspended	1974-1983	39	60	3	18
Dissolved	1979-1982	12	688	98	268
Total	1972-1983	29	10700	118	1032
Specific Conductivity	1972-1983	45	21250	117	1373
Sulphate	1972-1983	36	323	10.5	61.5
Temperature	1972-1983	46	25	1.9	12.3
Turbidity	1972-1975	6	35	3.4	13.5

+ Median

* All values are as mg/L except (1) Coliform as MPN/100 mL (2) Colour as Colour units, (3) pH (4) Temperature as °C (5) Turbidity as N.T.U. (6) Specific Conductivity as µS/cm (7) % Saturation as %

Data Source: Ministry of Environment and Parks.

Appendix 4: Sediment chemistry data summary 1979, Nicomekl River at King George highway in Surrey BC (Holmes & Swain, 1988).

DATA SUMMARY SEDIMENT CHEMISTRY
NICOMEKL RIVER

Constituent	VALUES (mg/g dry-weight)							
	Site 1100007	Site 0300061	Site 1100006	Site 1100005$^+$ Maximum	Site 1100005$^+$ Minimum	Site 0300060	Site 1100003$^+$ Maximum	Site 1100003$^+$ Minimum
Arsenic*	16	<25	16	17	15	43	10	<5
Boron*	-	<1	-	-	-	<1	-	-
Calcium	2.82	2.39	2.94	4.23	2.46	4.6	4.24	2.74
Carbon-organic	-	<0.3	-	-	-	26	-	-
-inorganic	-	1.7	-	-	-	10	-	-
METALS:								
Aluminum	-	6.42	-	10.9	-	12.9	7.58	-
Barium	-	0.034	-	0.043	-	0.043	0.038	-
Beryllium*	-	<1	-	-	-	<1	-	-
Cadmium	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Chromium	0.023	0.018	0.023	0.36	0.022	0.052	0.035	0.021
Cobalt	-	<0.01	-	0.022	-	0.017	0.014	-
Copper	0.008	0.011	0.009	0.022	0.02	0.039	0.012	0.011
Iron	14	13.1	14.8	26.6	19.2	33.5	20.5	14.6
Lead	0.017	0.012	0.016	0.071	0.034	0.156	0.03	0.02
Magnesium	4.64	3.52	5.09	7.22	5.17	8.7	6.18	5.11
Manganese	0.341	0.545	0.438	0.372	0.297	0.387	0.214	0.209
Molybdenum*	2	7	2	2	<1	13	<1	<1
Nickel	0.016	0.02	0.019	0.028	0.027	0.057	0.022	0.021
Selenium*	-	<10	-	-	-	15	-	-
Strontium*	-	10	-	14	-	44	23	-
Tellurium*	-	<20	-	-	-	<20	-	-
Thallium*	-	<20	-	-	-	<20	-	-
Tin*	-	<5	-	-	-	9	-	-
Titanium	-	0.334	-	0.427	-	0.223	0.311	-
Vanadium*	-	26	-	28	-	39	21	-
Zinc	0.045	0.035	0.041	0.057	0.055	0.133	0.048	0.042
Nitrogen:								
- Kjeldahl	0.43	0.14	0.33	1.42	1.06	3	1.31	0.83
Phosphorus-total	0.297	0.352	0.334	0.614	0.46	1.4	0.531	0.406
Residuals: % of organic material	-	<1	-	-	-	10	-	-

Data Collected in 1979
* Units = µg/g dry weight
$^+$ n=2
Data Source: Ministry of Environment and Parks

Appendix 5: Nicomekl River vegetation sampling (transect ID: T1-S southern inside, T2-N northern waterside; cover types: O = mixed debris, V = vegetation, B = bare soil) data sheet collected March 20, 2017 in Surrey, BC.

STN	Transect T1-S (m)	CVR. Type %	Transect T2-N (m)	CVR. Type %
1	5	B = 85 V = 15	3	B = 100
2	20	B = 60 V = 40	18	B = 100
3	35	B = 20 V = 80	33	B = 95 V = 5
4	50	B = 40 V = 60	48	B = 90 V = 10
5	65	B = 50 V = 50	63	B = 100
6	80	B = 95 V = 50	78	B = 100

Appendix 6: Nicomekl River water salinity compiled sampling data sheet collected August 29 and September 5, 2016.

		Salinity (ppt)	
Station	Depth (m)	29-Aug	05-Sep
1	0.5	1.05	1.08
	1.0	1.05	1.01
	1.5	2.17	3.32
	2.0	9.51	10.36
	2.5	14.37	13.71
2	0.5	1.03	0.99
	1.0	1.04	1.12
	1.5	3.22	2.96
	2.0	9.44	8.21
3	0.5	1.02	0.80
	1.0	1.02	0.93
	1.5	0.87	1.06
	2.0	6.54	6.36
4	0.5	1.01	0.92
	1.0	1.01	1.06
	1.5	3.2	3.12
	2.0	5.83	5.94
5	0.5	0.98	1.00
	1.0	0.99	1.07
	1.5	3.61	3.76
	2.0	8.67	8.41
6	0.5	0.97	1.00
	1.0	0.97	1.11
	1.5	2.97	3.09
	2.0	8.62	7.94
7	0.5	0.92	0.93
	1.0	0.99	0.99
	1.5	3.18	2.96
	2.0	8.63	8.03
8	0.5	0.88	0.95
	1.0	0.91	1.01
	1.5	2.81	2.90
	2.0	7.94	8.44

Appendix 7: T-test comparison of percent vegetation coverage between riparian area transects at Nicomekl project site.

	T1-S	*T2-N*
Mean	49.16666667	2.5
Variance	464.1666667	17.5
Observations	6	6
Pearson Correlation	0.582509892	
Hypothesized Mean Difference	0	
df	5	
t Stat	5.889844267	
P(T<=t) one-tail	0.001002717	
t Critical one-tail	2.015048373	
P(T<=t) two-tail	0.002005433	
t Critical two-tail	2.570581836	